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Stainless Steel Round Robin Test: Centrifugally Cast Stainless Steel Screening Phase

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Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

This report presents the results of the Centrifugally Cast Stainless Steel Round Robin Test (CCSSRRT). The CCSSRRT is the first phase of an effort to investigate and improve the capability and reliability of NDE inspections of light water reactor piping systems. This phase was a screening test to identify the most promising procedures presently available for CCSS. The next phase will be an in-depth program to evaluate the capability and reliability of inservice inspections (ISI) for piping.

In the CCSSRRT, 15 centrifugally cast stainless steel pipe sections containing welds and laboratory-grown thermal fatigue cracks in both columnar and equiaxed base material were used. These pipe specimens were inspected by a total of 18 teams from Europe and the United States using a variety of NDE techniques, mostly ultrasonic (UT). The inspections were carried out at the team's facilities and included inspections from both sides of the weld and inspections restricted to one side of the weld.

It was anticipated that the anisotropic and coarse-grained structure of the specimens would present the inspecting teams with the problem of not only detecting the cracks that existed but also of not concluding that uncracked material was cracked. Because of this, measurement of each team's performance included summaries of their results in both cracked and uncracked material.

Several of the procedures employed in the CCSSRRT demonstrated a potential for discriminating between cracked and uncracked material. However, because of the high number of false crack calls reported by many of the inspecting teams it was difficult to demonstrate that some of the procedures could effectively discriminate between thermal fatigue cracks and uncracked centrifugally cast stainless steel.

The results of the CCSSRRT make it apparent that a more detailed study on the capability and reliability of procedures to inspect stainless steel materials is needed to better understand the specific material and flaw properties and how they affect the outcome of an inspection.

This report has been approved and authorized for publication by the PISC III Managing Board at its meeting of 14 November 1986.

FOREWORD

This report is the first technical report to arise from the PISC III project, and it is to be noted that there are some differences from the several reports issued in the PISC I and PISC II projects.

The programme on which this report is based, the Centrifugally Cast Stainless Steel Round Robin Test (CCSSRRT), was designed to identify for further testing those procedures which showed the best promise for effective detection of thermal fatigue cracks while also effectively classifying correctly any innocuous indications. Part of the NDE testing plan, destructive examination, and data evaluation phase were commenced or planned before this programme was incorporated into the PISC III programme and followed the pattern of the preceding Piping Inspection Round Robin (PIRR). Each of these phases was conducted in a somewhat different way from the procedures adopted in the PISC I and PISC II exercises. However, because the PISC III Management Board considered that the early completion of this work was essential to the establishment of the wider PISC III stainless steel programme, it should be completed as planned, and the results reported because of their general interest and importance. This was done even though the nature of the programme meant that the performance values reported have wide confidence limits.

We hope that readers will note these differences, taking care when comparing with earlier PISC work and not use the results for comparing the effectiveness of different procedures. The results largely relate to thermal fatigue cracks in centrifually cast stainless steel with columnar and equiaxed grain structures and should not be generalized to other defect types or different austenitic materials (microstructures); these aspects form part of the ongoing PISC III programme.

The PISC III Management Board recognizes this work as a part of the United States contribution to the PISC III programme, and it welcomes the initiative of the U.S. institutions in supporting, organizing, and evaluating this work. It also wishes to express appreciation to the Joint Research Centre of Ispra for conducting the destructive examination, and thanks to the many teams from the various countries cooperating in the PISC III programme for their participation.

R. W. Nichols, Chairman
PISC III Management Board

EXECUTIVE SUMMARY

As a result of meetings of the Committee on Safety of Nuclear Installations, Principal Working Group 3 - Primary Circuit Integrity, Task Group on NDE Reliability, it was decided that a round robin test on stainless steel was needed to address the issue of NDE inspection capability and reliability of light water reactor piping systems. Futhermore, it was realized that to answer the overall question of capability and reliability, a major study would have to be undertaken. Because it was suspected (based on previous work and experience) that the capability for inspecting cast stainless steel might be poor, it was decided to conduct this study by using a two-step approach. First, start a test almost immediately using available centrifugally cast stainless steel (CCSS) specimens as a screening test to identify the most promising procedures and also initiate planning for an in-depth program to evaluate the capability and reliability of inservice inspections (ISI) for piping. This first step was to become part of the PISC-II program. The second step was to become part of PISC III. This report deals only with the first step that was taken for immediately beginning a centrifugally cast stainless steel round robin test (CCSSRRT).

The specimens that were available to start a round robin activity were some centrifugally cast stainless steel pipe segments. These pipe segments each contained a weld and were approximately 400-mm long by 190-mm wide by 60-mm thick. The specimens had either equiaxed or columnar microstructure and most contained thermal fatigue cracks while a few had no cracks. Each had a steel plate welded on the bottom to assure that the status of the specimen was not disclosed. The specimens had the weld crowns ground but still had valleys remaining between weld passes. Some of the specimens had been used in a previous round robin study at Pacific Northwest Laboratory (PNL) and were found to be difficult to reliably inspect because the material is anisotropic and coarse grained.

It is recognized that the inspection reliability for cast material is based on the flaw types and microstructures. The results of this study should be carefully evaluated when trying to be used for other types of flaws and microstructures that were not included in this study.

The reason that a round robin could be initiated quickly is that the specimens already existed and a test design had previously been established along with a developed analysis scheme and a proven test protocol. However, because there were only 15 specimens available, the round robin would not provide a vehicle for quantifying the performance of procedures with a high level of confidence. It could at best differentiate those procedures which show the greater potential for detecting thermal fatigued cracked material. For this reason the first round robin has been called the screening phase for centrifugally cast stainless steel.

Eighteen teams from Europe and the United States participated in this study. A variety of ultrasonic procedures and one radiographic procedure using a linear accelerator were employed. The majority of the teams used dual or twin crystal transducers that operated in the longitudinal mode at a frequency of 1 MHz. A substantial number of teams operated at the noise level of the material.

The team's procedures were classified in the following categories:

Manual (M) - The use of a transducer that was manually scanned on the specimen. All data recording was done by hand.

Automated (A) - Either a manual or automatic scan of the specimen but with an automatic recording of the data and simple plotting for display of the results.

Automated with Signal Processing (ASP) - Automated as defined above along with some type of signal processing.

Non-Ultrasonic (N-UT) - A non-ultrasonic NDE technique.

Each team was basically limited to one week for the inspection of the specimens and was required to provide the resultant data sheets to the test organizers within two weeks following the inspection. The teams were requested to inspect the specimens under restricted access conditions; that is, only to scan the specimens from one side of the weld, and to rescan them without any access restrictions. The data from the reporting forms were entered into a computer and checked for errors. The computerized data were then sent out to the teams for verification and clarification of any ambiguous areas.

Two basic data analysis schemes were chosen to measure the effectiveness of the procedures used. The first method was based on a very discrete set of questions and asked whether the technique classified a particular cracked unit of weld as cracked and whether it classified a similar blank unit of weld as cracked. This leads to two summary statistics defined as:

FCP: False Call Probability

$$= \frac{\text{\# of blank weld units classified as cracked}}{\text{\# of blank weld units inspected}} \times 100$$

PODCI: Probability of Detection and Correct Interpretation

$$= \frac{\text{\# of cracks weld units classified as cracked}}{\text{\# of cracked weld units inspected}} \times 100$$

If a procedure was to perform ideally, it would have an FCP near 0 and a PODCI close to 100. On the other hand, if a procedure is not able to effectively discriminate between blank and cracked material, then its FCP and PODCI will be nearly equivalent.

The second method eliminated any axial location information and reduced the problem to a one-dimensional one along the weld. This second method addressed how much of the cracked length of the weld was classified as cracked and how much of the blank length was classified as cracked. These two summary statistics are defined as:

P(C|B): Proportion of blank weld length called cracked

$$= \frac{\text{Length of blank weld classified as cracked}}{\text{Length of blank weld inspected}} \times 100$$

P(C|C): Proportion of cracked weld length called cracked

$$= \frac{\text{Length of cracked weld classified as cracked}}{\text{Length of cracked weld inspected}} \times 100$$

Once this basic information was gathered for each procedure, a series of summary statistics and graphical presentations were made from the data to generate results that permitted a detailed analysis of the effect of base material and inspection access restrictions on inspection performance and allowed for a general comparison of the techniques used to inspect the CCSSRRT specimens. Also, general summaries were obtained for location and sizing errors.

The Joint Research Center (JRC) at Ispra verified the presence of the intended thermal fatigue cracks through dye penetrant examination and optimized radiographic examinations. The JRC also destructively analyzed specimens 1, 5, and 12 and basically verified the existence of the intended defects and found no unintended defects.

As was expected before initiation of the CCSSRRT, the laboratory-induced thermal fatigue cracks in the centrifugally cast stainless steel specimens proved difficult to detect. Several teams did show an ability to discriminate between cracked and uncracked test specimens, but it was hard to associate the success with any particular inspection procedure, technique, or method in general, as other teams using the same techniques did not appear to perform as well. The rate of false crack classifications exhibited by many techniques in the CCSSRRT made it difficult to unambiguously analyze the inspection results and come to clear conclusions.

Included here are two diagrams that give the most basic summary of the results obtained from procedures that were used in the CCSSRRT. The diagrams represent the behavior of a procedure in blank material and in cracked material simultaneously and are commonly known as receiver or relative operating characteristics (ROC) diagrams. Each procedure and access restriction is represented by one data point on the diagrams. A perfect procedure would be positioned in the upper left-hand corner by calling all cracked material cracked and not calling any blank material cracked. Also included on these diagrams is an extremely important diagonal reference line. This reference line consists of all the points for which a procedure would be judged to be ineffective in discriminating between blank and cracked material; that is, FCP = PODCI (or $P(C|B) = P(C|C)$).

Figure ES.1 shows the relative operating characteristics diagram using FCP and PODCI as the two axes. As can be seen, several of the procedures have a high probability of classifying cracked weld units as cracked. However, for some of these procedures, it is possible that these results may have simply been achieved by classifying most of the weld units as cracked, whether they were or not, as indicated by their high FCPs. The square symbol in the upper left-hand corner is the result of JRC's post-CCSSRRT optimized radiographic examination used for guiding the destructive examination and shows a perfect score.

Figure ES.2 shows the relative operating characteristics diagram using $P(C|B)$ and $P(C|C)$ as the two axes. It can be seen that the procedures have generally shifted toward the lower left-hand corner of the ROC diagram. This is because the performance rated in Figure ES.1 depends only on putting a crack indication of any sort into a rather large area. On the other hand, the performance rated in Figure ES.2 depends also on the degree of matching lengths of cracked and uncracked material, a task that is even more difficult. The square symbol near the upper left-hand corner of the ROC diagram is the result from the post-CCSSRRT optimized radiographic examination. Again, several of the procedures demonstrate an ability to discriminate between blank and cracked material. Also, more of the procedures seem to be more closely clustered around the ineffective discrimination line.

Conclusions

This study was designed as a screening test to identify those procedures that show the most promise to detect thermal fatigue cracks in purely equiaxed and columnar CCSS material. The thermal fatigue crack is considered to be ultrasonically conservative but has been identified as a probable degradation mechanism in nuclear plants. In the analysis reported here, inspection performance has been quantified by two parameters, PODCI and FCP. Any statements regarding inspection performance are based on these two parameters and both must be used to assess effectiveness of the procedures. Since this was a screening test, the performance parameters (PODCI and FCP) are not known with high precision; that is, they have wide confidence limits. The data should not be used for comparing the effectiveness of different procedures. Nevertheless, global trends can be extracted from the data. The following conclusions have been drawn from the data analysis performed on the CCSSRRT data.

1. In general, the inspection performance (PODCI, FCP) on the centrifugally cast stainless steel samples containing thermal fatigue cracks was rather poor. However, several operator-technique combinations have been identified as having the potential to correctly classify cracked CCSS piping. This ability seems to depend on the team's application as well as on the procedure itself, since other teams using the same general procedure did not perform as well.

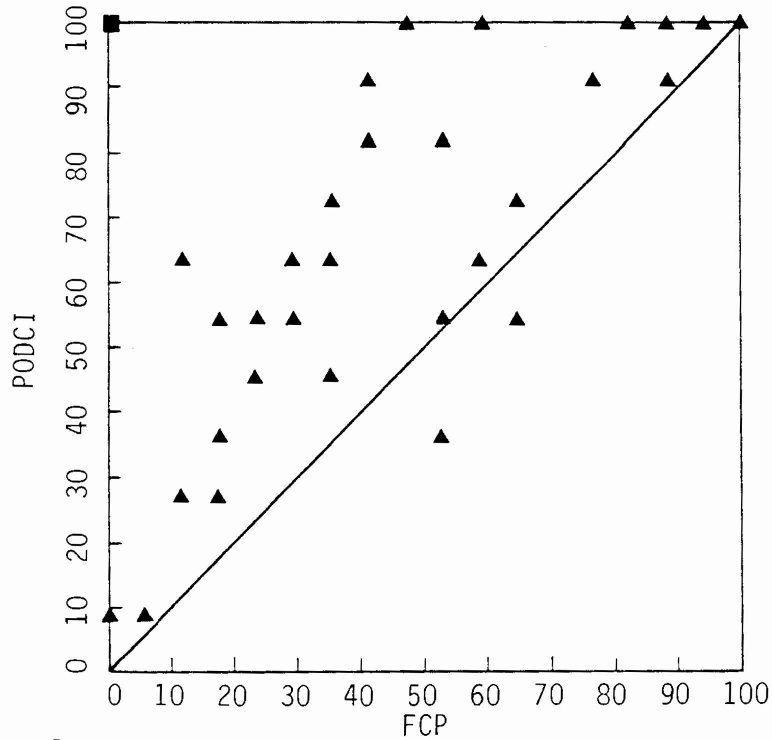

FIGURE ES.1. Relative Operating Characteristics Diagram of PODCI Versus FCP without Confidence Levels

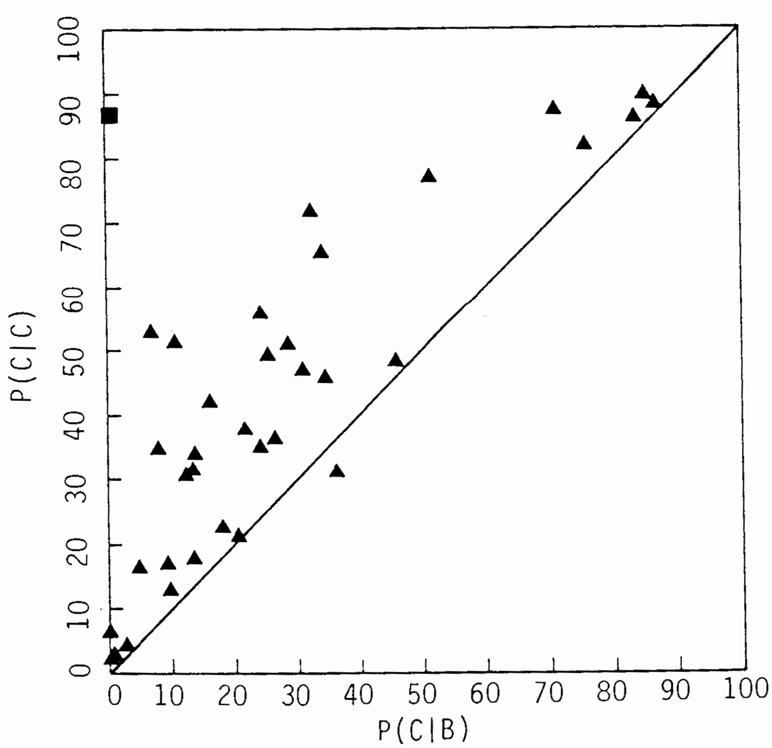

FIGURE ES.2. Relative Operating Characteristics Diagram of P(C|C) Versus P(C|B)

2. The amount of false crack calls in the CCSSRRT has made it difficult to unambiguously analyze the results. Although data analysis techniques have been applied that attempt to account for these false calls, there is still inherent uncertainty when trying to quantify the capabilities of procedures with many false calls, both in their classification ability and their characterization ability. Procedures with high false call rates may indeed be able to discriminate cracked material from uncracked, but the false calls have made it difficult to establish this.

3. The performance on specimen 11, the only specimen that had been thermally and mechanically stress relieved after the thermal fatigue crack was introduced, was better than on any of the other cracked specimens. Relaxation of crack tightness would appear to be the explanation for the difference in crack characteristics between this specimen and the others in the specimen set.

4. In general, the acoustic properties of the columnar material in the CCSSRRT appear to make the probability of false calls much higher than in equiaxed material. Although this was not true for four of the teams.

5. The overriding effect of false calls in columnar material has made the task of determining the effect of inspection restrictions for single-sided access on the probability of classifying cracked material as cracked virtually impossible, since the CCSSRRT specimens are mostly columnar on one side of the weld and equiaxed on the other side.

6. At different stages of the program, two laboratory-type radiographic inspections were performed. The second inspection was used to guide the destructive examination. Although these radiographic results were good, these laboratory techniques are not adaptable for field inspections.

GLOSSARY AND DEFINITION OF TERMS

A - Automation with either manual or automated transducer scanning and with automated recording of the data and simple plotting for display of the results

ASME Code - American Society of Mechanical Engineers, Boiler and Pressure Vessel Code

ASP - Automated with Signal Processing which includes A and some type of signal processing for improved imaging or signal classification

Blank - CCSS specimen that contains no defects

C - Columnar or dendritic grain structure in CCSS

CCSS - Centrifugally Cast Stainless Steel

CCSSRRT - Centrifugally Cast Stainless Steel Round Robin Test

CEC - Commission of European Communities

Cracked - CCSS specimen that contains a thermal fatigue crack

DAC - Distance Amplitude Curve

E - Equiaxed grain structure in CCSS

FCP - The False Call Probability is the probability that a blank grading unit will be called cracked and is measured by the number of blank grading units classified as cracked

Far Side - An inspection in which the transducer is on one side of the weld center line and the thermal fatigue crack is on the other side

Grading Unit - A unit of material that is selected which contains fully each crack or has no cracks in it. The cracked grading units are used to compute PODCI and the blank grading units are used to compute FCP.

ISI - Inservice Inspection

Ispra - Ispra Establishment of the CEC Joint Research Centre

JRC - Joint Research Centre (of the CEC)

M - Manual transducer scanning and data recording

NDE - Non-Destructive Examination

NEA - Nuclear Energy Agency of the OECD

Near Side - An inspection in which the thermal fatigue crack is on the same side of the weld center line as the transducer

NRC - The United States' Nuclear Regulatory Commission

N-UT - A non-ultrasonic NDE technique

OECD - Organization for Economic Co-operation and Development

ROC - Relative Operating Characteristic Curve that is a plot of PODCI versus FCP or P(C|C) versus P(C|B)

RRT - Round Robin Testing, in which specimens are circulated to various locations for inspection by different teams

PIRR - Piping Inspection Round Robin, conducted by PNL in 1982

PNL - Pacific Northwest Laboratory, operated by Battelle Memorial Institute

PODCI - The Probabilityof Detection and Correct Interpretation is the probability that a signal is classified as being from a crack and is measured by the number of cracked grading units properly classified

PTE - The report "Post-Test Examinations of the SSRRT-Phase 1 Specimens at the JRC Ispra," 173/40-33/86/pj/rmb, January 1986

P(C|B) - In a one-dimensional analysis, this is the proportion of the blank weld length that is classified as cracked

P(C|C) - In a one-dimensional analysis, this is the proportion of the cracked weld length that is classified as cracked

Specimen - A piece of CCSS material that is roughly 180-mm wide by 60-mm thick by 400-mm long

True State - The actual status of a specimen confirmed by destructive testing or a validated NDE result

CONTENTS

CONTENTS (cont'd)

FIGURES

TABLES

1.0 INTRODUCTION

The first section of this report contains the background data and the list of participants in this study. The second section provides a description of the specimens and the defects placed in the specimens. The third section contains a detailed description of the CCSSRRT test design that was developed to answer the questions identified for this study. The fourth section provides a short review of the techniques that the various teams employed in this study. The fifth section provides a description of the performance parameters and the analysis scheme to be used with the concept of grading units introduced. The sixth section provides an overall summary of the teams' performance and addresses the effects of grain structure, inspection access, and crack dB response. The seventh section provides an evaluation of procedure performance, introduces the ROC diagram, provides a statistical test on procedure effectives, and summarizes crack location and sizing performance. The eighth section deals with conclusions that can be drawn from this data and analysis. The nineth section provides a series of recommendations for future designers of round-robin tests.

1.1 BACKGROUND

For many years the difficulties associated with the inspection of large-grained and/or anisotropic materials have been well known. Due to the grain structure of these materials, an ultrasonic signal undergoes redirection and attenuation resulting in a very poor signal-to-noise ratio, thereby making detection and characterization unreliable. Many researchers around the world have looked at this problem from the ultrasonic inspection capability standpoint. However, few definitive studies on inspection reliability have been conducted. One study dealing with reliability was performed by Battelle, Pacific Northwest Laboratory (PNL). The PNL study was conducted for the U.S. Nuclear Regulatory Commission (NRC) and dealt with both centrifugally cast and austenitic stainless steel. The PNL work has highlighted the problem of reliably inspecting cast material.

The PNL study was called the Piping Inspection Round Robin (PIRR) and dealt only with pipe-to-pipe butt welds. In relation to centrifugally cast stainless steel (CCSS), two teams declined to partake in this part of the PIRR due to their own lack of confidence in their ability to detect such cracks in this material. In addition, the PIRR study found that three out of the four inspection teams that did participate had less than a 25% chance of classifying cracked material for the thermal fatigue cracks in the specimens examined. The fourth team was able to classify about 70% of the cracked specimens but also classified about 50% of the uncracked specimens as cracked. This suggests that the fourth team was able to identify cracked material but unable to distinguish between signals from metallurgical reflectors in uncracked specimens and the signals from cracked material.

During meetings of the Committee on Safety of Nuclear Installations, Principal Working Group 3 - Primary Circuit Integrity, Task Group on NDE Reliability, the issue of stainless steel inspection was given extensive discussion. The Task Group on NDE Reliability considered this to be a very important issue and felt that work should begin immediately. PNL was directed to develop a stainless steel round robin test (SSRRT) plan and to present this proposal to the Task Group on NDE Reliability. A preliminary test plan was developed and presented to the Task Group on NDE Reliability in May 1984 that proposed an initial RRT screening phase that could be quickly implemented on readily available centrifugally cast stainless steel specimens (CCSSRRT), followed by a more rigorous second phase designed to build on results of the screening phase. The test plan was modified as a result of the May meeting and then testing for the CCSSRRT was started in the United States. PNL was responsible for the overall program management, data collection for the U.S. teams, analysis of the results, and drafting of a report for the CCSSRRT. PNL's effort was sponsored by the Office of Nuclear Regulatory Research of the NRC. The Joint Research Centre (JRC) - Ispra, Italy of the Commission of European Communities was responsible for management of the European portion of the CCSSRRT as well as the verification of the conditions of the CCSSRRT specimens and destructive analysis for selected specimens.

Four U.S. teams ultrasonically inspected the specimens at their facilities during August, September, and October 1984. The specimens were then shipped to JRC-Ispra for initial radiographic examination and coordination of the European portion of the CCSSRRT. A total of 11 European teams ultrasonically inspected the specimens between December 1984 and June 1985 at their respective facilities. Upon return of the specimens to the U.S. in July 1985, three additional U.S. teams ultrasonically examined the specimens. The specimens were then returned to JRC-Ispra in October 1985 for optimized radiographic examination and the destructive analysis of three of the specimens. Most of the teams using ultrasonic methods employed some variant of the ASME Section XI procedure; however, other techniques such as signal averaging and SAFT were also represented.

1.2 CCSSRRT PROGRAM

The design of the CCSSRRT was patterned after the PIRR. A relatively fast turn-around time for the program plan occurred because the specimens used were already available, the design of the test had already been established, the analysis scheme was already developed, and the test protocol had been tested. The design only included centrifugally cast stainless steel because there were insufficient samples of any other type immediately available. In addition, it was realized that there were inadequacies with regard to the conditions included in this set of CCSS specimens. It was decided that the existing specimen set would provide a means to initially evaluate but not quantify the potential capability of procedures. Hence, a two-phase program was recommended with the first phase being referred to as a screening test. The majority of the CCSS specimens had been used in the PIRR and contain both columnar and equiaxed grain structure.

Ideally an assortment of specimens produced by different casting methods, specifically centrifugal and static; a range of microstructures, specifically columnar, equiaxed, and combinations; a variety of component configurations, specifically elbows, pipe, valve bodies, and pump housing; and a variety of crack configurations, specifically different types and sizes, would be needed to quantify the classification capability, characterization (sizing) capability, and inspection reliability potential of any procedure. A lot of planning and specimen fabrication will be required for this type of exhaustive program. Consequently, this will have to be the goal of Phase Two of the CCSSRRT program (officially the Austenitic Steel Test of the PISC III programme).

The objective of the first phase of the CCSSRRT program is to identify nondestructive evaluation methods that have the capability to correctly classify and then characterize (size) thermal fatigue cracks in centrifugally cast stainless steel.

1.3 PARTICIPATING ORGANIZATIONS

The following organizations contributed directly to the technical guidance, review, and administration of the CCSSRRT in time and funding.

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Special mention must be made of the work and significant contribution by the JRC staff in conducting dye penetrant testing, macrography, x-ray examinations, and destructive examination of three specimens. Specifically, Mr. P. Jehenson, F. Violin, W. Burgers, and E. Burck conducted this work, and this work is included as Appendices C and D to this report.

In addition to the above organizations, special acknowledgement is given to Serge Crutzen of JRC-Ispra and Brychan Watkins of the UKAEA for their efforts on behalf of this round robin test.

Acknowledgement of the efforts extended by each team that participated in the inspection of the CCSSRRT specimens is made for their timely completion of the inspections and the dedication of their organizations to furthering the capabilities of NDE inspections in nuclear power plants.

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2.0 DESCRIPTION OF THE CCSSRRT SPECIMENS

This section contains the detailed description of the specimens used in the CCSSRRT. In addition, the thermal fatigue cracks grown in the specimens are described and their pertinent characteristics reported.

2.1 PHYSICAL DESCRIPTION

The CCSS specimens used in the screening phase of the CCSSRRT consist of sections cut from butt-welded, 845-mm outer diameter, 60-mm-thick centrifugally cast stainless steel pipe. This CCSS pipe material was from two different heats of ASTM A-351 Grade CF-8A (which is a cast 304 material). Appendix C contains macrographs of the grain structure of each section. Each section is an approximately 190-mm circumferential by 400-mm axial piece weighing about 32 kg (see Figure 2.1). The welds are located approximately in the middle of each section and were made by welders qualified to meet Section III requirements of ASME Code. The welds were made under shop conditions but are typical of field practice. The weld crowns were ground relatively smooth and blended with the parent pipe, although troughs between weld paths are still present.

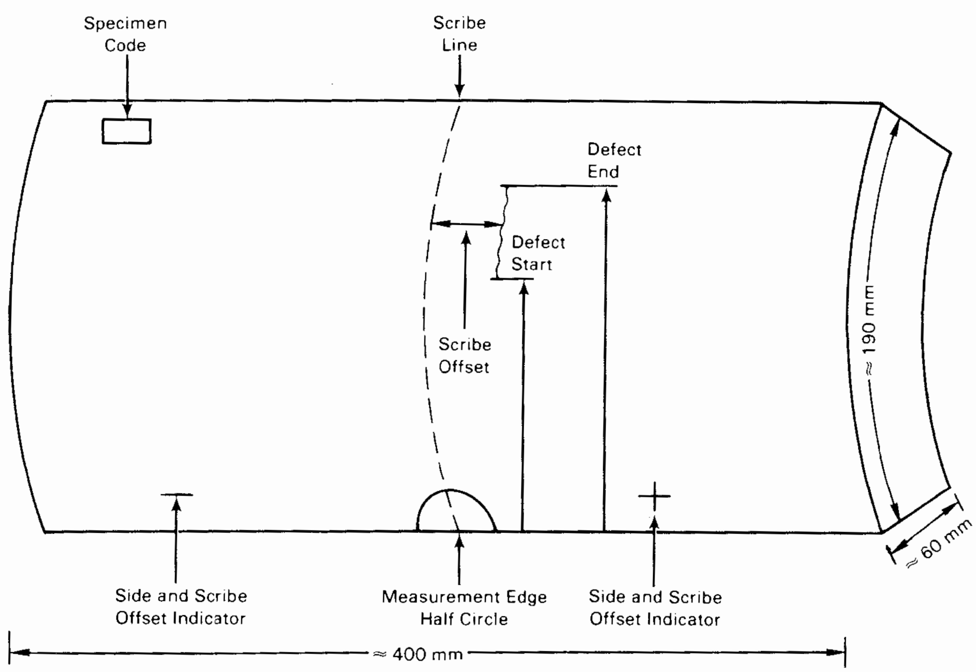


FIGURE 2.1. CCSSRRT Specimen Sketch and Measurement Directions

The cracks in the pipe sections were created using laboratory methods developed at PNL that have proven useful in producing realistic surface-connected thermal fatigue cracks. The flaws in the CCSSRRT specimens are basically considered to be planar cracks, parallel to the weld centerline, and perpendicular to and connected to the inner diameter. However, the fabrication process has also created shallow transverse cracking in some of the specimens, most notably 1 and 14 (see dye penetrant results in Appendix C and is why specimen #1 was selected for destructive examination). The tightness and roughness of the thermal fatigue cracks generally make them more difficult to detect in comparison to mechanical fatigue cracks. Because of the difficulty in detecting these cracks only the most effective techniques were expected to perform well during the screening phase. The only specimen which was an exception to this was specimen 11, which had been thermally stress relieved, mechanically bent open, and then bent back to its original shape. This resulted in an open, easy to detect crack which does not mimic defects anticipated to be found in service.

Fifteen specimens were used in the CCSSRRT, with 11 containing thermal fatigue cracks while four were uncracked or blank. These specimens have grain structures that are columnar and/or equiaxed. The calibration block included with the specimens contains ASME side-drilled holes at 1/4, 1/2, and 3/4 T, and 10% end-milled notches and was also made from columnar and equiaxed grain structures.

Figure 2.1 is a sketch of a pipe specimen and a map of measurement directions. Each specimen was stamped with an identifying code in the upper left corner. Each specimen had a scribe line located near, but not necessarily coincident with, the weld center line, which was to be used as the reference line for axial offset measurements. One side of the specimen was marked "-" and the other side "+" to indicate which half of the specimen was to be examined in a restricted access inspection and also to give the directional sign to put on the axial scribe offset measurement for any indications. Also, a half circle was placed on the edge from which all circumferential measurements were to be made for maximum signal response location and defect starting and ending points.

2.2 FLAW CHARACTERISTICS

Since most of the CCSSRRT specimens are not to be destructively analyzed so that they can be used for further study, the locations of the cracks for the purpose of scoring the inspection results are determined by information gathered from other nondestructive techniques. Specifically, information is used from PNL dye penetrant tests and JRC-Ispra dye penetrant and optimized radiography results, all of which show good agreement within amounts that seem reasonable for techniques that are each open to individual interpretation. These results have been reported in Table 2 of "POST-TEST EXAMINATIONS OF THE SSRRT-PHASE 1 SPECIMENS AT THE JRC ISPRA," Appendix C (PTE). For the purpose of scoring the CCSSRRT inspection results, an area on each specimen was defined such that it included all the possible near-weld crack locations on a specimen referenced in the PTE; that is, the axial offset was allowed to vary over the minimum and maximum axial offsets reported in the PTE, while the crack start was taken as the smallest crack start reported in the PTE, and the crack end was taken as the largest crack end reported in the PTE. Using these rules, a true-state cracked area was defined for each specimen.

A basic description of the CCSSRRT Flaw Characteristics is given in Table 2.1. Note that an extra axial offset allowance is given on specimens 1 and 14 to account for shallow auxiliary cracks that appear parallel to the main

Table 2.1. Characteristics of CCSSRRT Screening Phase Specimens

Specimen Code	Weld Length (mm)	Weld Offset (mm)	Grain Structure Negative Side	Grain Structure Positive Side	Specimen Type	Flaw Side	Minimum Offset (mm)	Maximum Offset (mm)	Crack Start (mm)	Crack End (mm)	Crack Length (mm)	Estimated Crack Depth % T-Wall
1	168	0	E	E	Cracked	+	-16	13	30	121	91	.
2	188	-1	E	C	Cracked	+	1	3	98	167	69	35
3	191	1	C	E	Cracked	+	2	4	106	147	41	23
4	177	-10	C	E	Cracked	-	-12	-6	118	152	34	21
5	191	15	E	C	Cracked	+	15	17	99	172	73	28
6	178	-1	E	C	Blank		B	B	B	B	.	0
7	176	-14	C	E	Cracked	-	-17	-16	22	61	39	23
8	186	1	E	C	Cracked	-	-9	-2	28	92	64	28
9	187	-1	E	C	Blank		B	B	B	B	.	0
10	178	-8	C	E	Cracked	+	-5	-4	109	149	40	23
11	182	0	C	E	Cracked	+	1	6	95	142	47	28
12	176	-6	E	C	Blank		B	B	B	B	.	0
13	176	-16	C	E	Cracked	-	-19	-19	128	168	40	.
14	166	25	E	E	Cracked	+	13	39	30	141	111	.
15	182	5	C	E	Blank		B	B	B	B	.	0

Grain structure is recorded as E for Equiaxed and C for Columnar
Crack depth is estimated based on intended fabrication depth
Cracks in Specimens 1 and 14 are given larger offset measurements due to existence of shallow cracks parallel to the main crack

intended crack. The major grain structure for each side of the weld has been determined by PNL ultrasonic velocity measurements and confirmed by JRC-Ispra macrographic inspection, and is given in Table 2.1 as E for equiaxed and C for columnar. The type of each specimen is noted as either containing a Crack or being a Blank specimen with no crack. For those specimens labelled as being cracked, there is an indication of which side of the weld root the crack is on, noting that for specimens 1 and 14 this refers to the single intended crack. The crack depth given is an estimate based on the intended % through-wall fabrication depth. There may be considerable error in these crack depth estimates; and for several of the specimens, no estimates are given although the cracks in specimens 1 and 14 are believed to be greater than 40% through-wall.

The information given in Table 2.1 is graphically represented in Figure 2.2. The map in Figure 2.2 has the following information:

1. A scale on the first specimen, in millimeters (mm)

2. The visible markings on the fifteen specimens used in the CCSSRRT

   - the specimen number in the upper left corner
   - + and - markings as they appeared on the specimens
   - a whole-length dashed line to indicate the scribe reference line to be used for axial location measurements
   - a half-circle to indicate the reference point to be used as the point for circumferential location measurements as they appeared on specimens

3. The physical characteristics of each specimen

   - whole-length solid line for the location of the weld centerline
   - an E (equiaxed) or C (columnar) for grain structure on each side
   - a cross-hatch box representing the position and length of the crack area as defined in Table 2.1

More detailed information on the characteristics of the CCSSRRT specimens can be found in Appendices C and D which contain reports from JRC-Ispra on specific specimen properties and the destructive analysis of specimens 1, 5, and 12.

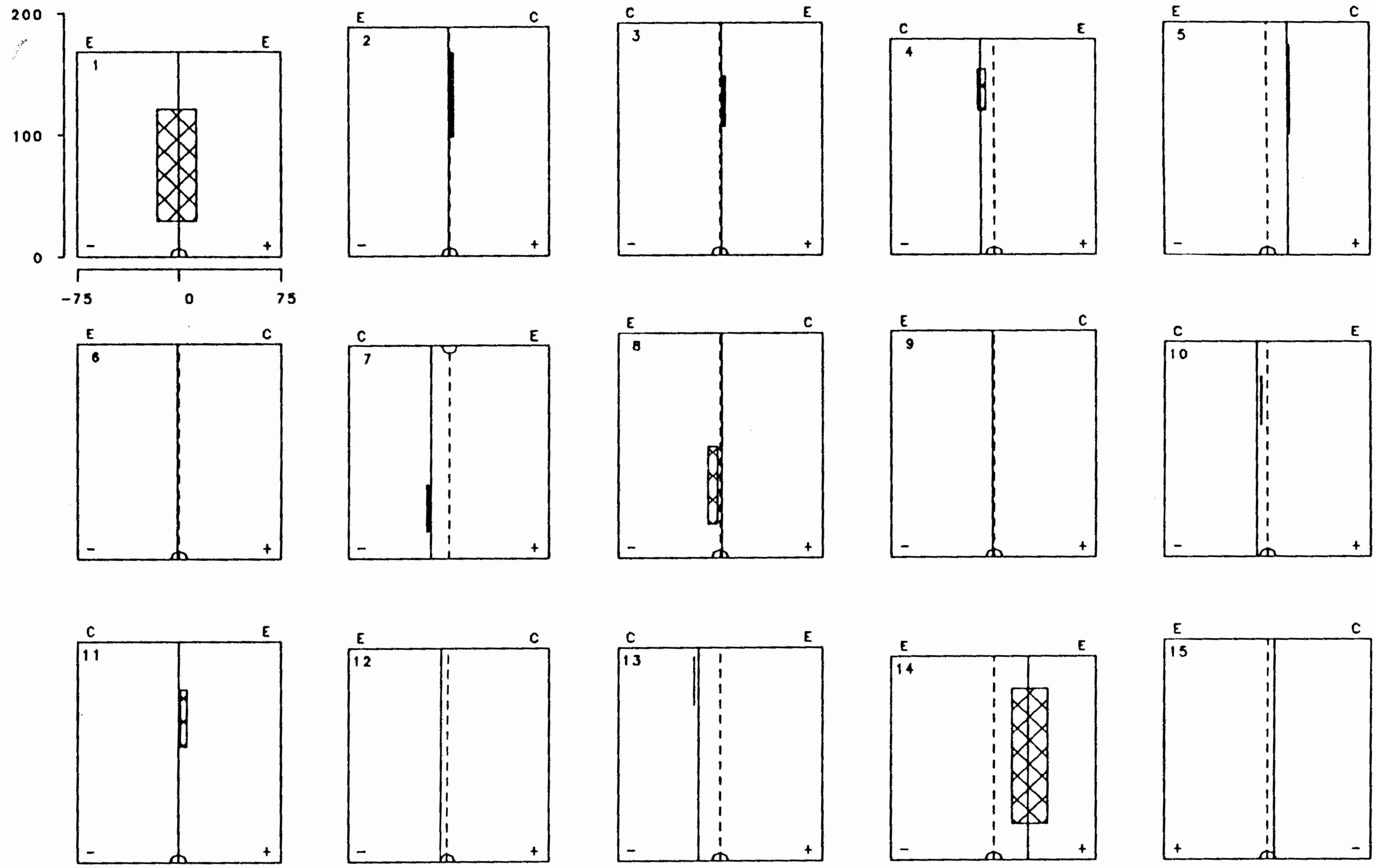


FIGURE 2.2. Map of CCSSRRT Specimen Characteristics

3.0 DESCRIPTION OF THE CCSSRRT TEST DESIGN

This section provides a description of the test protocol followed in this study and the reporting requirements, which includes the reporting forms and the procedures followed to ensure that no errors were present in the final data set used for analysis.

The CCSSRRT was designed as a screening test that would allow for easy shipment of the specimens to the individual inspection teams where they could inspect the specimens in unsupervised conditions. Therefore, it is realized that because the CCSSRRT does not meet the rigorous constraints of a fully designed reliability test and because the specimen set is small and contains only a few different conditions, the statistical analysis of the inspection results will probably not lead to conclusive results and in some cases may not even be prudent.

3.1 INSPECTION PROTOCOL

Each inspecting team was asked to first inspect the specimens in any order they chose but all from the positive (+) side of the weld only (see Figure 2.1) and record the results for each individual specimen on an Inspection Report Form (Figure 3.1). The data recording, analysis, indication disposition, and crack sizing were to be fully completed for the positive side before the other side of the specimens were inspected. The Inspection Report Forms were to be dated, timed, signed, and not to be altered after completion. Then the inspection teams were requested to re-examine all specimens only from the negative (-) side of the weld and again record the results on a new set of Inspection Report Forms. Again, the teams were requested to complete all phases of the negative-side inspection, including data recording, analysis, and form completion, before proceeding to the next step of the inspection. Finally, the inspection teams were requested to examine the specimens with no access constraints and again asked to record the results on a third set of Inspection Report Forms. The purpose of examining separately from each side is to characterize the ability to classify a crack and size it when access to the weld area may be restricted due to physical limitations. This should also provide data on the inspection reliability that can be achieved through equiaxed or columnar grain structures. This information would be most useful if the teams did not use any information from having inspected the opposite half of the specimen. The final unconstrained examination should characterize classification and sizing capabilities when information from both sides of the weld can be integrated.

When individual teams were inspecting the specimens, they were expected to use their normal operating procedures and data recording methods. A description of the particular technique and procedure being used by the team was to be included when reporting results from the method, especially explaining the crack detection and sizing (length and depth) techniques that were used. Each team was to provide information pertaining to calibration methodology used and include all data sheets normally used to document calibration. Also, the team was to include a copy of all the raw data collected during the inspections, work sheets, steps involved in processing the data, and the final processed results and evaluation. In addition, the results were to be summarized

Inspection Report Form

1	Team	USA – PNL
2	Method	SAFT
3	Specimen Code	16
4	Weld Side (-,+, or Both)	+
5	Observer	–

Date = yy/mm/dd
Time = hh:mm (24 hour)

		Date	Time	
		Year/Month/Day	Start	End
6	Inspection	85/06/04	11:40	12:30
7	Analysis	85/06/06	09:50	10:30

Defect Indications

	Maximum dB Response	Signal Location (mm)	Defect Start (mm)	Defect End (mm)	Scribe Offset (-,+ mm)	Depth %Thru-Wall	Disposition C(Crack) N(No crack)
11	6	47	32	56	+4	33	C
12	5	111	109	115	-2	–	N
13							
14							
15							
16							
17							
18							
19							
20							

8 RB — Inspector 1
9 ____ Inspector 2
10 ____ Inspector 3

FIGURE 3.1. Example of Completed CCSSRRT Inspection Report Form

and reported to PNL on the Inspection Report Form so that the inspection results would be in a consistent format.

3.2 REPORTING THE RESULTS

The following instructions were given for completing the Inspection Report Form and an example of a completed form is given in Figure 3.1.

- Inspection Information

  For each inspection, a team must fill out the following information:

  Team - Enter the country and organizational name for the inspecting team

  Method - Give a brief description of the method being used for the inspection

  Specimen Code - Identify which specimen this report is for

  Weld Side - Indicate the side of the specimen being inspected in restricted access inspections, or both sides for an unrestricted inspection

  Observer - The inspection observer, if any, should sign the form

  Inspection Date and Time - Enter the date and the starting and ending times for the physical inspection of the specimen

  Analysis Date and Time - Enter the date and the starting and ending times for analysis of the inspection results.

- Defect Indication Information

  For each recordable defect indication found on a specimen, the following information must be recorded:

  Maximum dB Response - Enter the maximum dB response from the defect indication

  Signal Location - Enter the circumferential location of the maximum dB response

  Defect Start - Enter the circumferential start point of the defect indication

  Defect End - Enter the circumferential ending point of the defect indication

  Scribe Offset - Enter the axial offset from the scribe line, using - or + to indicate which side of the scribe line the indication is on

Depth % Through-Wall - Enter the estimated percent through-wall depth of the defect indication (include work sheet showing how depth was determined)

Disposition - Enter whether the defect indication has been classified as a crack or no crack defect.

The back of the form should be used to include any additional information that is felt will be useful but has not been requested on the form. When the form has been completed members of the inspecting team should sign it. These forms, along with the method and procedure descriptions, copies of raw data on the teams standard forms, and all other pertinent information should then be forwarded to PNL for compilation and analysis.

Note that the team has only two alternatives for indication disposition; the indication is either a crack (C) or not a crack (N). For the purposes of analyzing the data, all indications reported by a team with no indication disposition given were treated as if an N (Not a crack) had been entered. During confirmation of the data with the teams, they were asked to clarify the call for this condition.

Upon return of all Inspection Report Forms and raw data (when available) to PNL, the data from the Inspection Report Forms were entered into a computerized data base for further handling and analysis. Steps were taken to ensure the quality of the data being analyzed by several procedures. First the data were double checked for correct entry. Then several validation checks were made for missing data and data that could not physically be the reported value. The data were then reviewed by looking for indication location errors, especially any that might be systematic. If any missing or questionable data or location errors were observed, an attempt was made to use the raw data forms returned by the team to correct the problem. After all these steps had been taken, a listing of the data for each team, along with a graphical mapping of the indications, was returned to the team for their final concurrence on the correctness of the data. Corrections or changes returned by the team, if any, were then entered into the computerized data base for final analysis.

4.0 DESCRIPTION OF PROCEDURES USED IN THE CCSSRRT

This section includes a classification scheme for the procedures used by the various teams in this study. The procedures were also categorized in terms of detection criteria employed and sensitivity used to conduct the inspections.

4.1 SUMMARY OF INSPECTIONS PERFORMED

Not all teams involved in the CCSSRRT completed all phases of the requested inspections. Table 4.1 gives a summary of the number of procedures/techniques that were used in certain inspections and whether they used a sizing technique. Procedure identification numbers were randomly assigned upon receipt of data so that the results of individual teams could not be identified.

4.2 PROCEDURE DESCRIPTIONS

The number and type of techniques employed by each team in the CCSSRRT were quite varied, although most teams used only one procedure/technique and the majority of the procedures used were in the "spirit of ASME." Some teams reported with several variations of the same general technique, with the biggest difference being in the angle or size of the transducer. Also, several teams reported results as a summary of several individual techniques. After carefully reviewing all of the procedures employed by the participants, the following categories were defined:

Manual (M) - The use of a transducer that was manually scanned on the specimen. All data recording was done by hand.

Automated (A) - Either a manual or automatic scan of the specimen, but with an automatic recording of the data and simple plotting for display of the results.

Automated with Signal Processing (ASP) - Automated as defined above along with some type of signal processing.

Non-Ultrasonic (N-UT) - A non-ultrasonic NDE technique.

The only obvious category that did not appear was a manual procedures that also employed some type of signal processing. Using this classification scheme, the procedures employed in the CCSSRRT can be grouped for comparison of their results. In general, most of the procedures used transducers that operated in a 40 $\pm$ 5 degree longitudinal mode. Three of the procedures used automated systems that provided images in terms of B-scans or C-scans. Three other procedures used automated systems that provided additional data by performing signal processing on the collected A-scans. The non-ultrasonic technique that was used was a radiographic examination by the JRC-Ispra laboratories. Procedures 87 and 94 represent the results of their examination of the specimens in their original state and under optimized inspection conditions, respectively. These procedures are not readily adaptable to field inspections and are included in the report only as a source of reference.

TABLE 4.1. Summary of Inspections Performed

Procedure	Inspection Accesses		Depth Sizing
01	±		
05	±		
06	±,	B	Yes
11	±,	B	Yes
18	±,	B	Yes
22	±,	B	
23		B	
25	±,	B	Yes
28	±		Yes
29	±		Yes
33	±		
35	±		
36		B	
39	±		
40	±,	B	
46	±		
48	±		Yes
51	±,	B	Yes
52		B	Yes
53	±,	B	Yes
56		B	
71	±		
75	±		Yes
81		B	
85	±		Yes
* 87		B	Yes
88	±		Yes
90	±,	B	Yes
* 94		B	
95	±		
	23	16	15

Inspection Accesses shows whether a particular technique did single-sided access inspections (±) and/or unrestricted access from both sides (B).

* Radiographic examinations by JRC-Ispra, 94 is optimized.

Most of the procedures would make corrections for the type of material condition they were inspecting (columnar or equiaxed). Several of the teams felt that it was a major advantage to have access to both sides of the weld, and in fact a number of teams only reported results from unrestricted inspections. About half of the procedures recorded indications which exceeded the noise level of the material. It should be noted that the noise level of the material was not a constant, and even scanning in the parent material there were signals from metallurgical conditions well above the average noise level that occurred. This means that working at the noise level is not working at a constant sensitivity level.

Table 4.2 presents the classification of the techniques by detection criteria and sensitivity. For clarification, the final column has an entry "Data Shape" because some of the automated systems that used imaging did not reference their analysis to ASME but instead relied on special properties they observed in the image that they used for the crack classification decision.

TABLE 4.2. Classification of Procedures

Procedure	Inspection Category	Detection Criteria and Sensitivity
01	M	Noise level
05	M	Noise level
06	M	ASME, 50 %
11	A	ASME, 50 %
18	M	ASME, 50 %
22	M	ASME, Noise level
23	M	ASME, Noise level
25	M	ASME, Noise level
28	M	Noise level
29	M	Noise level
33	A	Data shape
35	A	Noise level, Data shape
36	A	Data shape
39	M	Noise level
40	ASP	Noise level, Data shape
46	M	ASME, Noise level
48	ASP	Noise level
51	M	Noise level
52	M	ASME, 20 %
53	M	Noise level
56	M	ASME
71	ASP	Data shape
75	ASP	Noise level, Data shape
81	M	ASME, 50 %
85	M	Noise level
* 87	N-UT	Radiography
88	M	ASME, Noise level
90	M	ASME, 50 %
* 94	N-UT	Optimized Radiography
95	M	Noise level

M - Manual
A - Automated
ASP - Automated with Signal Processing
N-UT - Radiography at JRC-Ispra, 94 is optimized

5.0 INSPECTION PERFORMANCE MEASUREMENT

This section provides the definition of the performance metrics used to evaluate the data in terms of a one- and two-dimensional analysis. The analysis was examined to determine how sensitive the performance parameters are to the size of the grading units employed. Finally, the results for independent inspections are described with the complete data contained in an appendix.

5.1 BASIC PERFORMANCE INTERPRETATION

The basic question of how well a particular procedure performed in inspecting the CCSSRRT specimens is answered by how well the results of an inspection agree with the actual condition of the specimen, not only in the vicinity of cracks but also in material that is not cracked. That is, the question is not solely whether a procedure can detect and classify cracks, but whether a procedure can discriminate between cracked and uncracked material. For it is not only important to detect and classify cracks when they exist, but it is also important to not call material cracked if no cracks exist in the material. Therefore, the final measures of inspection performance to be used in this report will be given in pairs that must necessarily be used together to judge a procedure's ability. One will measure the procedure's behavior in uncracked or blank material, while the other will measure the procedure's behavior in cracked material.

In general terms, the results of an inspection are usually a complicated two-dimensional pattern of indications which must be compared to the true state of the specimen, which is another two-dimensional pattern. Since there is rarely exact matching of the inspection results with the true state of the specimen, any evaluation of performance must identify some method which measures how closely the pattern of inspection results matches the pattern of the true condition of the specimen. There are many quantities that could be chosen to make such a comparison, each with its own weaknesses and strengths. For the purpose of summarizing the performance of inspection procedures employed in the CCSSRRT Screening Phase, two distinct methods of comparing inspection results with actual specimen conditions have been chosen.

The first method is based on a pair of discrete yes/no questions:

- Was a particular Cracked unit of weld classified as cracked?
- Was a similar Blank unit of weld classified as cracked?

A secondary method of comparison depends on reducing the two-dimensional patterns to a single dimension of weld length and is based on the following questions:

- What percentage of Cracked weld length was classified as cracked?
- What percentage of Blank weld length was classified as cracked?

For the purpose of answering the questions of whether a particular Cracked unit or Blank unit of weld was classified as cracked, Cracked and Blank grading units were defined on the CCSSRRT specimens as follows:

- A Cracked grading unit was defined around the location of each crack with a specified amount of tolerance. The grading unit selected for analysis had tolerances of ± 5 mm in the circumferential direction and ± 15 mm in the axial direction. This is rather large, but a 10% variation in velocity is anticipated in this material and a large limit of error was considered acceptable. If any indications labelled "C" on the Report Form intersected a Cracked grading unit, the crack was considered detected and classified as cracked (see Figure 5.1).

```
+------------- w -----------+
|              w            |
|    1         w            |
|    1         w 2          |
|    1 ggggggggwg2gg        |
|    1 g       w 2 g        |
|    1 g     C w 2 g        |
|    1 g     C w 2 g        |
|      g     C w 2 g        |
|      g     C w   g        |
|      g     C w   g        |
|      g     C w   g        |
|      g     C w   g        |
|      g     C w   g        |
|      g   3 C w   g        |
|      g   3 C w   g        |
|      g   3   w   g        |
|      gggg3gggwgggg        |
|           3   w            |
+------------- w -----------+
```

www = Weld Line
CCC = Intended Crack
ggg = Grading Unit
111 = Crack Indication 1
222 = Crack Indication 2
333 = Crack Indication 3

If Crack Indication 1 was the only crack indication, then the intended crack would not be considered detected.

Crack Indications 2 and/or 3 would lead to considering the crack detected since they intersect the grading unit.

If Crack Indications 2 and 3 were both reported, Crack Indication 2 would be the "associated" indication due to its greater mutual overlap with the crack.

Mutual overlap of 2=(3/10)*(3/6) = 0.15
Mutual overlap of 3=(2/10)*(2/5) = 0.08

FIGURE 5.1. Use of Grading Unit for Crack Calls and Associated Indication

- Blank grading units were defined in blank areas on the CCSSRRT specimens. These Blank grading units were designed to approximate the location and dimensions of the Cracked grading units and satisfy the following conditions:

  - 60-mm long, the approximate average length of the Cracked grading units (except for specimens 1 and 14),
  - 20 mm in from the edge to avoid any edge effects,
  - at least 15 mm away from any other grading units,
  - centered on the weld centerline, which approximates crack locations, and
  - 30-mm wide, which is the additional tolerance used for the Cracked grading units.

If any indications labelled "C" on the Report Form intersected a Blank grading unit it was considered to be classified as cracked.

Figure 5.2 gives a map showing the location of the Cracked and Blank grading units that were defined for the CCSSRRT specimens. This map will serve as the background for plotting of the inspection results reported by each procedure, allowing for a clear understanding of how each procedure's inspection results were scored and demonstrating the problems that must be faced when trying to summarize performance in a simple and unambiguous manner.

Once a crack has been judged to be detected and classified, further questions can be posed as to the ability of an inspection procedure to determine its characteristics; i.e., its location, length, and depth. To investigate this problem, the characteristics of the reported indication can be compared with the characteristics of the crack. If only one indication intersects a Cracked grading unit, there are no difficulties in comparing the indication's characteristics against the crack's. However, when more than one indication intersects a Cracked grading unit, this task is much more ambiguous. For the purposes of this report, the method used in these situations was as follows:

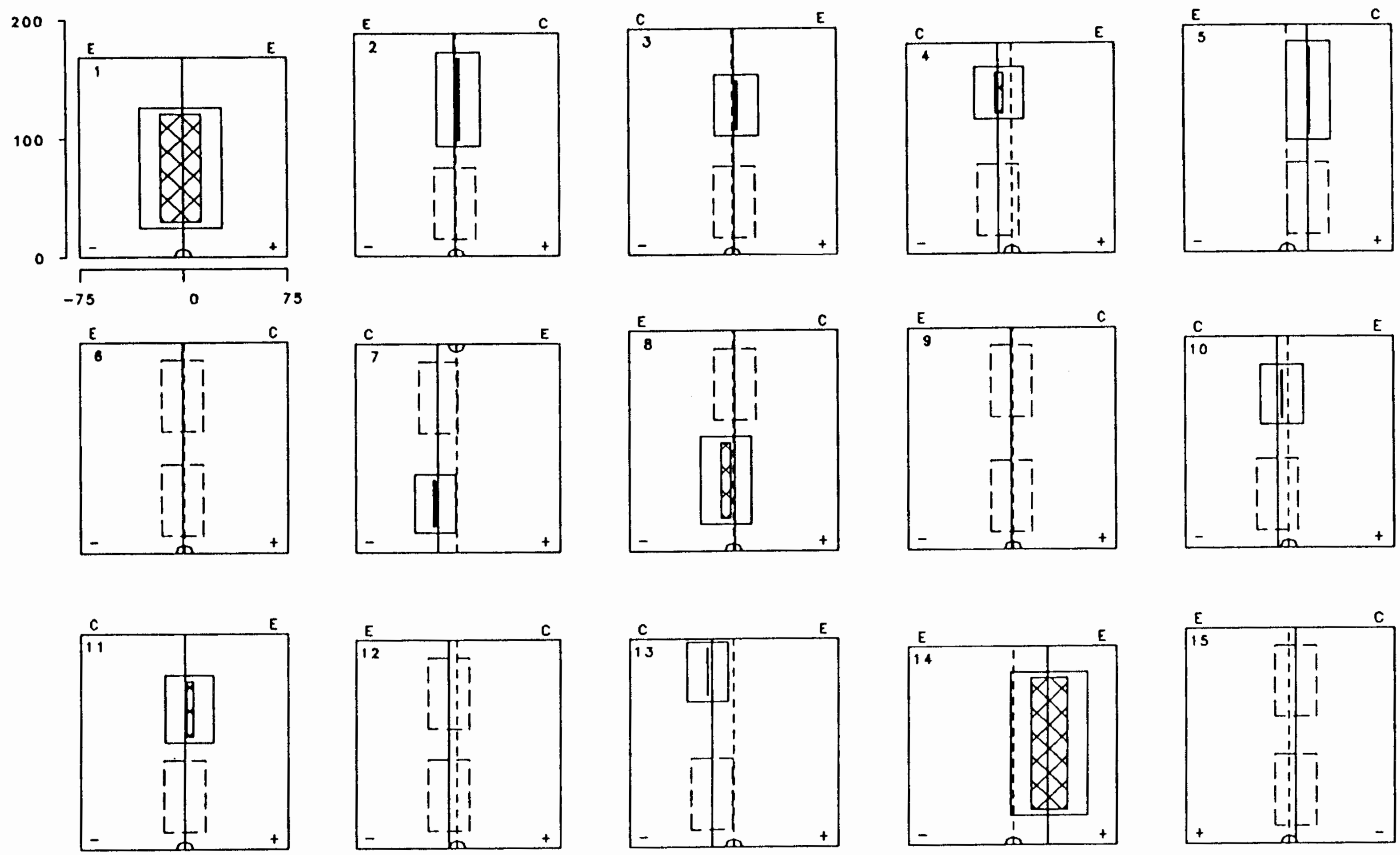
> If there were several "C" indications that intersected a particular Cracked grading unit, they were narrowed to one unique "associated" indication by use of a similarity index. The similarity index was defined as (see Figure 5.1):
>
> proportion of the crack length overlapped by the indication
>
> times
>
> proportion of the indication length overlapped by the crack

This similarity index gives a measure of mutual overlap in the circumferential direction between the crack and any indication. The crack indication with the highest similarity index was then selected as the "associated" indication and used for the characteristics comparison. Naturally, the results of any simple analysis of the crack characterization capability of an inspection technique rest heavily on the way the scoring procedure summarizes results when multiple indications are given for a single crack.

For the purpose of answering the questions of what percentage of Cracked or Blank weld length was classified as cracked, the following method was used to collapse cracks and indications labelled as "C" into single-length dimensions (see Figure 5.3):

1. All axial offset information was ignored; i.e., only circumferential location information was used.

2. Each specimen was divided into 1-mm segments along the weld. Each segment was called either Cracked or Blank according to the circumferential location of actual cracks.



Cracked Grading Units are Solid; Blank Grading Units are Broken
(weld centerline is solid and specimen scribe line is broken)

FIGURE 5.2. Map of CCSSRRT Grading Units

Two-Dimensional Pattern

```
+-----------w-----------+
            w
  1         w
  1         w 2
  1 gggggggwg2gg
  1 g       w 2 g
  1 g     C w 2 g
  1 g     C w 2 g
    g     C w 2 g
    g     C w   g
    g     C w   g
    g     C w   g
    g     C w   g
    g     C w   g
    g   3 C w   g
    g   3 C w   g
    g   3   w   g
    gggg3gggwgggg
        3   w
+-----------w-----------+
```

One-Dimensional Patterns

True-State	Inspection Indications
B	B
B	B
B	C
B	C
B	C
B	C
C	C
C	C
C	C
C	B
C	B
C	B
C	B
C	B
C	C
C	C
B	C
B	C
B	C
B	B

B = Blank (true-state or indication)
C = Cracked (true-state or indication)

FIGURE 5.3. Reduction of Two-Dimensional Patterns to One Dimension

3. If the circumferential location of one or more of the "C" indications for an inspection overlapped a segment, that segment was labelled as called cracked.

The performance measures are then simply the percentages of 1-mm cracked and blank segments that were called cracked by an inspection. In addition, this method partially compensates for procedures that may have many crack indications recorded for a single crack, but only one was used as the "associated" crack call for generating length sizing errors.

5.2 SENSITIVITY STUDY OF GRADING UNIT TOLERANCES

Selection of any tolerances used in defining the Grading Units given in Section 5.1 must of course be justified. Therefore, a sensitivity study was done on the effect of different tolerance allowances to be used in grading the CCSSRRT inspections.

Tolerances of $\pm$ 5 mm circumferentially and $\pm$ 15 mm axially were originally chosen because:

1. Past experience had shown that for large 25-50 mm probes there can be an error in the length sizing of defects. Therefore, a 5-mm circumferential tolerance was deemed appropriate to allow these teams a small location error while not allowing so much tolerance that spurious crack calls might be erroneously given credit for correctly classifying the cracked grading unit.

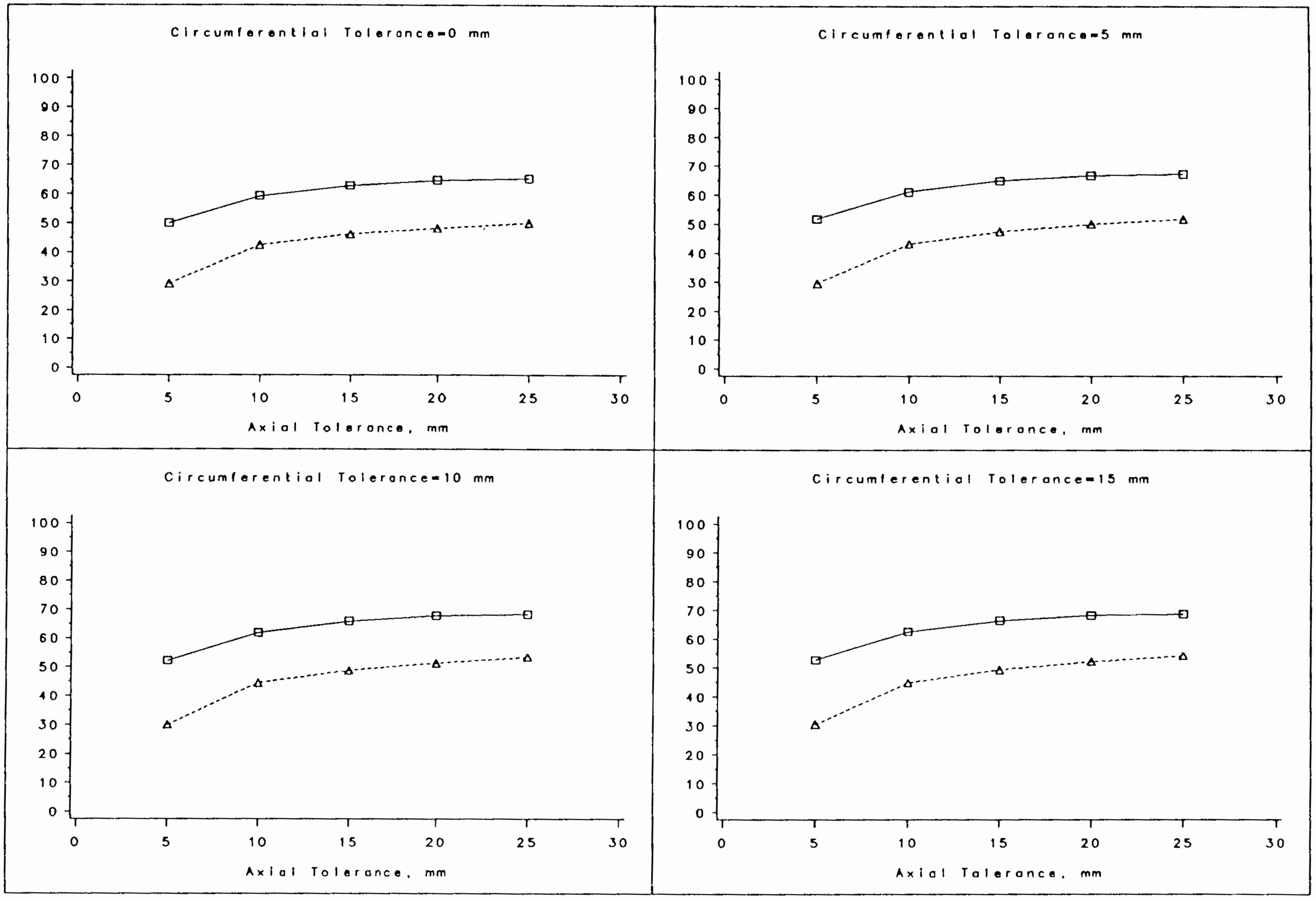
2. Past experience in columnar and equiaxed materials have generally shown that axial location errors of up to 15 mm are possible, especially when inspecting both materials at the same time due to the differing sound velocities and attenuations.

Although it was felt that these tolerances were reasonable for the CCSSRRT specimens, it is possible that this particular choice might be adversely affecting the scoring of the inspection results. In order to investigate this, a sensitivity study was conducted, allowing the circumferential tolerance to vary over 0, 5, 10, and 15 mm while the axial tolerance was varied over 5, 10, 15, 20, and 25 mm. Of course, these different tolerance levels were applied simultaneously to the Cracked and Blank grading units. Results of these different grading unit tolerances are presented graphically in Figure 5.4. The values plotted are overall average PODCIs and FCPs for the data. These two summary statistics, calculated from the grading unit results, are described in Section 7.1. The effect of the tolerances used must be investigated on both of these summary statistics together.

The first conclusion drawn from this analysis is that FCP and PODCI statistics both rise together with increasing tolerances, although FCP may be rising a little faster. Therefore, the amount of tolerance used seems to have negligible effect on the difference between these two statistics. The circumferential tolerance appears to have almost no effect at all on the scored results because the curves in each plot basically match up with the curves in the other plots. Also, although there is a marked effect between axial tolerances of 5 and 10 mm, both on PODCI and FCP, the effect for larger tolerances is relatively negligible. It appears from this analysis that overall it does not seem to make a great deal of difference what tolerances were used. However, it should be mentioned that these are overall results and individual teams may feel that their particular results should have been scored differently. It should also be stated that if a procedure is performing an excellent inspection, no reasonable method of selecting grading units could possibly hide its capabilities.

5.3 BASIC RESULTS FOR INDIVIDUAL PROCEDURES

Now that the basic performance measures have been defined in Section 5.1, the individual techniques employed in the CCSSRRT can be scored against them. The intent of this section is to describe the information contained in the plots and tables in Appendix A, which constitute the graphical and numerical presentation of each procedure's performance. The tables in Appendix A contain the basic performance measures for each procedure's inspections for each specimen and inspection access. The purpose of the remainder of this report



Solid Line is PODCI Result; Dotted Line is FCP Result -- Averaged over all Procedures

FIGURE 5.4. Grading Unit Tolerance Sensitivity Study

will be to use these basic performance measures to investigate the capabilities of the procedures.

For the purpose of consistency in presentation of results, all measurements given in this report are referenced to a single coordinate system. This takes the specimen code as being in the upper-left corner. The bottom edge is then the zero reference for circumferential measurements and all axial measurements to the left of the scribe line are considered negative and those to the right are considered positive. This was the marking system on all specimens except 7 and 15. Adjustments made to the results reported to PNL are as follows:

Specimen 7 - Circumferential measurements reported by the teams were adjusted using the bottom edge as the zero reference instead of the top edge as marked on the specimen.

Specimen 15 - The signs on all axial measurements were reversed.

For each inspection in the CCSSRRT, the following basic performance data is presented in Appendix A:

- A map of the inspection results.
  - For each inspection access ("+", "-", or "Both") employed by a procedure, a map is given that overlays "C"rack calls reported by the procedure on the specimens and their respective Grading units. Each "C"rack call is represented by a thick line with cross marks at the reported crack start and crack end. If a location was reported for the maximum signal response, it is plotted as a third cross mark.
- A table with the following scoring information:
  - Specimen inspected (1-15)
  - Side inspected (+, -, or Both)
  - Grain for single-side inspections (Equiaxed or Columnar)
  - Crack access for single-side inspections (Near or Far for Cracks, None for Blanks)
  - Number of Blank grading units classified as "C"racked
  - Whether a Cracked grading unit was classified as "C"racked
  - Location errors for correctly classified cracks

    Offset = (offset of associated crack indication) - (offset of crack)
    A positive value says the indication was farther to the right

    Center = (center of associated crack indication) - (center of crack)
    A positive value says the indication was higher on the specimen

- Sizing errors for correctly classified cracks

  Length = (length of associated crack indication) - (length of crack)
  A positive value says the indication was longer

  Depth = (depth of associated crack indication) - (depth of crack)
  A positive value says the indication was deeper

- Percent of weld length classified as cracked

  Blank = percent of Blank weld length classified as "C"racked

  Cracked = percent of Cracked weld length classified as "C"racked

6.0 SUMMARY OF OVERALL PERFORMANCE OF TEAMS ON CCSSRRT SPECIMENS

This section is used to summarize how the specimens and cracks themselves were viewed from the perspective of all the teams as a whole.

6.1 OVERALL PERFORMANCE SUMMARY

Table 6.1 is similar to the individual procedure performance tables described in Section 5.3 and reported in tables in Appendix A, except that the results presented are averaged over all the inspection procedures and one column has been added to show the number of times a sizing technique was applied to a correctly classified crack. This table gives information on how well the procedures worked, on the average, when inspecting the CCSSRRT specimens. Review of this table can be the starting point for many interesting hypotheses and summary conclusions. For instance, it can be quickly seen that all of the procedures detected and correctly classified the crack in specimen 11 when having unrestricted access, but many did not classify it as cracked under restricted access. Also, the offset (axial) location errors were very small on the average. Length sizing errors were small for specimens 2, 5, 11, and 13, while there were tendencies to greatly oversize or undersize cracks in other specimens. Other questions of specific interest will be addressed in sections below.

6.2 PLOTS OF CRACK CALL PROFILES

Using information generated for basic performance interpretation, Figures B.1 through B.15 in Appendix B summarize the percent of techniques that had a crack call for a particular section of a specimen under specified conditions. Those conditions are inspection access: '+' side, '-' side, or Both sides; grain structure for single-side inspections: Columnar or Equiaxed; and position of the crack during single-side inspections: Near side of the weld or Far side of the weld. Also given on the plots are two vertical lines, which are the circumferential boundaries of the crack location. From these plots, it is possible to see how many teams called a particular weld length cracked for each of the inspection conditions. These plots ignore any axial offset information. There are several conclusions to be obtained from these plots. First, for all specimens there is a tendency for crack calls not to be made toward either end in cracked or blank specimens. Second, the blank specimens 6, 9, 12, and 15 show how universal the tendency was to make crack calls in uncracked material. Another conclusion would seem to be that there is a greater tendency to make crack calls in columnar material than in equiaxed material.

6.3 GRAIN STRUCTURE EFFECTS

One of the purposes of an exercise of this type is to investigate the effect of different base materials on the ability to detect and classify cracks. In the CCSSRRT two different base materials were used, columnar and equiaxed. The clearest view of what this effect might be can be seen by looking at comparisons of results from single-sided inspections in uncracked material so that different responses caused by the cracks themselves do not obscure the results. The information in Table 6.2 is extracted from Table 6.1 and clearly

TABLE 6.1. Overall Summary of Specimen-Specific Results

Specimen	Inspection Side	Inspection Grain	Crack Access	Grading Units: % Blanks Classified as Cracked	Grading Units: % Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Length Errors mm	Correctly Classified Cracks: Depth Sizings	Percent Weld Length Classified Blank	Percent Weld Length Classified Cracked
1	+	Equiaxed	Near		61	2	-6	-57	.	10	29
	-	Equiaxed	Far		61	-8	8	-55	.	8	22
	B				76	2	-8	-49	.	16	43
2	+	Columnar	Near	52	91	-0	-22	-7	11	30	49
	-	Equiaxed	Far	35	17	-3	-13	-24	1	8	8
	B			44	88	-1	-12	-6	6	26	51
3	+	Equiaxed	Near	35	43	-1	-21	42	5	20	30
	-	Columnar	Far	17	61	-1	-3	8	5	15	50
	B			56	81	0	-10	36	5	31	66
4	+	Equiaxed	Far	22	48	3	-5	-5	4	14	30
	-	Columnar	Near	52	57	1	-34	74	5	35	44
	B			38	50	2	-33	60	4	28	35
5	+	Columnar	Near	48	48	1	-32	21	5	28	32
	-	Equiaxed	Far	4	22	2	-8	-7	.	9	18
	B			38	69	-1	-19	8	4	29	41
6	+	Columnar	None	46						29	
	-	Equiaxed	None	30						14	
	B			44						34	
7	+	Equiaxed	Far	26	30	1	32	73	1	20	24
	-	Columnar	Near	48	43	7	37	76	2	32	32
	B			50	50	3	30	38	4	24	27
8	+	Columnar	Far	35	57	5	17	31	6	23	43
	-	Equiaxed	Near	30	39	3	-3	-18	4	18	18
	B			38	63	-1	11	8	4	22	48
9	+	Columnar	None	41						29	
	-	Equiaxed	None	24						16	
	B			41						26	
10	+	Equiaxed	Near	26	35	-1	-16	30	2	16	22
	-	Columnar	Far	35	57	-0	-30	49	3	29	44
	B			31	75	-1	-15	20	4	22	57
11	+	Equiaxed	Near	13	61	-3	0	-5	5	4	50
	-	Columnar	Far	22	57	-3	5	-8	6	8	39
	B			13	100	-3	4	-5	8	6	79
12	+	Columnar	None	57						40	
	-	Equiaxed	None	26						20	
	B			47						35	
13	+	Equiaxed	Far	9	13	10	-13	-11	.	10	9
	-	Columnar	Near	22	48	2	-21	1	.	17	24
	B			19	38	3	-12	-1	.	13	30
14	+	Equiaxed	Near		61	-0	-30	-65	.	17	33
	-	Equiaxed	Far		22	-4	-2	-84	.	1	11
	B				63	-1	-16	-38	.	13	37
15	+	Equiaxed	None	20						8	
	-	Columnar	None	46						32	
	B			53						31	

indicates that the procedures generally found the columnar material more likely to generate ultrasonic responses that were incorrectly judged to be coming from cracked material.

TABLE 6.2. Comparison of Inspection Responses in Columnar and Equiaxed Material

% Blank Grading Units Incorrectly Classified as Cracked

Specimen	Material Columnar	Material Equiaxed
2	52	35
3	17	35
4	52	22
5	48	4
6	46	30
7	48	26
8	35	30
9	41	24
10	35	26
11	22	13
12	57	26
13	22	9
15	46	20
Average	40	23

These results can be statistically analyzed by use of methods for contingency tables where the response being measured (that is, whether a grading unit was intersected by a crack call) is qualitative rather than quantitative as are the conditions that are expected to affect that response, in this case the grain of the material. Because of the questions that will be addressed in the rest of this chapter, inspection results will only be analyzed for specimens that contain a crack and have equiaxed material on one side of the weld and columnar material on the other side of the weld. This means that the blank specimens 6, 9, 12, and 15, and the double equiaxed specimens 1 and

14 are not being used since they are not appropriate specimens for some of the questions.

Application of linear contingency table analysis to blank grading unit inspections shows that on the average 37% of the inspections in columnar material resulted in a false crack call while 22% of the inspections in equiaxed material resulted in a false crack call. This is a statistically significant difference (p=.001) and shows the base material to be a very important factor to be considered when analyzing the results of the CCSSRRT. Inclusion of the above information helps to make sense of why, except for specimen 11, teams were reporting more crack indications that intercepted the Cracked grading units from far-side inspections in columnar material than near-side inspections in equiaxed material. Further evidence of this effect is apparent in the profile plots given in the preceding section.

6.4 INSPECTION ACCESS EFFECTS

Another question of major importance is whether restricted inspection access has an effect on the ability to classify a cracked grading unit as cracked. This will be investigated by comparing near-side access inspection results to those of far-side inspections or unrestricted inspections. The results from the two double equiaxed specimens (1 and 14) are inconclusive in this regard and even then the results of such an inspection access effect may be confounded by the existence of the small auxiliary cracks on both sides of the weld in these specimens.

Table 6.3 gives the percentage of cracked grading units that were classified as cracked during near-side and far-side inspections. The results are further broken down depending on the material characteristics of the side that was being inspected. Contingency table analysis of this data indicates that the material grain structure is again a statistically significant determinant of the number of crack classifications that are made (p=.001). There is also a significant effect attributable to access restriction (p=.06) and the interaction between material grain and access restriction (p=.05). This latter effect means that the difference between near-side and far-side access

TABLE 6.3. Comparison of Near-Side and Far-Side Access Inspections

Percent of Cracked Grading Units Classified as Cracked

Inspected Material Grain	Inspection Access: Near-Side	Inspection Access: Far-Side	Average Access
Columnar	57	58	58
Equiaxed	45	26	35
Average Material	51	42	46

is different in columnar material than in equiaxed material. This is clearly exhibited in Table 6.3 where the percent of crack calls is essentially identical in the columnar material inspections but much higher for near-side access than far-side access in equiaxed material.

Table 6.4 gives the percentage of cracked grading units that were classified as cracked during near-side and both side-inspections. The results are further broken down depending on the material characteristics of the side the crack was on. Contingency table analysis of this data indicates that the interaction is the most significant effect (p=.09) so the data were re-analyzed for each material separately. This re-analysis showed that the difference in the percent of crack calls for both-side inspections in equiaxed material was statistically significant (p=.01).

TABLE 6.4. Comparison of Near-Side and Unrestricted Access Inspections

Percent of Cracked Grading Units Classified as Cracked

Inspected Material Grain	Inspection Access		Average Access
	Near-Side	Both	
Columnar	73	71	72
Equiaxed	72	92	82
Average Material	73	81	77

For equiaxed material the conclusion might be drawn that unrestricted access to a crack is important in increasing the likelihood of classifying a cracked grading unit as cracked. On the other hand, the conclusion to be drawn from similar results in columnar material is that access restriction has no effect on the probability of classifying a cracked grading unit as cracked. In viewing Table 6.4 the reader should be aware that it is a summary only of the nine techniques that performed both single-sided and unrestricted access inspections and that these particular techniques also had some of the higher false call rates, which may be why the percentage of cracked grading units called cracked is so high for this table.

It seems clear from the discussion of Sections 6.3 and 6.4 that the confounding effect of incorrect crack calls in general and the fact that there are higher rates of incorrect crack calls in columnar material than in equiaxed material has made any attempt at investigating the capabilities of the procedures under different access conditions unlikely to produce useful conclusions from the CCSSRRT specimens because they are almost all columnar material on one side of the weld and equiaxed on the other side.

6.5 dB RESPONSE COMPARISONS

After reviewing the number of incorrect crack calls that have been made in the CCSSRRT, the magnitude of the effect of material differences in making crack calls, and the different abilities to detect different cracks with differing amount of success, it may be informative to see if there is a relationship between any of these phenomena and the maximum dB responses recorded by the procedures. The data for these comparisons is somewhat limited as several of the techniques either did not use dB response as part or their procedure, did not record it, or gave insufficient information to recover a dB response value from their reported data. Also, several procedures reported dB response in such a way that conversions of their data had to be made in an attempt to get all of the data in a consistent format.

The first comparison made is between the dB response values recorded for crack calls in the blank specimens 6, 9, 12, and 15. The average dB response recorded for single-sided columnar inspections was -3.0 with a standard deviation of 5.0, while in equiaxed material the average was 3.2 with a standard deviation of 2.9. This difference was tested statistically and found to be nonsignificant (p=.90), indicating that there is no discernible difference in the dB response values reported in the CCSSRRT in blank columnar and blank equiaxed material.

The next relationship investigated is between crack calls in Cracked grading units and those made in Blank grading units. For this comparison single-side inspection results made on the same side of the weld as the crack were used for both the Cracked and Blank grading units. The average dB response for Blank grading units was -2.4 with a standard deviation of 3.2, while for Cracked grading units it was -2.1 with a standard deviation of 3.5. This difference was tested statistically and found to be nonsignificant (p=.48), indicating that the procedures were generally getting about the same magnitude of dB response from blank material as they were getting from cracked material.

The final question is whether any relationship can be found between dB response and the frequency that a particular Cracked grading unit was classified as cracked. To investigate this possibility, the dB response information from near-side crack calls was compared to the percent of inspections that classified each Cracked grading unit as cracked. This information is plotted in Figure 6.1. The general conclusion is that there is no relationship to be found between a crack's detectability and the dB response recorded by the procedures in the CCSSRRT, especially in relation to the amount of variability found in dB responses for each specimen.

From the three separate investigations given above, it appears that the dB information recorded by the procedures has no relationship to any of the phenomena it was compared to. This may mean that there actually is no relationship involved or that the varied ways of reporting this information in the CCSSRRT have made it impossible to recover the relationship.

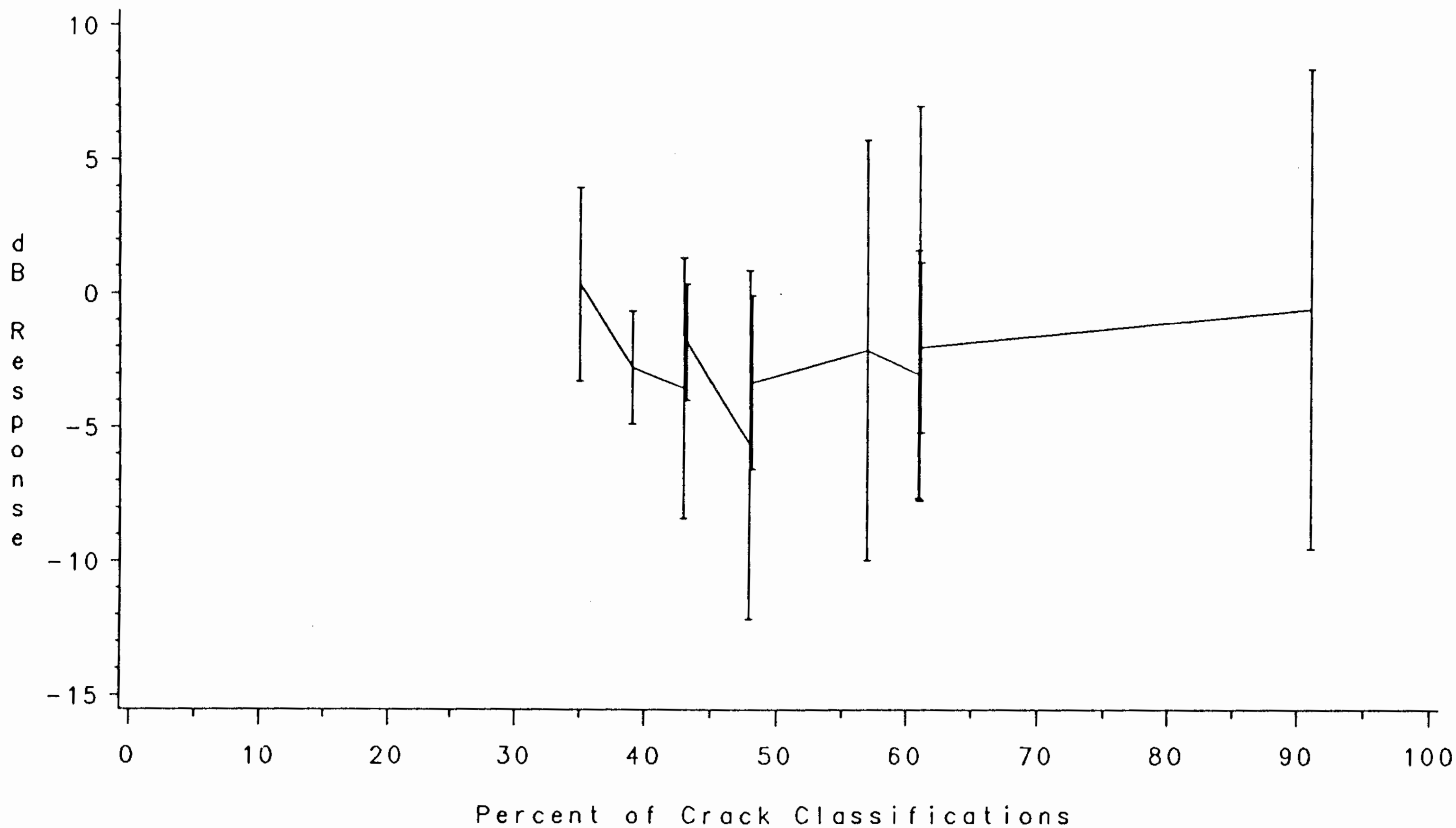


FIGURE 6.1. dB Response Versus Percent of Crack Classifications for Near-Side Indications that Intersected Cracked Grading Unit with Error Bars that are +/- Two Standard Deviations

7.0 COMPARISON OF PROCEDURE PERFORMANCE

Now that the method of comparing a procedure's performance to the actual conditions of the CCSSRRT specimens has been described and illustrated, it is possible to begin the task of satisfying the main objective of the CCSSRRT screening phase. That objective is to identify procedures that can reliably classify and characterize cracks in centrifugally cast stainless steel. This objective will be achieved by asking two related but fundamentally different questions. The first question is which are the best procedures. The second, and perhaps even more important question, is whether the procedures perform reliably enough to be of use for in-service inspection of the primary piping in a nuclear power plant.

7.1 MEASURES OF PROCEDURE PERFORMANCE

In order to characterize a procedure's performance in a way that is most useful in safety analysis, two probabilities, or classification statistics, will be estimated which quantify the effectiveness of the inspection procedure. These probabilities describe the frequency with which one or more "C"rack indications are associated with a unit of weld material. Since a particular unit of weld material may be either cracked or blank, it is again necessary to define two probabilities that must be used together. These probabilities are defined as:

FCP - False Call Probability. The probability that a Blank unit of weld will be called cracked.

PODCI - Probability of Detection and Correct Interpretation. The prob ability that a Cracked unit of weld will be called cracked.

FCP and PODCI can be estimated for each procedure's inspections from the basic inspection performance data given in Appendix A. Each is estimated by counting the number of units of one type that were intersected by one or more crack indications, divided by the number of units of that type that were inspected, and multiplying by 100 to express them as percentages

$$FCP = \frac{\#\text{ of Blank Grading Units Classified as Cracked}}{\#\text{ of Blank Grading Units Inspected}} \times 100$$

$$PODCI = \frac{\#\text{ of Cracked Grading Units Classified as Cracked}}{\#\text{ of Cracked Grading Units Inspected}} \times 100$$

These statistics have a rather obvious and natural interpretation. If a technique was to perform ideally, it would have an FCP near 0 and a PODCI close to 100. On the other hand, if a technique is not able to effectively discriminate between blank and cracked material, then FCP and PODCI will be nearly equivalent, no matter what the level of the PODCI statistic is.

Although FCP and PODCI are perhaps the most important measures of NDE performance, they are not the only useful measures that can be employed. FCP and PODCI have a few obvious drawbacks. First, they only compare the grossest features of the actual conditions and inspection results; that is, an indication need only intersect the grading unit without having to closely match the characteristics of the crack. Secondly, substantial numbers of inspections are required to produce accurate estimates of these statistics. For example, changing a single correct classification for a procedure that inspected the CCSSRRT specimens results in a 9-point change in their estimated PODCI. As additional evidence, Table 7.1 gives statistical confidence intervals that have a 90 percent probability of containing the true PODCI or FCP for a single technique based on simplifying assumptions of independence of inspections and using a binomial distribution to describe the probability of classifying a grading unit.

TABLE 7.1. 90% Binomial Confidence Intervals on PODCI and FCP for the CCSSRRT

Cracked Grading Units Classified as Cracked	PODCI Estimate	Lower Limit	Upper Limit	Blank Grading Units Classified as Cracked	FCP Estimate	Lower Limit	Upper Limit
0	0	0	24	0	0	0	16
1	9	1	36	1	6	0	25
2	18	3	47	2	12	2	33
3	27	8	56	3	18	5	40
4	36	13	65	4	24	9	46
5	45	20	73	5	29	12	52
6	55	27	80	6	35	17	58
7	64	35	87	7	41	21	64
8	73	44	92	8	47	26	69
9	82	53	97	9	53	31	74
10	91	64	100	10	59	36	79
11	100	76	100	11	65	42	83
				12	71	48	88
				13	77	54	92
				14	82	60	95
				15	88	67	98
				16	94	75	100
				17	100	84	100

An alternate set of summary statistics can be derived from the one-dimensional performance measurements described in Section 5.1. These statistics are considered reasonable because the cracks that are being analyzed are typically very close to and parallel to the weld so that the consideration of cracked material can reasonably be reduced to one of length of weld only. This strategy also makes sense from a structural perspective, because the length of a crack penetrating the wall in the circumferential direction of the pipe is highly related to the propensity of the weld to fail. These two statistics are defined as:

$P(C|B)$ - The proportion of Blank weld length classified as cracked

$P(C|C)$ - The proportion of Cracked weld length classified as cracked

Again, $P(C|B)$ and $P(C|C)$ can be estimated from the basic performance data given in Appendix A. Each is defined as the total amount of weld length of each type that is classified as cracked, divided by the total weld length of that type that was inspected, and multiplied by 100 to express as percentages.

$$P(C|B) = \frac{\text{Length of Blank Weld Classified as Cracked}}{\text{Length of Blank Weld Inspected}} \times 100$$

$$P(C|C) = \frac{\text{Length of Cracked Weld Classified as Cracked}}{\text{Length of Cracked Weld Inspected}} \times 100$$

These one-dimensional statistics are closely related to the classification statistics, FCP and PODCI, introduced above and have an obvious intuitive meaning. When the indication pattern closely matches the actual condition of the weld, $P(C|B)$ will be close to 0 and $P(C|C)$ will be close to 100. And, as already stated for FCP and PODCI, if a technique is essentially unable to effectively discriminate between blank and cracked material, then $P(C|B)$ and $P(C|C)$ will be approximately equal.

Table 7.2 gives a general overall summary of how well each procedure performed using the classification and one-dimensional statistics defined above. Also included are average location and sizing errors for each procedure along with the number of depth sizings that were done. For the purpose of summarizing performance in this table, the "+" and "-" inspection results were used together as if one inspection had been done and called "Single" inspection access.

7.2 RELATIVE OPERATING CHARACTERISTICS DIAGRAMS

As an aid in comparing the procedures and visualizing the effect of FCP (or $P(C|B)$) on interpreting the performance of any single technique in conjunction with PODCI (or $P(C|C)$), it is useful to use a Relative Operating Characteristics (ROC) diagram (see Figure 7.1). This is a simple plot of a procedure's behavior in cracked material versus its behavior in blank material. Each procedure is represented by one data point on the diagram. A perfect procedure would be positioned in the upper left-hand corner, as shown in Figure 7.1, by classifying all cracked units as cracked (PODCI=100%) and not classifying any blank units as cracked (FCP=0%). Also included on the diagram is an extremely important diagonal reference line. This reference line consists of all the points for which a procedure would be judged totally ineffective in discriminating between blank and cracked material; that is, FCP = PODCI (or $P(C|B) = P(C|C)$). Although there are many summary measures of performance that can be applied to a point on an ROC diagram, there is insufficient data generated by the CCSSRRT to meaningfully use them. Therefore, an extremely simplistic approach will be used that measures the relative discriminating effectiveness of a procedure as the vertical distance of the PODCI value from the ineffective discrimination reference line. That is, the measure of a team's performance is equivalent to PODCI - FCP (or $P(C|C) - P(C|B)$). For example, a procedure is plotted on Figure 7.1 with a value of 73 in cracked material but a value of 47 in blank material, so the simplest measure of its discrimination ability would be 73 - 47 = 26; that is, it will classify 26%

TABLE 7.2. Summary Data for Each Procedure's Inspections

Procedure Number	Inspection Access	Blank Units Classified as Cracked FCP (%)	Cracked Units Classified as Cracked PODCI (%)	Correctly Classified Cracks: Location Errors Offset (mm)	Correctly Classified Cracks: Location Errors Center (mm)	Correctly Classified Cracks: Length Errors (mm)	Correctly Classified Cracks: Depth Sizings	Percent Weld Length Classified Cracked: Blank P(C|B)	Percent Weld Length Classified Cracked: Cracked P(C|C)
01	Single	18	55	1	-8	-39	0	22	38
05	Single	0	9	2	-4	-26	0	0	7
06	Single	41	82	2	4	-44	8	14	18
	Both	24	45	1	3	-52	3	10	13
11	Single	47	100	-0	3	-26	0	34	65
	Both	29	64	-1	1	-15	5	14	32
18	Single	41	91	-0	-16	-5	8	24	56
	Both	41	91	-0	-16	-1	8	24	56
22	Single	53	36	2	-1	-30	0	24	35
	Both	65	55	-3	-32	19	0	36	31
23	Both	35	45	-2	4	-17	0	18	23
25	Single	53	55	-1	2	-20	3	29	51
	Both	53	82	-0	6	0	6	32	72
28	Single	8	0	-4	2	-63	1	0	3
29	Single	82	100	0	-9	56	2	75	82
33	Single	24	45	0	-11	-32	0	10	17
35	Single	82	100	-0	-5	-10	0	35	46
36	Both	29	55	-2	-2	-29	0	14	34
39	Single	65	73	1	-20	32	0	46	49
40	Single	100	100	2	-13	3	0	51	77
	Both	78	91	2	-11	-5	0	31	47
46	Single	18	27	1	-4	-36	0	5	17
48	Single	24	55	-3	-5	-17	3	11	52

TABLE 7.2. (cont'd)

Procedure Number	Inspection Access	Blank Units Classified as Cracked FCP (%)	Cracked Units Classified as Cracked PODCI (%)	Correctly Classified Cracks: Location Offset (mm)	Correctly Classified Cracks: Location Errors Center (mm)	Correctly Classified Cracks: Length Errors (mm)	Correctly Classified Cracks: Depth Sizings	Percent Weld Length Classified Cracked: Blank P(C|B)	Percent Weld Length Classified Cracked: Cracked P(C|C)
51	Single	94	100	1	-12	57	1	87	88
	Both	88	91	1	-19	87	1	83	86
52	Both	0	0	-7	14	-27	1	1	3
53	Single	94	100	1	-12	57	5	87	88
	Both	88	100	1	-12	85	5	85	90
56	Both	35	64	-2	5	-37	0	13	31
71	Single	59	64	1	-7	-13	0	21	22
75	Single	35	73	-0	-15	-32	5	16	42
81	Both	18	36	0	5	-22	0	8	35
85	Single	12	27	-0	9	-55	2	3	5
87	Both	12	64	1	-3	-15	2	7	53
88	Single	53	82	-2	-24	-29	6	26	37
90	Single	59	100	0	-17	-17	8	25	49
	Both	59	100	1	-18	-12	8	25	49
94	Both	0	100	1	-1	-9	0	0	87
95	Single	82	100	-0	-15	45	0	71	88

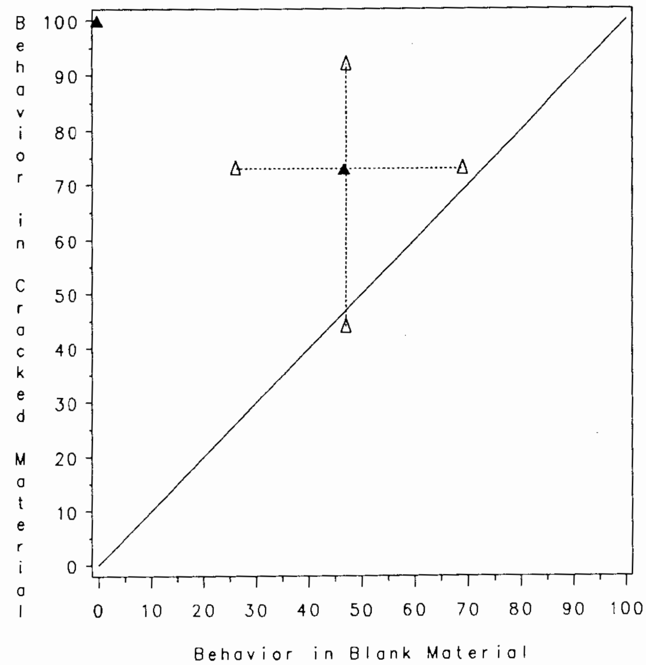


FIGURE 7.1. Example of Relative Operating Characteristics Diagram

more of the cracked grading units as cracked than it will classify blank grading units as cracked. Of course, if all procedures had very low FCP statistics, then the FCP could reasonably be ignored and the measure of a technique's performance could be reduced to one of PODCI only. Also include on Figure 7.1 are 90% confidence limits on the PODCI and FCP values that can be used to judge the amount of certainty attached to these two estimates from the CCSSRRT study. As can be seen, they are quite wide and again point to the fact that the CCSSRRT is only a screening test.

Figure 7.2 shows the relative operating characteristics diagram using PODCI and FCP for the techniques reporting in the CCSSRRT screening phase. As can be seen, several of the procedures have a high PODCI (greater than 80%) but for more than half of these procedures, this was offset by classifying a great deal of material cracked whether it was cracked or not. The points plotted at FCP=12,PODCI=64 and FCP=0,PODCI=100 are the results of the original and post-test radiography of the CCSSRRT specimens performed by JRC-Ispra. From this ROC, it appears that several of the ultrasonic techniques have shown promising results (based on the vertical distance of their ROC point from the ineffective discrimination line), while the verdict for several others is not too clear. Also, there are a number of procedures that are near to the ineffective discrimination reference line. Notice that two procedures actually have negative PODCI-FCP values, which is an indication of the uncertainty in estimating both PODCI and FCP with the small number of specimens employed in the screening phase, since it is generally assumed that a procedure can perform no worse in cracked material than in blank material. Ninety percent confidence intervals could also be plotted around these individual points but, as seen from the example in Figure 7.1, they would make the plot unreadable.

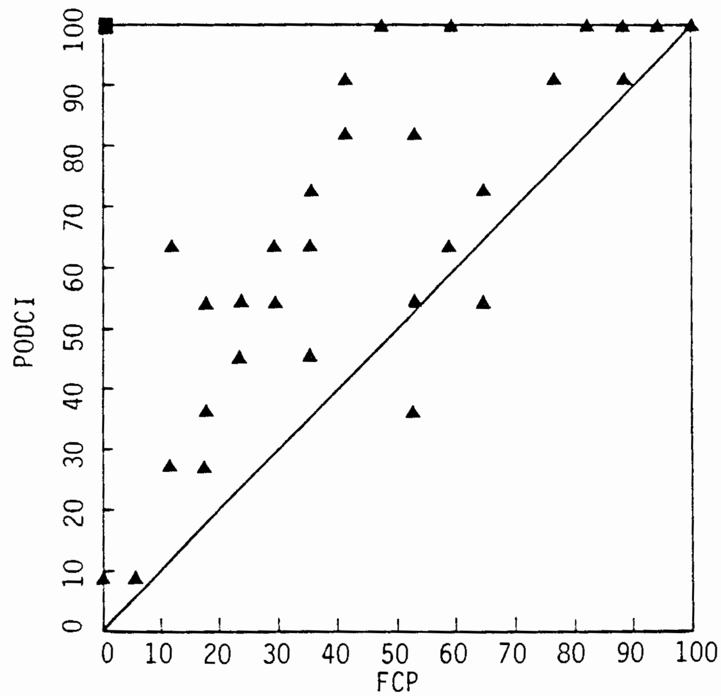


FIGURE 7.2. Relative Operating Characteristics Diagram of PODCI versus FCP without Confidence Intervals

Figure 7.3 shows the relative operating characteristics diagram using P(C|C) and P(C|B). The first point to note about Figure 7.3, in comparison to Figure 7.2, is that the techniques have generally shifted more into the lower left-hand corner. This is because the performance rated in Figure 7.2 depends only on putting a crack indication of any sort into a rather large area. On the other hand, the performance rated in Figure 7.3 depends also on the degree of matching lengths of cracked and uncracked material, a task that is even more difficult. Again, several of the procedures demonstrate an ability to discriminate between blank and cracked material. Also, more of the techniques now seem to be more closely clustered around the ineffective discrimination line, indicating that their abilities at determining the amount of cracked weld length are not as good as their ability to simply classify it as cracked.

7.3 STATISTICAL TEST OF DISCRIMINATION EFFECTIVENESS

Now that the procedures have been compared to each other in general, the question becomes one of whether they are effective enough to be used for the inspection of primary piping in nuclear power plants. For instance, criteria for adequately reliable yet cost-effective inspection procedures might be stated as: PODCI must be greater than 80% while maintaining an FCP below 20%. At this time such a definition of being reliable enough is not available, thereby making it difficult to compare the results of the CCSSRRT against any fixed criteria. Therefore, the following simple question will be asked: If a particular procedure has no ability to discriminate between cracked and uncracked material, then what is the probability that it could have gotten the FCP and PODCI values it did in the CCSSRRT screening phase? A statistical test

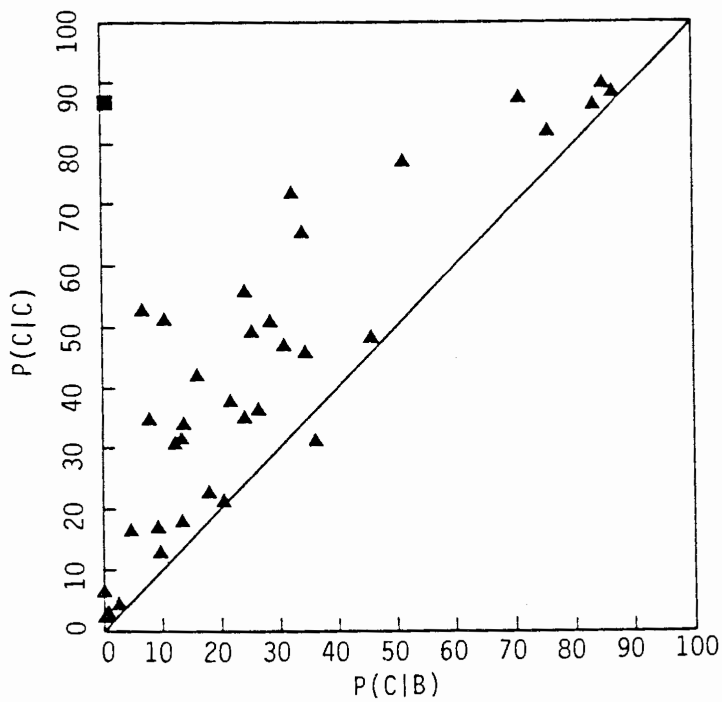


FIGURE 7.3. Relative Operating Characteristics Diagram of P(C|C) versus P(C|B)

can be used to answer this question, and any procedures with a low probability of having no discriminating capability will be judged to be at least minimally effective. However, this statistical test assumes that each classification of a grading unit was made independently of all other classifications. This is probably not true for the CCSSRRT, since the grading units are rather close to each other due to the physical limitations of the specimens themselves. Therefore, the statistical test can be expected to give overly optimistic results; that is, it will tend to make individual procedures look better than they really are, but it will still serve a useful purpose in ranking the procedures' performances.

A one-sided Fisher's exact probability test for PODCI-FCP=0 will be used since it is assumed that, except for random chance, a procedure's PODCI can only be greater than its FCP. The results of applying this test are given in Table 7.3 with the procedures then ranked by the probability that they have no discriminating ability. Those with a low probability of no discrimination appear to exhibit the best discriminating ability based on their FCP and PODCI scores. There are, of course, many other criteria that might be used to rank the teams. When reviewing this table, it must be kept in mind that the CCSSRRT was not designed to precisely quantify capability and that the exact ranking of any technique is not known with much certainty. It would be very easy for a technique to have only one of its calls changed and move many positions up or down in the rankings.

TABLE 7.3. Probabilities of No Discrimination Effectiveness

Procedure	Inspection Access	FCP	PODCI	Ranked Probability	Mode	Inspection Technique
* 94	Both	0	100	0.00	N-UT	Radiography
11	Single	47	100	0.01	A	ASME, 50 %
* 87	Both	12	64	0.01	N-UT	Radiography
18	Single	41	91	0.01	M	ASME, 50 %
18	Both	41	91	0.01	M	ASME, 50 %
90	Single	59	100	0.02	M	ASME, 50 %
90	Both	59	100	0.02	M	ASME, 50 %
06	Single	41	82	0.04	M	ASME, 50 %
01	Single	18	55	0.05	M	Noise level
75	Single	35	73	0.06	ASP	Noise level, Data shape
11	Both	29	64	0.08	A	ASME, 50 %
48	Single	24	55	0.10	ASP	Noise level
25	Both	53	82	0.12	M	ASME, Noise level
88	Single	53	82	0.12	M	ASME, Noise level
56	Both	35	64	0.14	M	ASME
36	Both	29	55	0.18	A	Data shape
29	Single	82	100	0.21	M	Noise level
35	Single	82	100	0.21	A	Noise level, Data shape
95	Single	82	100	0.21	M	Noise level
06	Both	24	45	0.21	M	ASME, 50 %
33	Single	24	45	0.21	A	Data shape
81	Both	18	36	0.25	M	ASME, 50 %
85	Single	12	27	0.29	M	Noise level
40	Both	76	91	0.33	ASP	Noise level, Data shape
53	Both	88	100	0.36	M	Noise level
05	Single	0	9	0.39	M	Noise level
52	Both	0	9	0.39	M	ASME, 20 %
23	Both	35	45	0.44	M	ASME, Noise level
46	Single	18	27	0.44	M	ASME, Noise level
39	Single	65	73	0.49	M	Noise level
53	Single	94	100	>0.50	M	Noise level
51	Single	94	100	>0.50	M	Noise level
71	Single	59	64	>0.50	ASP	Data shape
28	Single	6	9	>0.50	M	Noise level
51	Both	88	91	>0.50	M	Noise level
25	Single	53	55	>0.50	M	ASME, Noise level
40	Single	100	100	>0.50	ASP	Noise level, Data shape
22	Both	65	55	>0.50	M	ASME, Noise level
22	Single	53	36	>0.50	M	ASME, Noise level

* Procedures 87 and 94 are JRC-Ispra Radiographic Examinations, 94 under optimized conditions.

One thing to notice about this table, other than the fact that the radiography inspections are right at the top, is that there is no sharp separation into groups of procedures, say where the difference between one procedure and the next was more than .05 on the probability ranking index. This indicates that the procedures cover a broad range of capabilities with no apparent sharp separation between better ones and those that do not work as well. It is also apparent that no particular subset of the procedures performs exceptionally different from the others. For example, there is little evidence in these results that automated procedures with signal processing (ASP) are to be recommended over other modes of inspection or that the level of sensitivity used in the inspection will necessarily globally affect the ability to discriminate between blank and cracked material.

7.4 SUMMARY OF CRACK LOCATION AND SIZING PERFORMANCE

Table 7.4 gives a summary of each procedure's location and length sizing performance. For this table, the results are summarized over cracked specimens only and the summaries of location and length sizing errors depend on first classifying the grading unit as cracked, while the summaries for Percent Weld Length Classified Cracked do not. Also, the summary has been restricted to only "Near"-side inspections for single-side access. The values given in the table are average errors with their standard deviations in parentheses.

Table 7.5 summarizes the results for those procedures that used a depth-sizing technique on the CCSSRRT specimens. These results should only be viewed as indications of depth-sizing capabilities, because the crack depths of the specimens have been given as intended depth and have not been verified by destructive analysis, and the number of cracks that were actually sized is quite small. Review of the table for those techniques with more than two depth-sizing results generally indicate that a particular technique would consistently overestimate or underestimate the depth of the crack.

TABLE 7.4. Summary of Crack Location and Length Sizing Errors on Cracked Specimens

Procedure Number	Inspection Access	Cracked Units Correctly Classified	Location Errors Axial Offset (mm)	Location Errors Crack Center (mm)	Length Sizing Errors (mm)	Percent Weld Length Classified Cracked Blank P(C|B)	Percent Weld Length Classified Cracked Cracked P(C|C)
01	Near	5	9 (11)	-4 (14)	-36 (36)	5 (10)	23 (32)
05	Near	1	2 (.)	-4 (.)	-26 (.)	0 (0)	6 (19)
06	Both	5	1 (7)	3 (15)	-52 (24)	5 (6)	14 (25)
	Near	6	1 (6)	3 (24)	-49 (19)	6 (9)	10 (13)
11	Both	7	-1 (4)	1 (18)	-15 (26)	15 (15)	35 (36)
	Near	10	-1 (5)	-4 (19)	-24 (27)	22 (18)	52 (23)
18	Both	10	-0 (3)	-16 (28)	-1 (54)	20 (24)	60 (39)
	Near	7	-2 (4)	-16 (36)	-3 (63)	17 (26)	30 (33)
22	Both	6	-3 (7)	-32 (17)	19 (68)	23 (30)	34 (38)
	Near	2	2 (1)	-14 (19)	-26 (19)	12 (31)	19 (36)
28	Near	1	-4 (.)	2 (.)	-63 (.)	0 (0)	4 (9)
29	Near	9	3 (7)	-23 (30)	54 (84)	53 (41)	68 (41)
33	Near	1	3 (.)	-11 (.)	-33 (.)	4 (8)	5 (16)
35	Near	7	1 (3)	-12 (39)	-3 (43)	20 (22)	25 (28)
36	Both	6	-2 (7)	-2 (23)	-29 (26)	8 (8)	28 (32)
39	Near	5	0 (6)	-18 (38)	30 (94)	28 (37)	31 (43)
40	Both	10	2 (5)	-11 (29)	-5 (46)	22 (21)	47 (32)
	Near	11	2 (4)	-11 (31)	4 (39)	29 (24)	58 (30)
46	Near	2	4 (4)	-7 (4)	-51 (37)	0 (0)	9 (21)
48	Near	5	-5 (9)	-13 (17)	-25 (32)	6 (9)	30 (40)

TABLE 7.4. (cont'd)

Procedure Number	Inspection Access	Cracked Units Correctly Classified	Location Errors Axial Offset (mm)	Location Errors Crack Center (mm)	Length Sizing Errors (mm)	Percent Weld Length Classified Cracked Blank P(C|B)	Percent Weld Length Classified Cracked Cracked P(C|C)
51	Both	10	1 (3)	-19 (33)	87 (78)	73 (39)	86 (31)
	Near	11	2 (6)	-25 (28)	65 (77)	72 (31)	87 (18)
52	Both	1	-7 (.)	14 (.)	-27 (.)	0 (0)	4 (13)
53	Both	11	1 (3)	-12 (34)	85 (70)	75 (37)	91 (17)
	Near	11	3 (5)	-25 (27)	65 (76)	72 (31)	87 (18)
56	Both	7	-2 (5)	5 (27)	-37 (28)	9 (12)	28 (26)
71	Near	3	5 (7)	-21 (32)	6 (54)	10 (20)	13 (24)
75	Near	6	2 (13)	-17 (25)	-41 (27)	12 (10)	24 (19)
81	Both	4	0 (9)	5 (9)	-22 (26)	8 (8)	34 (39)
85	Near	2	-9 (1)	-1 (13)	-63 (54)	0 (1)	4 (10)
87	Both	7	1 (2)	-3 (5)	-15 (13)	7 (14)	49 (39)
88	Near	7	-2 (4)	-23 (15)	-26 (23)	18 (21)	27 (35)
90	Both	11	1 (4)	-18 (28)	-12 (48)	20 (18)	57 (35)
	Near	8	-1 (5)	-17 (35)	-22 (50)	15 (20)	26 (22)
94	Both	11	1 (3)	-1 (2)	-9 (8)	0 (0)	84 (13)
95	Near	9	1 (8)	-18 (31)	42 (80)	49 (35)	75 (32)

(.) Only one number was recorded, so no standard deviation could be computed.

TABLE 7.5. Summary of Crack Depth-Sizing Results Versus Intended Depths

Procedure	Inspection Access	Cracked Units Classified as Cracked	Average Sizing Difference (% T-wall)	Standard Deviation of Differences
06	Both	3	-21	4
	Near	5	-23	4
11	Both	5	10	19
18	Both	8	-12	5
	Near	6	-17	5
25	Both	6	-10	4
	Near	3	-6	7
28	Near	1	5	.
29	Near	1	-20	.
48	Near	3	-5	8
51	Both	1	-15	.
	Near	1	-15	.
52	Both	1	32	.
53	Both	5	12	5
	Near	3	12	7
75	Near	3	-19	6
85	Near	1	19	.
87	Both	2	5	4
88	Near	6	-14	7
90	Both	8	-12	5
	Near	6	-17	5

8.0 CONCLUSIONS

This study was designed as a screening test to identify those procedures that show the most promise to detect thermal fatigue cracks in purely equiaxed and columnar CCSS material. The thermal fatigue crack is considered to be ultrasonically conservative but has been identified as a probable degradation mechanism in nuclear plants. In the analysis reported here, inspection performance has been quantified by two parameters, PODCI and FCP. Any statements regarding inspection performance are based on these two parameters and both must be used to assess effectiveness of the procedures. Since this was a screening test, the performance parameters (PODCI and FCP) are not known with high precision; that is, they have wide confidence limits. The data should not be used for comparing the effectiveness of different procedures. Nevertheless, global trends can be extracted from the data. The following conclusions have been drawn from the data analysis performed on the CCSSRRT data.

1. In general, the inspection performance (PODCI, FCP) on the centrifugally cast stainless steel samples containing thermal fatigue cracks was rather poor. However, several operator-technique combinations have been identified as having the potential to correctly classify cracked CCSS piping. This ability seems to depend on the team's application as well as on the procedure itself, since other teams using the same general procedure did not perform as well.

2. The amount of false crack calls in the CCSSRRT has made it difficult to unambiguously analyze the results. Although data analysis techniques have been applied that attempt to account for these false calls, there is still inherent uncertainty when trying to quantify the capabilities of procedures with many false calls, both in their classification ability and their characterization ability. Procedures with high false call rates may indeed be able to discriminate cracked material from uncracked, but the false calls have made it difficult to establish this.

3. The performance on specimen 11, the only specimen that had been thermally and mechanically stress relieved after the thermal fatigue crack was introduced, was better than on any of the other cracked specimens. Relaxation of crack tightness would appear to be the explanation for the difference in crack characteristics between this specimen and the others in the specimen set.

4. In general, the acoustic properties of the columnar material in the CCSSRRT appear to make the probability of false calls much higher than in equiaxed material. Although this was not true for four of the teams.

5. The overriding effect of false calls in columnar material has made the task of determining the effect of inspection restrictions for single-sided access on the probability of classifying cracked material as cracked virtually impossible, since the CCSSRRT specimens are mostly columnar on one side of the weld and equiaxed on the other side.

6. At different stages of the program, two laboratory-type radiographic inspections were performed. The second inspection was used to guide the destructive examination. Although these radiographic results were good, these laboratory techniques are not adaptable for field inspections.

9.0 RECOMMENDATIONS

After the experience of conducting the CCSSRRT and its results are reviewed, the following recommendations are made for the Phase II Austenitic Steel Test (AST).

9.1 NEED FOR FURTHER STUDIES

- There is a need for further work on the identification and development of capable techniques for the detection and sizing of the relevant differing defect types in wrought, cast, and combinations of wrought and cast stainless steel.

- There is a need to carry out parametric studies, putting the emphasis on the effect of microstructures, defect characteristics, and geometrical features.

- There is a need to conduct reliability studies in wrought, cast, and combinations of wrought and cast stainless steel.

- Further work on reliability should include other aspects such as human factors.

9.2 SUGGESTIONS FOR TEST PROTOCOL

The following points are drawn to the attention of the organizers of the AST program:

1. Make it very clear to participants that there will be a "penalty" for calling blank material cracked. This is very true in real-world field inspections, and should be simulated in some manner in RRTs, such as through the Blank grading units employed in the CCSSRRT.

2. Make a concerted effort to obtain more participants so that there will be more representation for different techniques and more definitive conclusions can be drawn.

3. Use a larger specimen set with more types of inspection conditions to make conclusions more globally applicable to SS inspection.

4. Make Phase II more "field" representative so that the results may be extrapolated to field conditions. The CCSSRRT was conducted more as a laboratory study.

5. Use larger specimens so that more separation can be put between grading units to avoid the possibility of one crack call intersecting two grading units at the same time and to avoid crowding grading units near to the physical limits of the specimen.

6. Add a graded Disposition scale so that once a team has made a Crack/No Crack classification they additionally give some measure of confidence in that decision. This may help to make results less ambiguous when comparing techniques and allow for more sophisticated analysis of the inspection results.

7. The next step in the investigation of near-side versus far-side or both--side access should be part of a parametric program using uniform base material so that the problems experienced in the CCSSRRT with the columnar and equiaxed material response overshadowing any other effects will not be repeated.

8. An additional column should be placed on the Inspection Report Form that identifies which side of the weld a defect is thought to be on. Analysis of the CCSSRRT results seemed to be somewhat ambiguous when crack calls were located on the opposite side of the weld from a crack. It is then impossible to judge whether it is a location error or an incorrect call.

9. Give explicit directions to the participants for recording the dB responses so that this information can be more usefully employed.

APPENDIX A

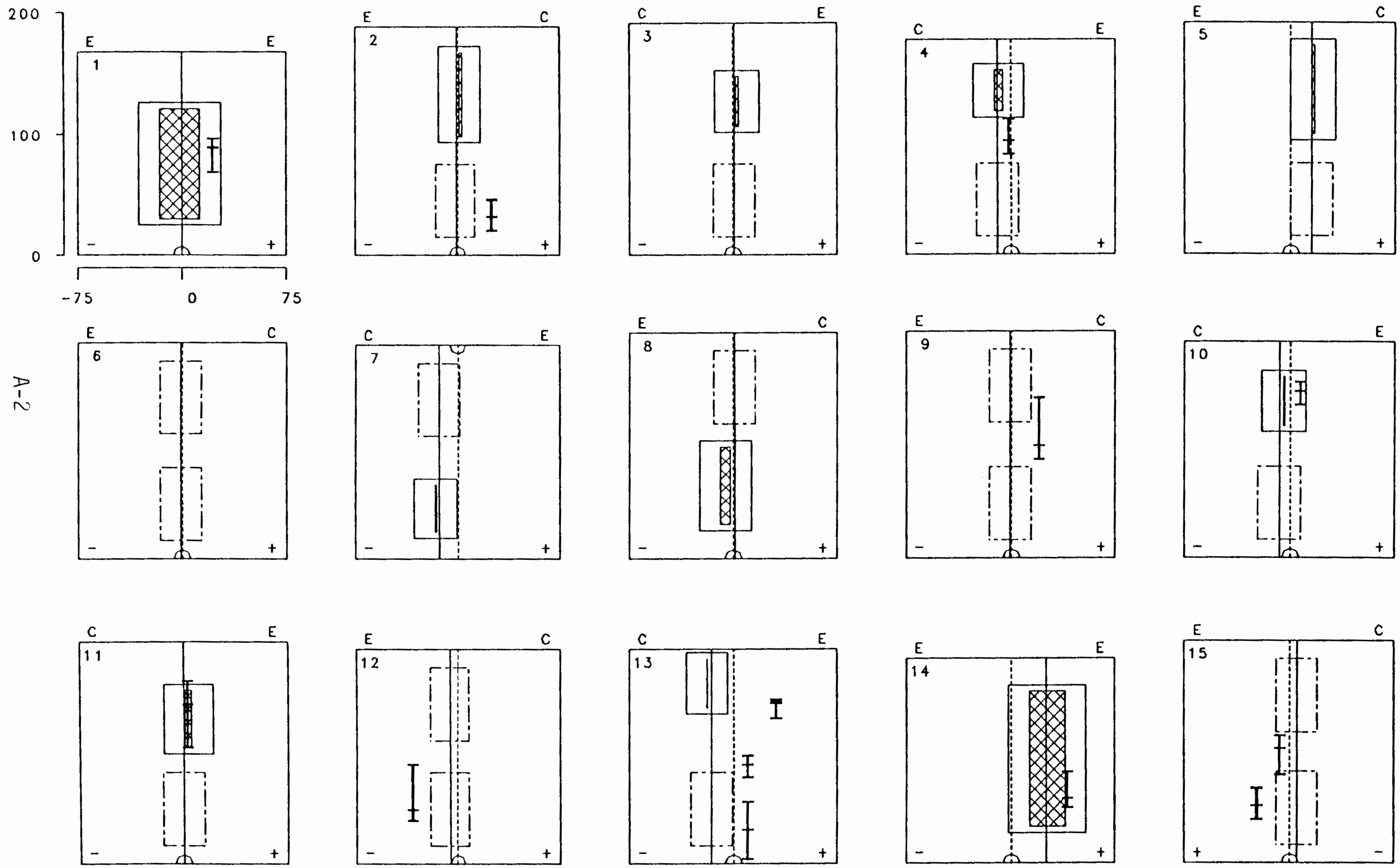
Maps and Tables of Each Procedure's Inspection Results

This Appendix contains the basic inspection performance results for each procedure used in the CCSSRRT. See Section 5.3 for a complete description of the information contained in these plots and tables. In this appendix, the procedures were listed as techniques so the reader should understand that these two descriptions are interchanged; i.e., technique 01 should·be procedure 01.

TABLE A.1 Basic Inspection Performance Results for Technique 01

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors: Offset mm	Correctly Classified Cracks: Location Errors: Center mm	Correctly Classified Cracks: Sizing Errors: Length mm	Correctly Classified Cracks: Sizing Errors: Depth %T-Wall	Percent Weld Length: Classified Blank	Percent Weld Length: Cracked Cracked
1	+	Equiaxed	Near		Yes	24	7	-63	.	0	32
	-	Equiaxed	Far		Yes	-22	-23	-52	.	0	43
2	+	Columnar	Near	0/1	No	.	.	.	.	23	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
4	+	Equiaxed	Far	0/1	No	.	.	.	.	21	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	1/1	Yes	-14	-19	-53	.	16	53
6	+	Columnar	None	0/2						0	
	-	Equiaxed	None	1/2						23	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
8	+	Columnar	Far	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	0/2						28	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	0/1	Yes	12	6	-21	.	0	49
	-	Columnar	Far	0/1	No	.	.	.	.	21	0
11	+	Equiaxed	Near	0/1	Yes	-1	4	8	.	6	98
	-	Columnar	Far	0/1	Yes	-2	14	-9	.	7	60
12	+	Columnar	None	0/2						27	
	-	Equiaxed	None	0/2						15	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	55	20
	-	Columnar	Near	0/1	Yes	-4	-10	-23	.	27	44
14	+	Equiaxed	Near		Yes	14	-25	-82	.	0	27
	-	Equiaxed	Far		No	.	.	.	.	0	24
15	+	Equiaxed	None	1/2						32	
	-	Columnar	None	1/2						17	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=01   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=01 Inspection access="-" side

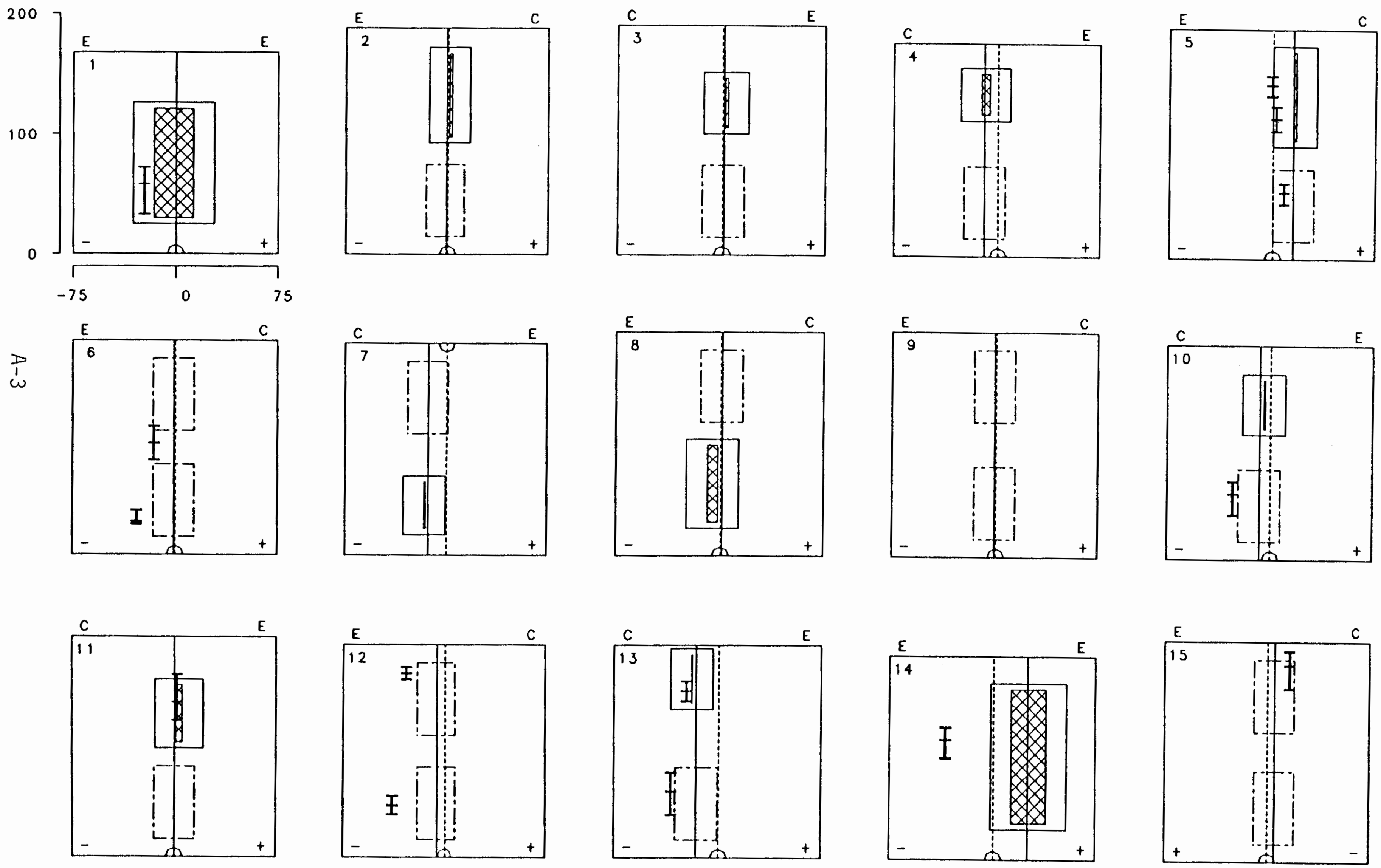
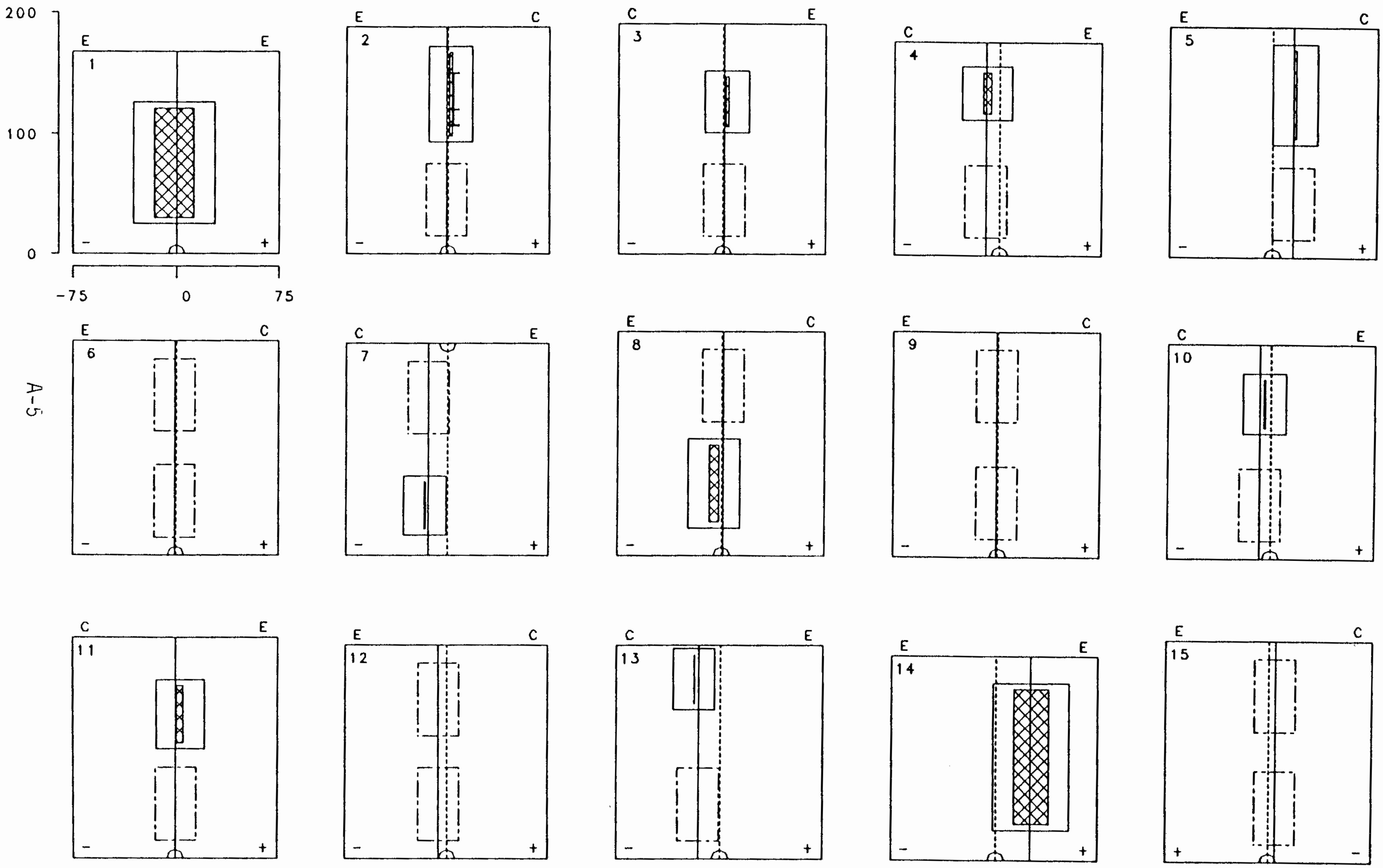


TABLE A.2 Basic Inspection Performance Results for Technique 05

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
2	+	Columnar	Near	0/1	Yes	2	-4	-26	.	0	63
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
4	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
8	+	Columnar	Far	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
11	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
12	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=05   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=05 Inspection access="-" side

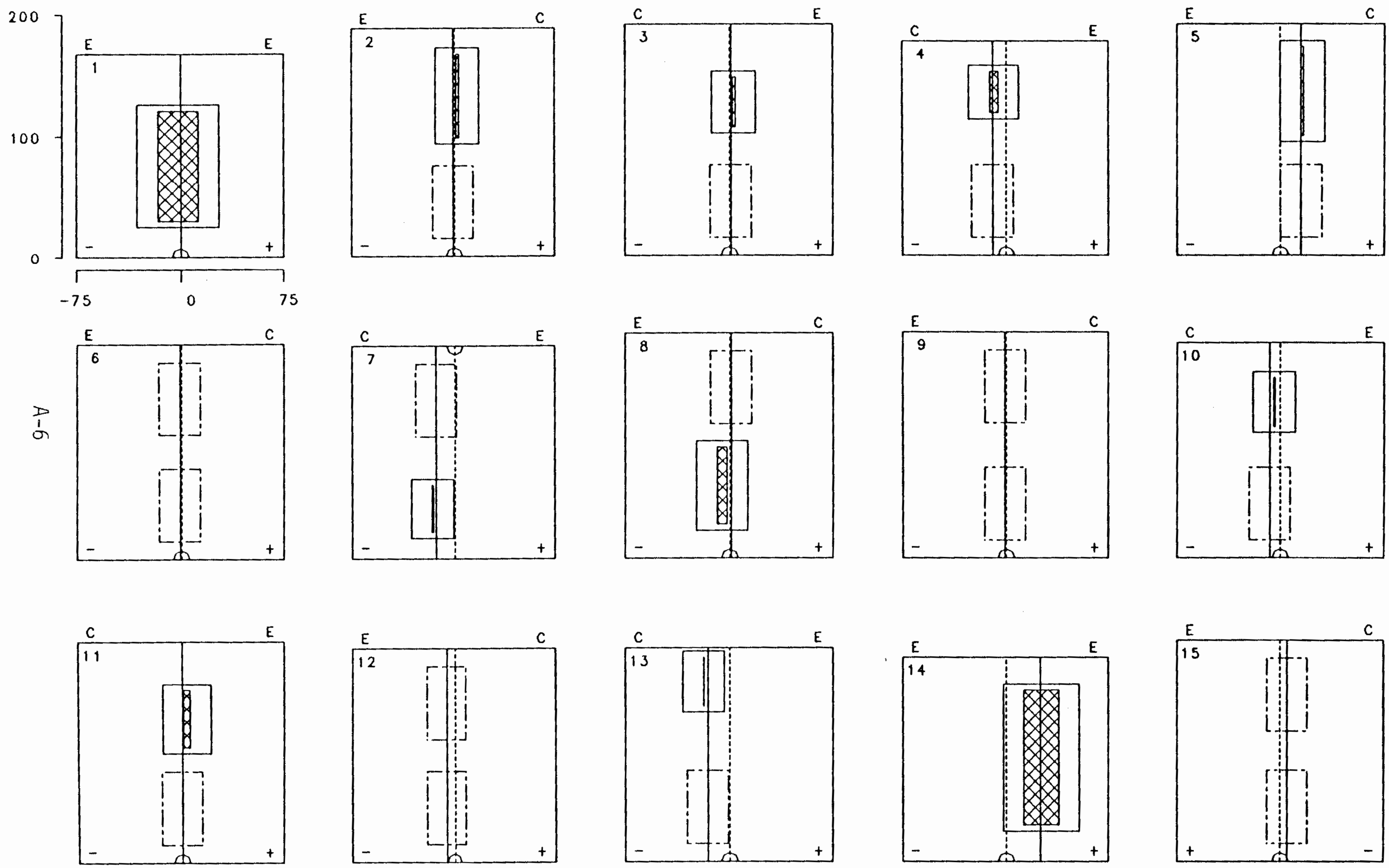
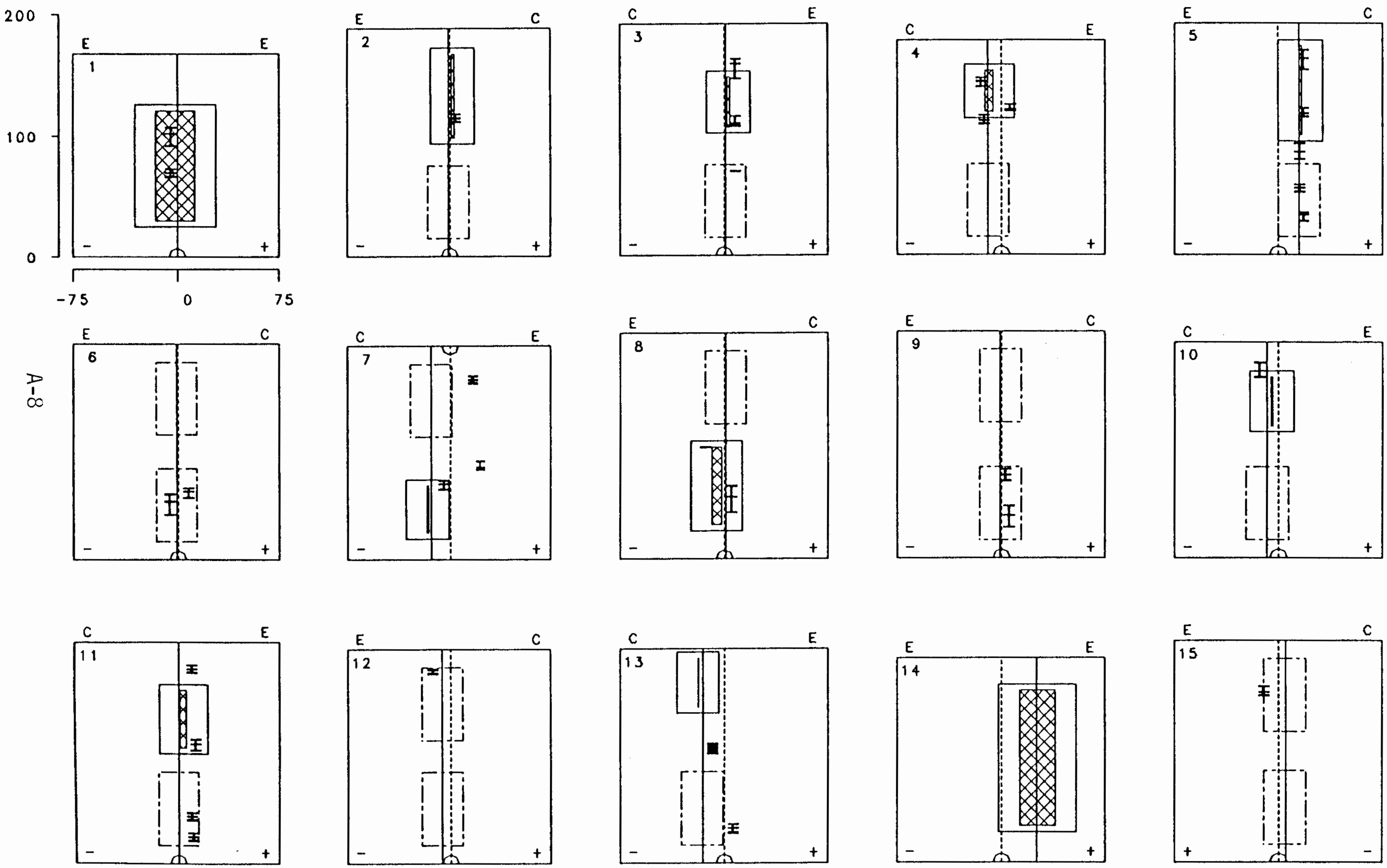


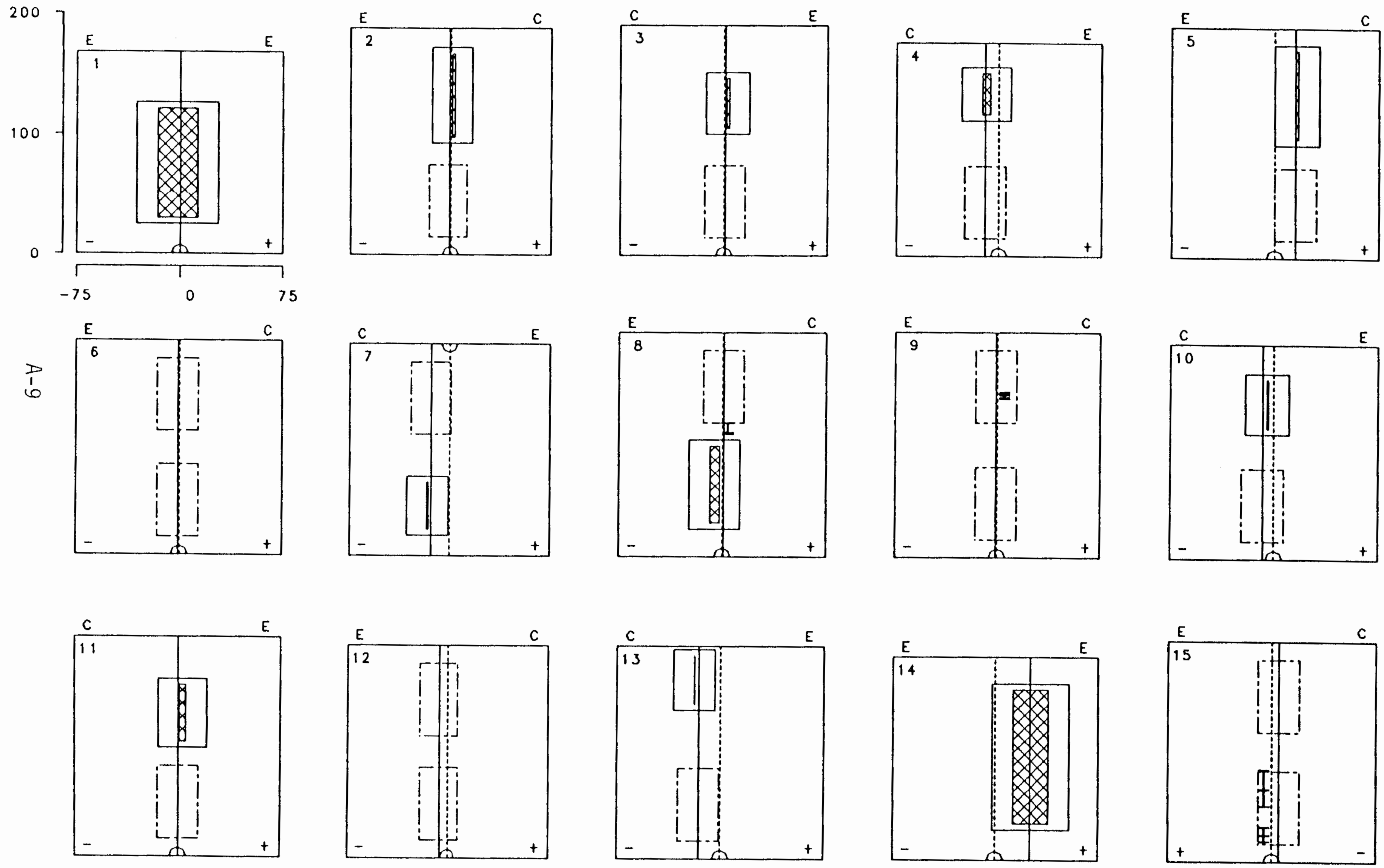
TABLE A.3 Basic Inspection Performance Results for Technique 06

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	-4	24	-76	.	0	26
	-	Equiaxed	Far		No	.	.	.	.	0	1
	B				Yes	11	-13	-83	.	5	10
2	+	Columnar	Near	0/1	Yes	2	-18	-63	-27	0	10
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	B			0/1	No	.	.	.	.	1	6
3	+	Equiaxed	Near	1/1	Yes	5	-16	-33	-20	11	26
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
	B			0/1	No	.	.	.	.	0	0
4	+	Equiaxed	Far	0/1	Yes	-6	8	-27	-12	6	40
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			0/1	No	.	.	.	.	5	0
5	+	Columnar	Near	1/1	Yes	2	26	-57	-26	25	34
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	B			1/1	Yes	5	27	-59	-26	18	22
6	+	Columnar	None	1/2						29	
	-	Equiaxed	None	0/2						0	
	B			0/2						5	
7	+	Equiaxed	Far	0/1	Yes	12	20	-32	-20	14	10
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			1/1	Yes	-1	6	-25	-19	13	40
8	+	Columnar	Far	0/1	Yes	11	-11	-42	-21	0	37
	-	Equiaxed	Near	0/1	No	.	.	.	.	8	0
	B			0/1	Yes	-10	-4	-64	.	2	3
9	+	Columnar	None	1/2						16	
	-	Equiaxed	None	1/2						3	
	B			0/2						0	
10	+	Equiaxed	Near	0/1	Yes	-9	26	-28	-20	9	2
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
	B			0/1	No	.	.	.	.	0	0
11	+	Equiaxed	Near	1/1	Yes	9	-21	-38	-25	18	17
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
	B			0/1	Yes	1	1	-31	-18	1	79
12	+	Columnar	None	1/2						3	
	-	Equiaxed	None	0/2						0	
	B			0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	13	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			0/1	No	.	.	.	.	10	0
14	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
	B				No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						5	
	-	Columnar	None	1/2						24	
	B			2/2						72	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=06   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=06   Inspection access="-" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=06   Inspection access=Both sides

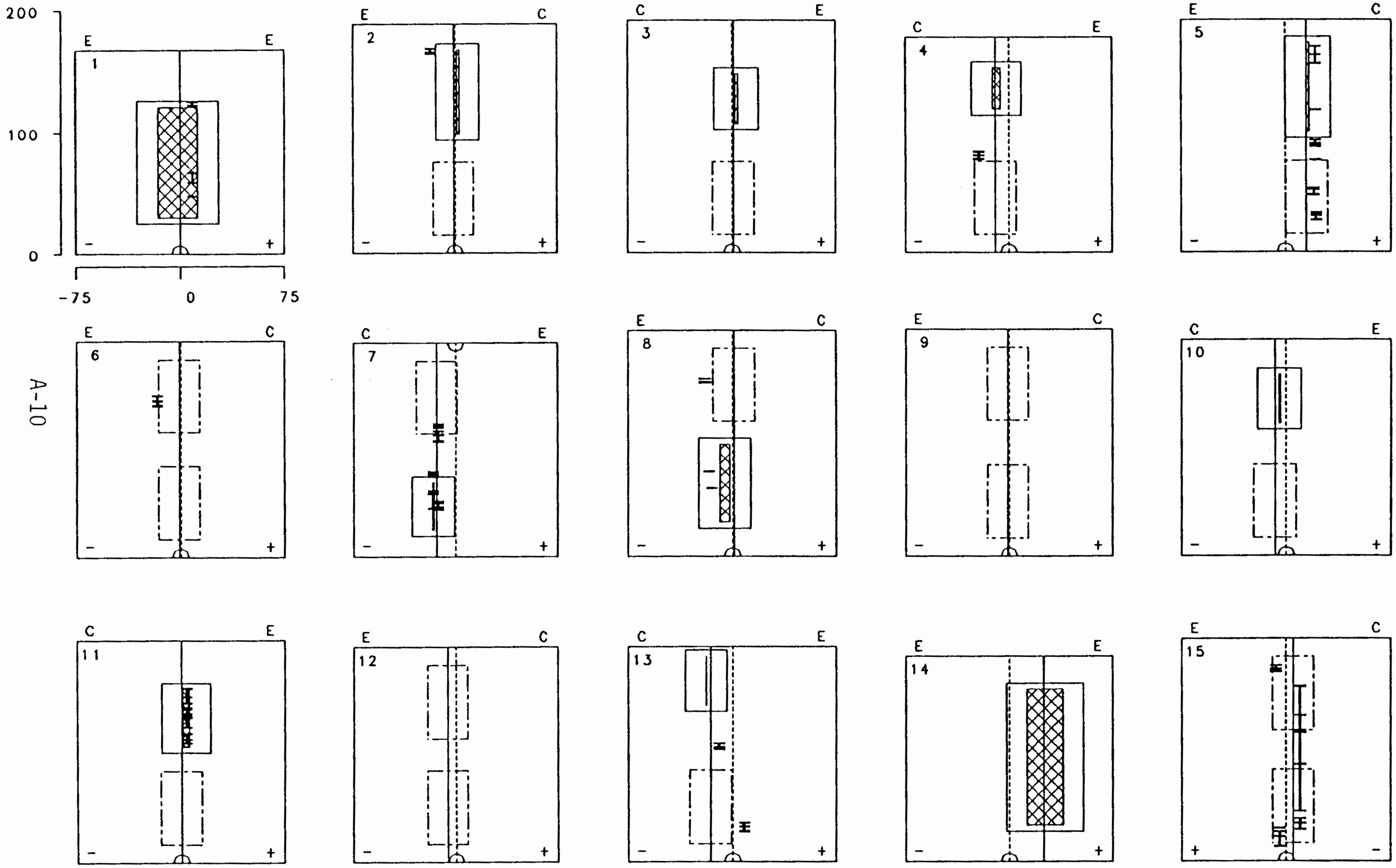
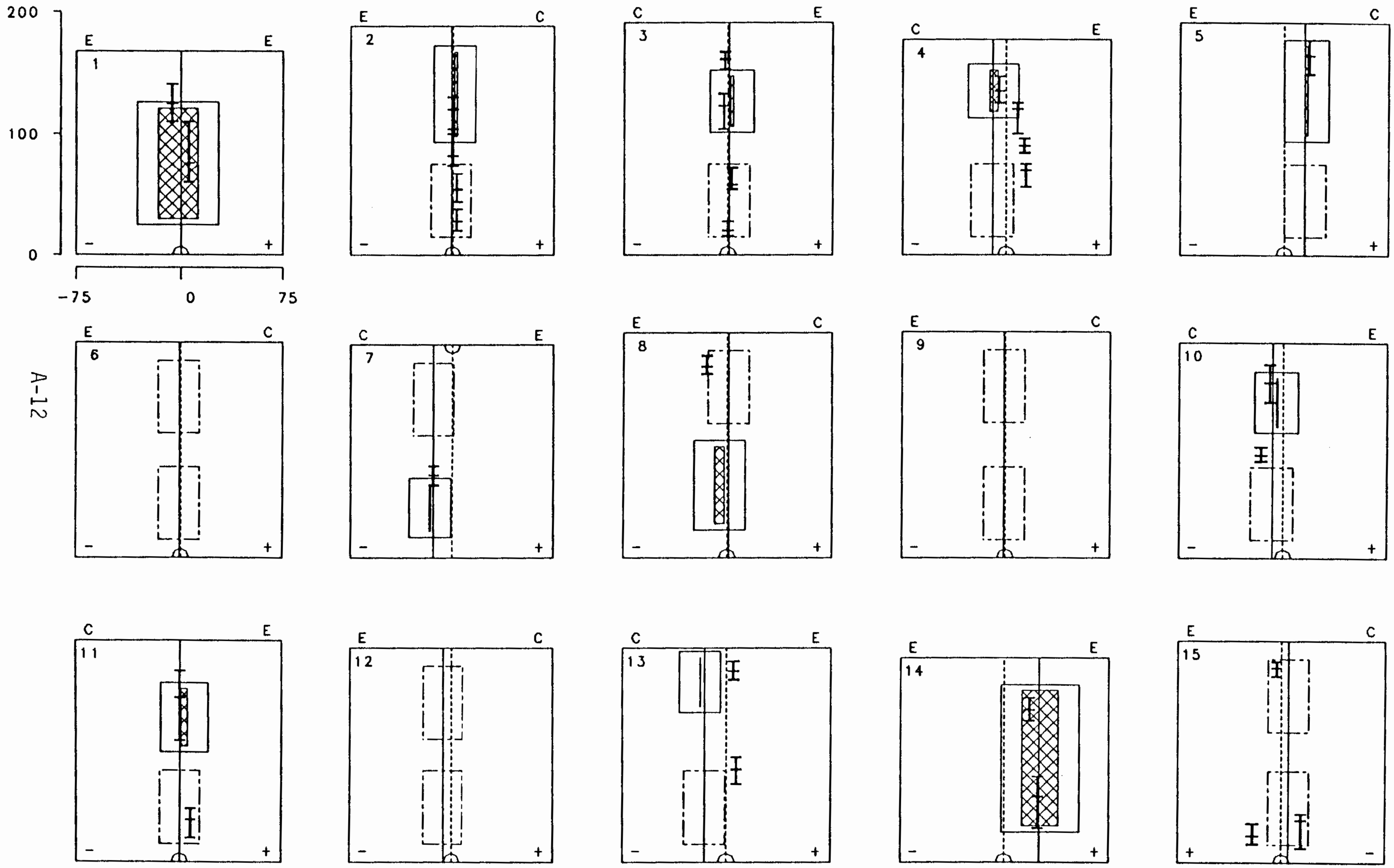


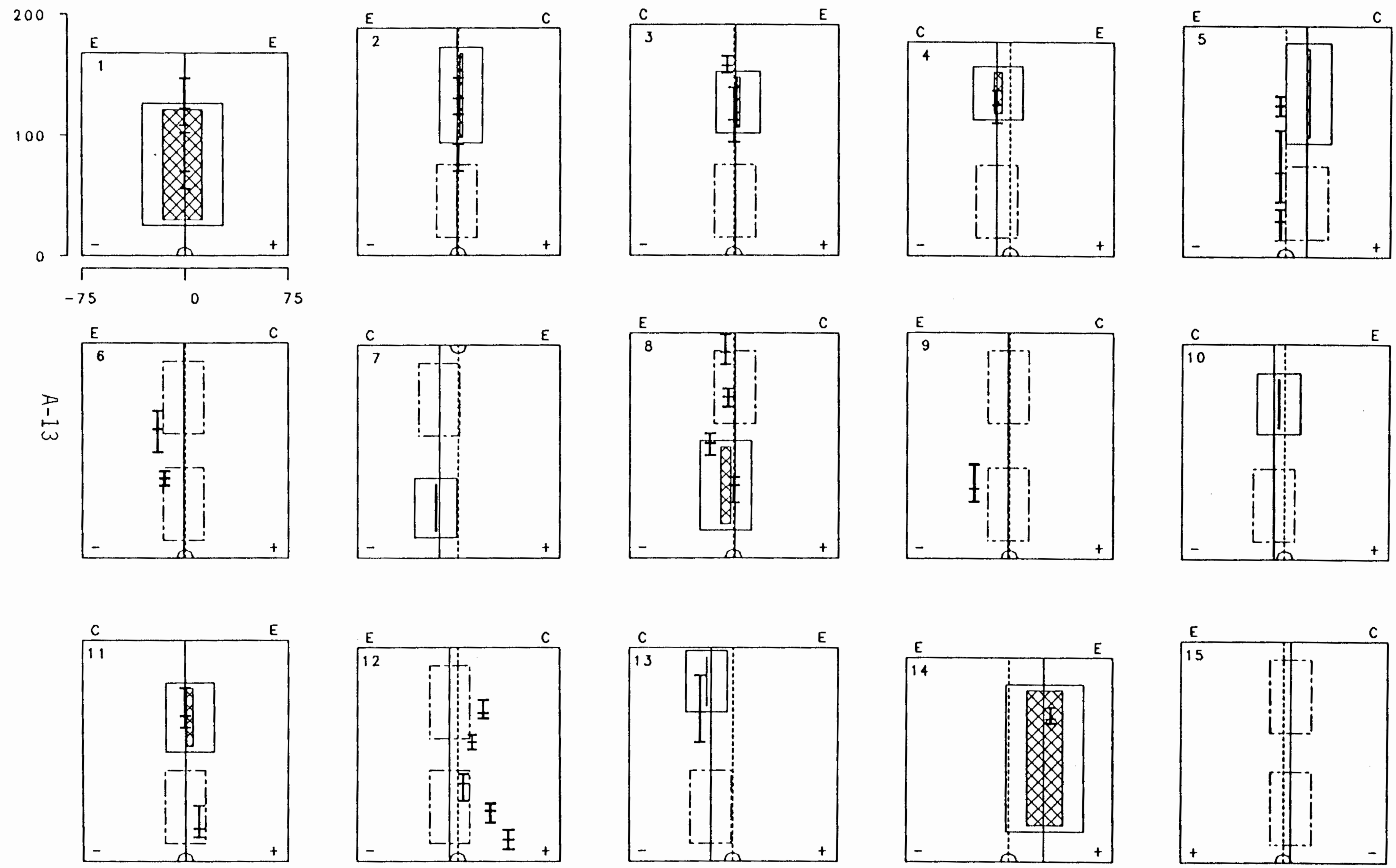
TABLE A.4 Basic Inspection Performance Results for Technique 11

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	8	10	-41	.	26	67
	-	Equiaxed	Far		Yes	2	4	-45	.	34	66
	B				Yes	5	3	-55	.	37	55
2	+	Columnar	Near	1/1	Yes	-2	-18	-39	.	57	47
	-	Equiaxed	Far	1/1	Yes	-2	-1	-39	.	19	44
	B			1/1	Yes	-2	-19	-42	0	19	40
3	+	Equiaxed	Near	1/1	Yes	-6	-8	-12	.	33	67
	-	Columnar	Far	0/1	Yes	-3	-10	4	.	18	81
	B			1/1	Yes	-3	-5	-2	2	36	86
4	+	Equiaxed	Far	0/1	Yes	4	1	-12	.	36	86
	-	Columnar	Near	0/1	Yes	-1	-12	-7	.	6	57
	B			0/1	No	.	.	.	.	0	0
5	+	Columnar	Near	0/1	Yes	2	28	-45	.	4	32
	-	Equiaxed	Far	0/1	No	.	.	.	.	68	32
	B			0/1	No	.	.	.	.	0	0
6	+	Columnar	None	0/2						0	
	-	Equiaxed	None	1/2						27	
	B			0/2						20	
7	+	Equiaxed	Far	0/1	Yes	3	27	-23	.	11	5
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			0/1	Yes	3	27	-23	-13	11	5
8	+	Columnar	Far	0/1	No	.	.	.	.	13	0
	-	Equiaxed	Near	1/1	Yes	6	-4	-43	.	44	46
	B			0/1	No	.	.	.	.	0	0
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						17	
	B			0/2						0	
10	+	Equiaxed	Near	0/1	Yes	-6	16	-9	.	18	51
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
	B			0/1	Yes	3	16	-9	32	8	51
11	+	Equiaxed	Near	1/1	Yes	-4	10	10	.	30	90
	-	Columnar	Far	1/1	Yes	-4	8	-14	.	21	69
	B			1/1	Yes	-4	10	10	27	31	90
12	+	Columnar	None	0/2						0	
	-	Equiaxed	None	1/2						49	
	B			0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	17	39
	-	Columnar	Near	0/1	Yes	-5	-23	15	.	22	63
	B			0/1	Yes	-5	-23	15	.	22	63
14	+	Equiaxed	Near		Yes	-2	-37	-69	.	4	54
	-	Equiaxed	Far		Yes	4	35	-98	.	0	13
	B				No	.	.	.	.	0	0
15	+	Equiaxed	None	2/2						23	
	-	Columnar	None	0/2						0	
	B			2/2						23	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=11   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=11   Inspection access="-" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=11 Inspection access=Both sides

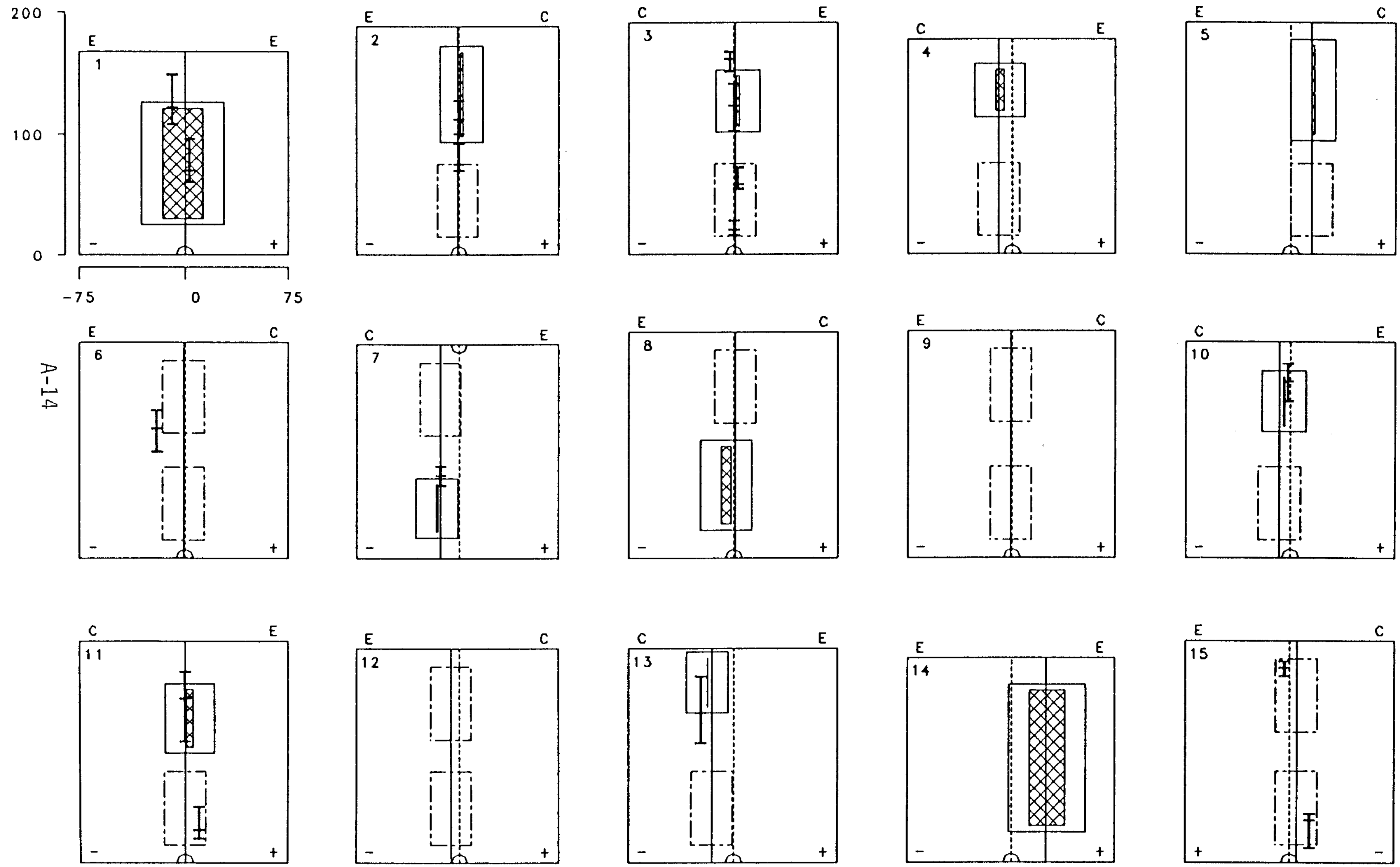
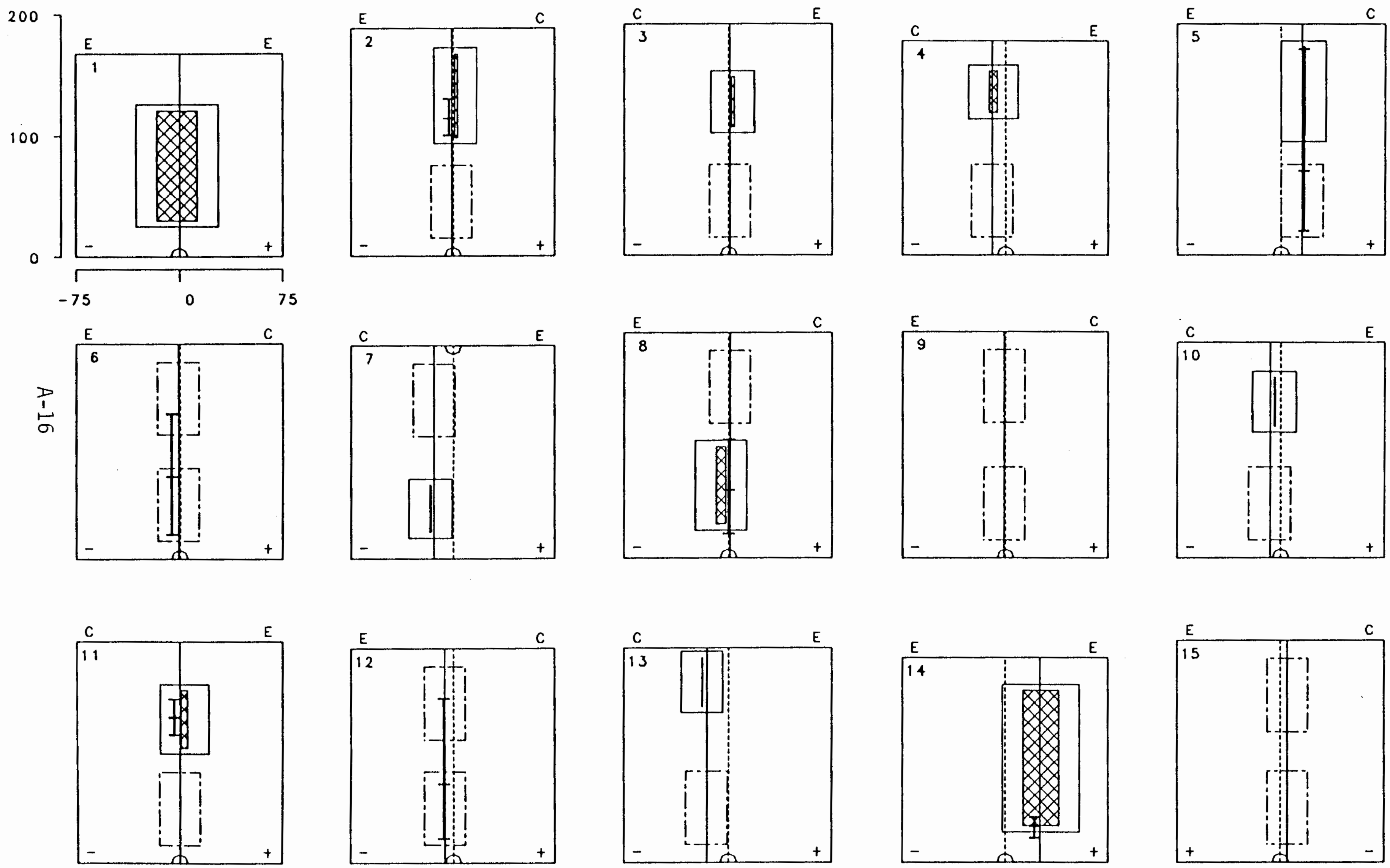


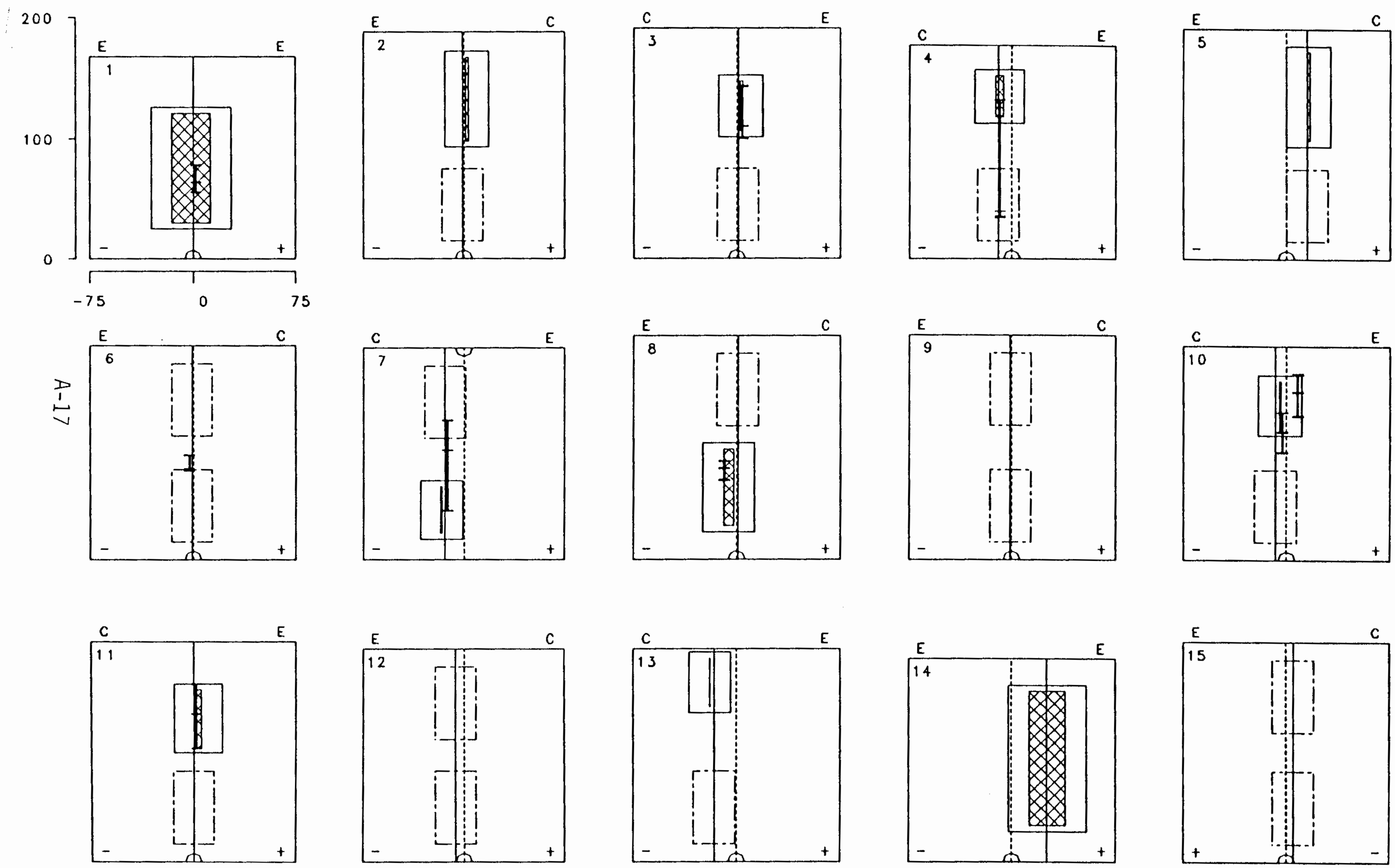
TABLE A.5 Basic Inspection Performance Results for Technique 18

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		Yes	4	-9	-69	.	0	25
	B				Yes	4	-9	-69	.	0	25
2	+	Columnar	Near	0/1	Yes	-5	-18	-39	-23	0	44
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	B			0/1	Yes	-5	-18	-39	-23	0	44
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	1	-5	2	-8	4	90
	B			0/1	Yes	1	-5	2	-8	4	90
4	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	0	-52	63	-13	58	43
	B			1/1	Yes	0	-52	63	-13	58	43
5	+	Columnar	Near	1/1	Yes	0	-41	77	-14	68	97
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	B			1/1	Yes	0	-41	77	-14	68	97
6	+	Columnar	None	2/2						57	
	-	Equiaxed	None	1/2						8	
	B			2/2						57	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	5	37	36	-11	40	53
	B			1/1	Yes	5	37	36	-11	40	53
8	+	Columnar	Far	0/1	Yes	6	-1	14	-12	12	100
	-	Equiaxed	Near	0/1	Yes	-4	14	-48	-23	0	26
	B			0/1	Yes	2	-1	14	-12	12	100
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
	B			0/2						0	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	2	-23	-7	-8	18	100
	B			0/1	Yes	2	-23	-7	-8	18	100
11	+	Equiaxed	Near	0/1	Yes	-8	2	-18	-15	0	63
	-	Columnar	Far	0/1	Yes	-2	2	6	-5	4	100
	B			0/1	Yes	-5	2	6	-5	4	100
12	+	Columnar	None	2/2						66	
	-	Equiaxed	None	0/2						0	
	B			2/2						66	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		Yes	-5	-57	-94	.	18	7
	-	Equiaxed	Far		No	.	.	.	.	0	0
	B				Yes	-5	-57	-94	.	18	7
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	0/2						0	
	B			0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=18 Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=18   Inspection access="-" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=18 Inspection access=Both sides

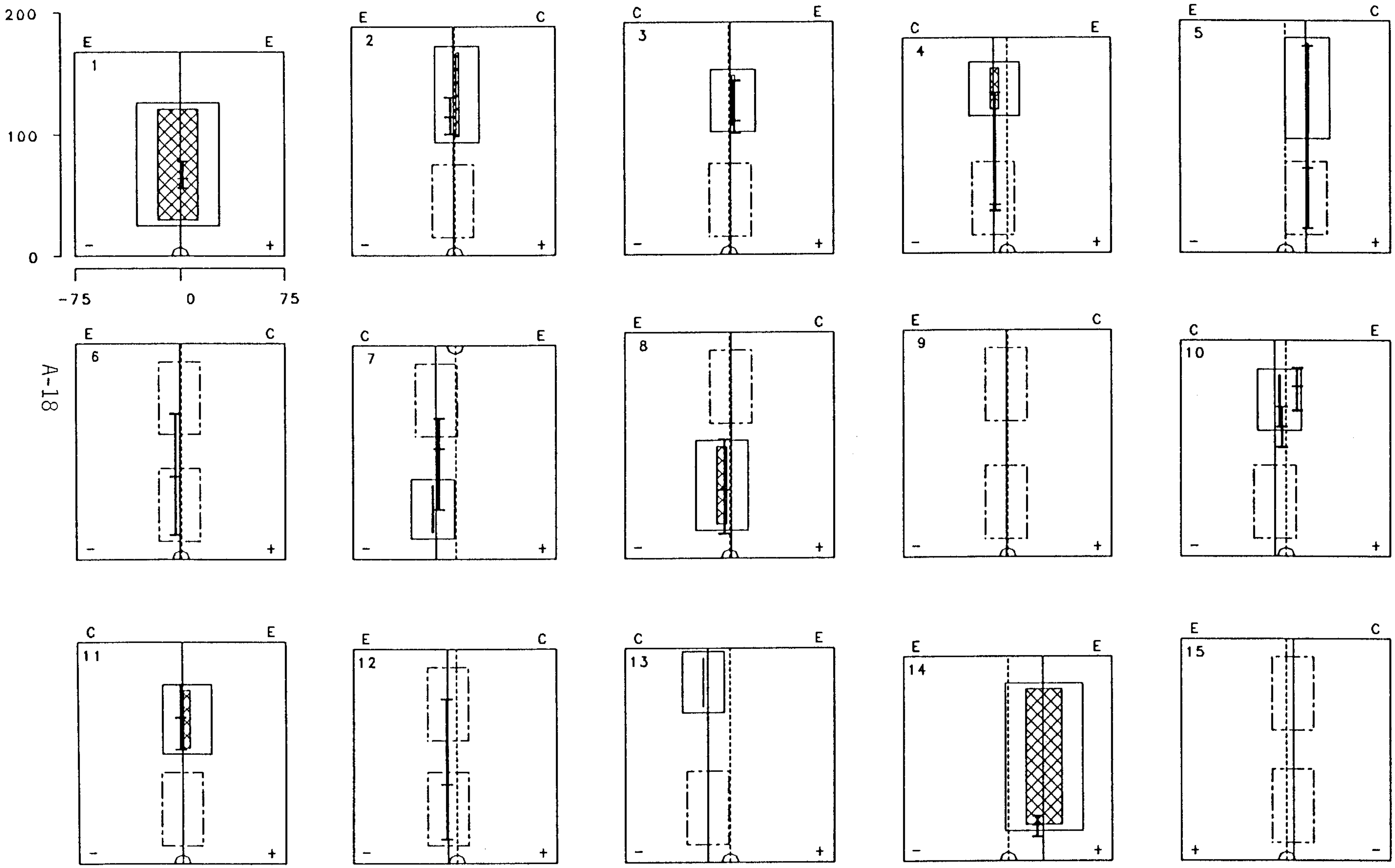
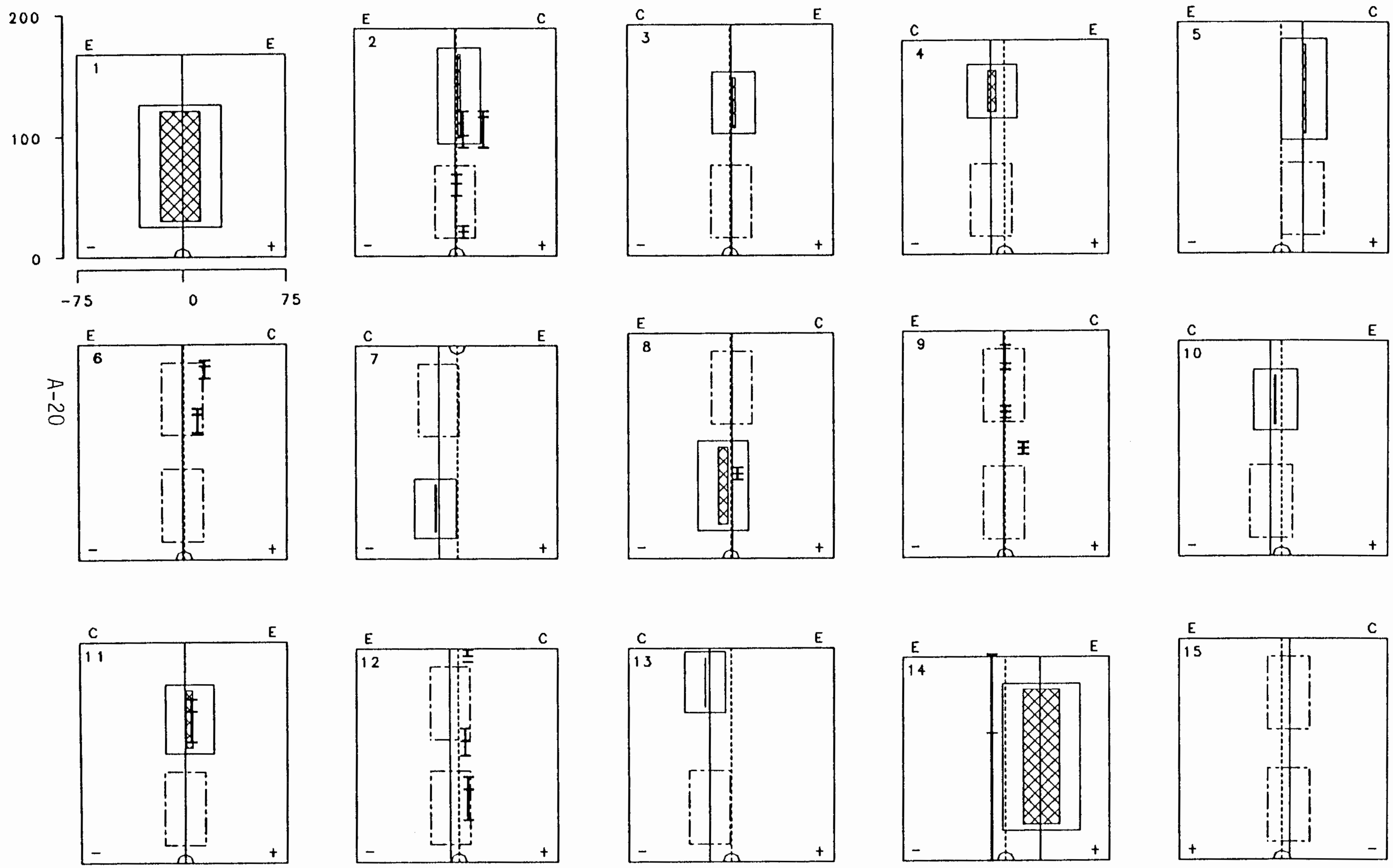


TABLE A.8 Basic Inspection Performance Results for Technique 22

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
	B				No	.	.	.	.	0	0
2	+	Columnar	Near	1/1	Yes	3	-28	-39	.	32	33
	-	Equiaxed	Far	0/1	Yes	-4	-8	-49	.	0	30
	B			1/1	Yes	-2	-53	91	.	82	90
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	21	0
	B			1/1	Yes	-3	-47	119	.	79	100
4	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			0/1	No	.	.	.	.	8	37
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	B			0/1	Yes	-16	-36	-23	.	30	36
6	+	Columnar	None	1/2						21	
	-	Equiaxed	None	0/2						0	
	B			2/2						66	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			1/1	No	.	.	.	.	15	0
8	+	Columnar	Far	0/1	Yes	11	10	-54	.	0	17
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	B			1/1	Yes	1	-20	-44	.	26	32
9	+	Columnar	None	1/2						23	
	-	Equiaxed	None	0/2						0	
	B			1/2						46	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	1/1	Yes	-6	6	-10	.	20	73
	B			0/1	Yes	5	-29	-20	.	14	5
11	+	Equiaxed	Near	0/1	Yes	2	-1	-12	.	0	75
	-	Columnar	Far	1/1	No	.	.	.	.	59	6
	B			0/1	Yes	-4	-6	-12	.	0	75
12	+	Columnar	None	2/2						37	
	-	Equiaxed	None	0/2						0	
	B			2/2						72	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		No	.	.	.	.	100	100
	-	Equiaxed	Far		No	.	.	.	.	0	0
	B				No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	2/2						69	
	B			2/2						45	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=22   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
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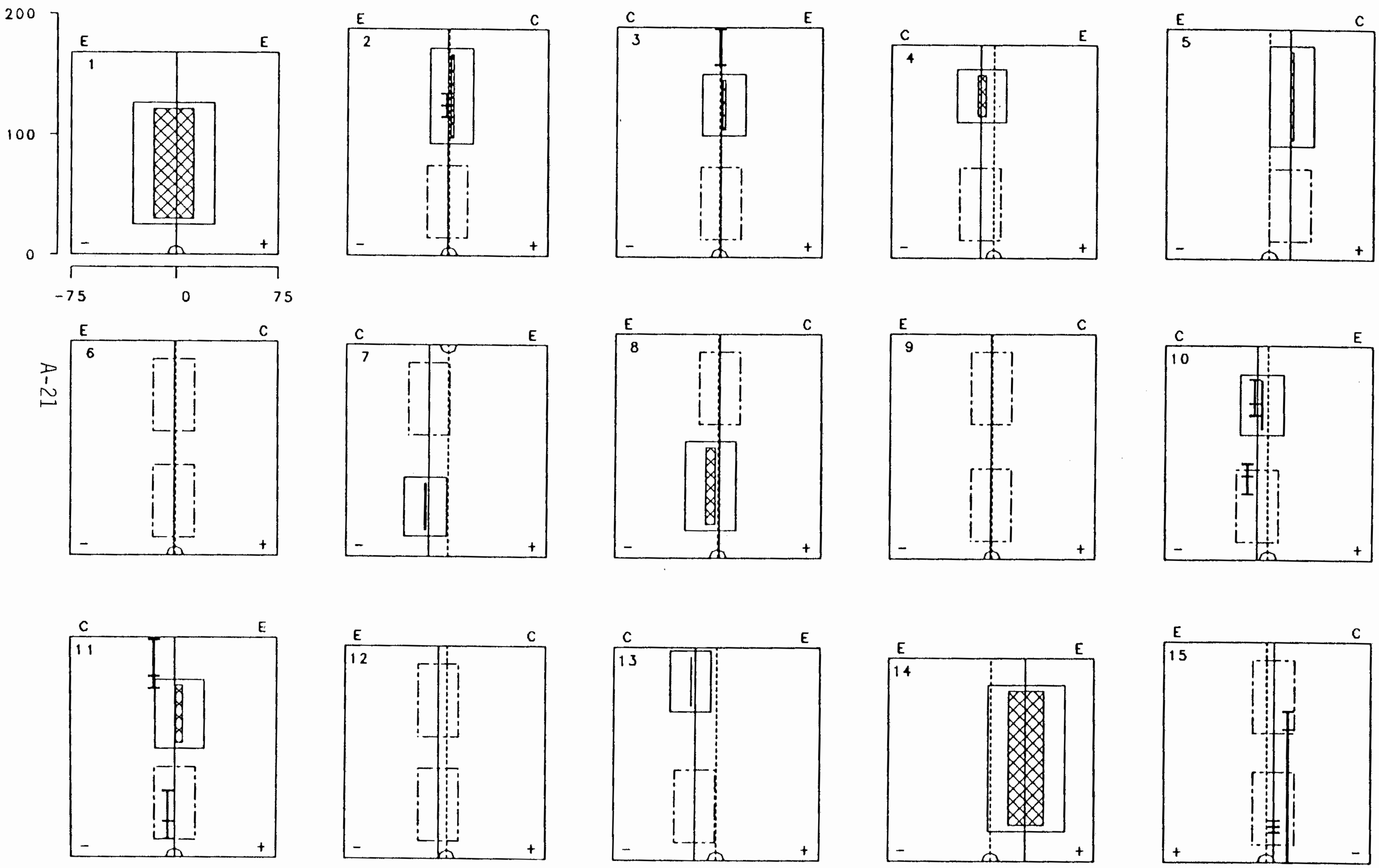


Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=22   Inspection access=Both sides

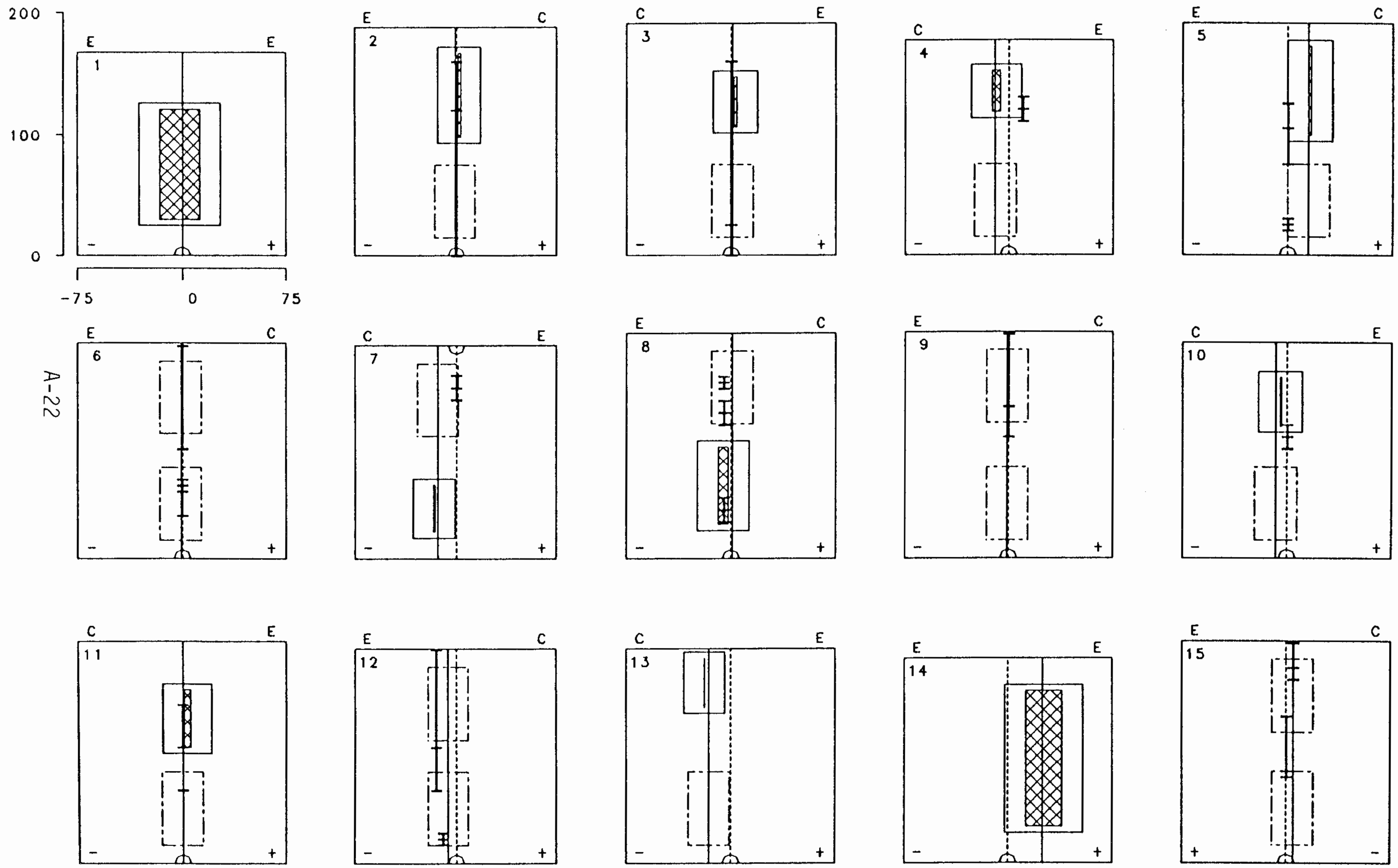


TABLE A.7 Basic Inspection Performance Results for Technique 23

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	B				No	.	.	.	.	0	0
2	B			0/1	Yes	3	18	-39	.	0	44
3	B			1/1	Yes	5	36	4	.	40	19
4	B			0/1	No	.	.	.	.	0	0
5	B			0/1	Yes	-16	-46	-13	.	33	30
6	B			1/2						26	
7	B			0/1	No	.	.	.	.	0	0
8	B			0/1	Yes	-1	-8	-19	.	0	71
9	B			2/2						47	
10	B			0/1	No	.	.	.	.	0	0
11	B			0/1	Yes	-4	22	-17	.	10	38
12	B			1/2						38	
13	B			0/1	No	.	.	.	.	13	56
14	B				No	.	.	.	.	0	0
15	B			1/2						25	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=23   Inspection access=Both sides

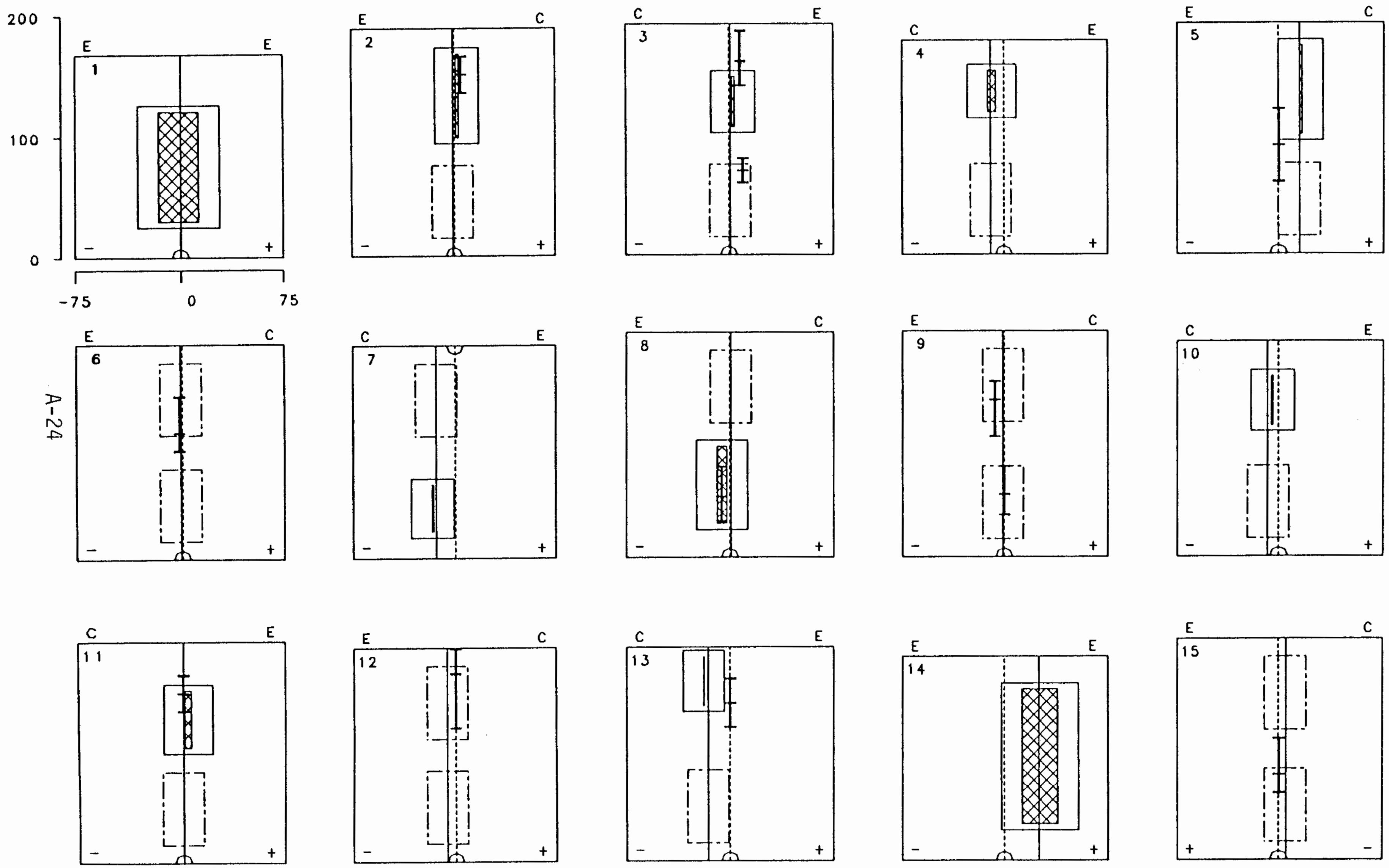
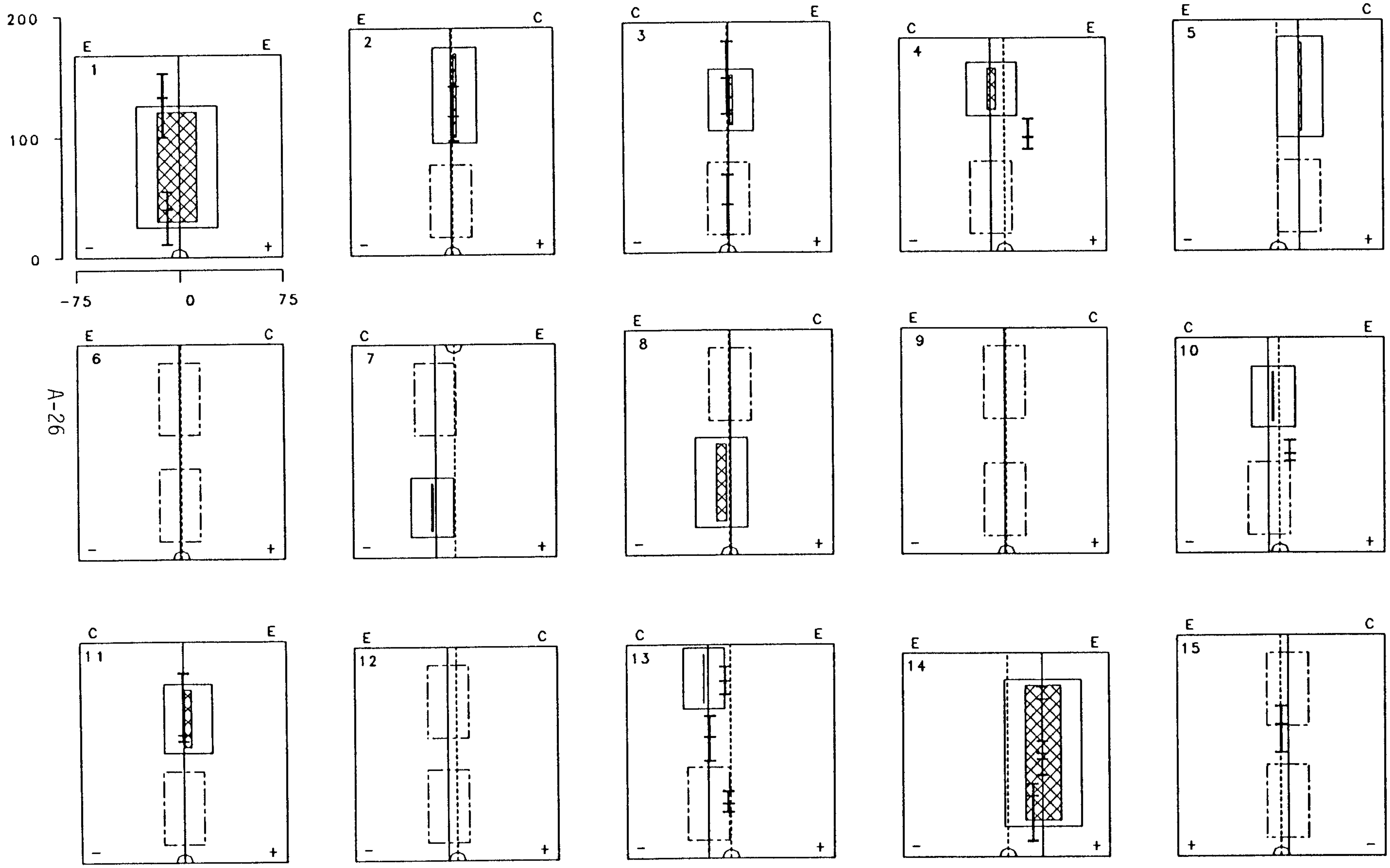


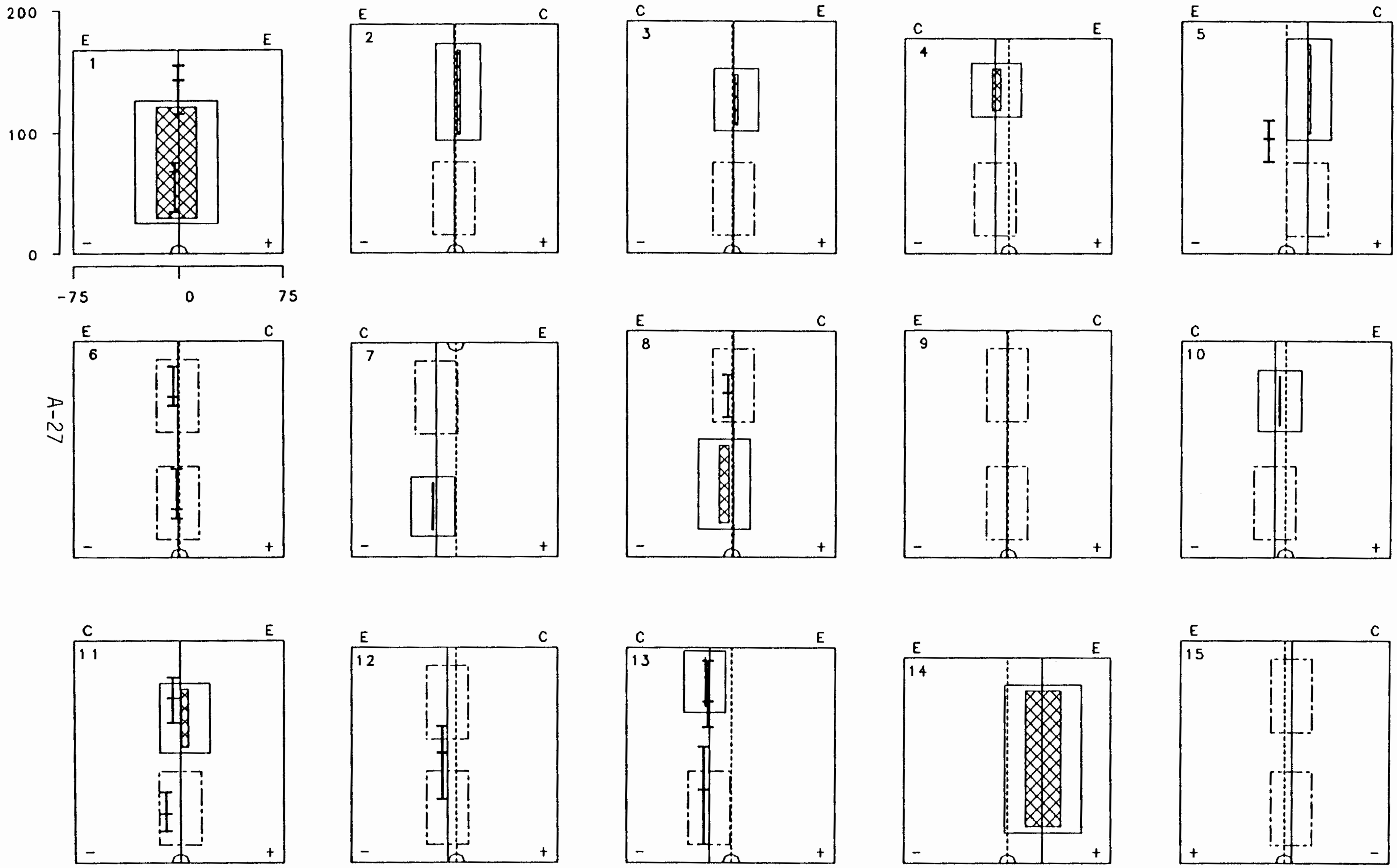
TABLE A.8 Basic Inspection Performance Results for Technique 25

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Blank	Percent Weld Length Classified Cracked
1	+	Equiaxed	Near		Yes	-8	-43	-47	.	67	52
	-	Equiaxed	Far		Yes	-2	-21	-51	.	45	52
	B				Yes	9	-6	-65	.	51	83
2	+	Columnar	Near	0/1	Yes	-1	-15	-24	-10	3	81
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	B			1/1	Yes	-12	0	6	-10	73	100
3	+	Equiaxed	Near	1/1	Yes	-3	19	19	-11	53	79
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
	B			1/1	Yes	1	13	33	-8	46	100
4	+	Equiaxed	Far	0/1	No	.	.	.	.	18	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			0/1	Yes	2	-10	16	-8	40	94
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	20	16
	B			1/1	No	.	.	.	.	68	16
6	+	Columnar	None	0/2						0	
	-	Equiaxed	None	2/2						42	
	B			0/2						0	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
	B			0/1	No	.	.	.	.	0	0
8	+	Columnar	Far	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Near	1/1	No	.	.	.	.	30	0
	B			1/1	Yes	-15	45	-34	-18	63	5
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
	B			1/2						14	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	13	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
	B			1/1	Yes	-5	10	8	-10	30	85
11	+	Equiaxed	Near	0/1	Yes	-4	10	9	2	10	90
	-	Columnar	Far	1/1	Yes	-9	15	-10	4	32	58
	B			0/1	Yes	4	8	11	-8	10	96
12	+	Columnar	None	0/2						0	
	-	Equiaxed	None	2/2						35	
	B			1/2						22	
13	+	Equiaxed	Far	1/1	Yes	15	-2	-17	.	41	59
	-	Columnar	Near	1/1	Yes	2	-10	14	.	73	93
	B			1/1	Yes	12	-7	8	.	59	93
14	+	Equiaxed	Near		Yes	-1	32	-66	.	30	88
	-	Equiaxed	Far		No	.	.	.	.	0	0
	B				Yes	2	-2	21	.	38	100
15	+	Equiaxed	None	1/2						21	
	-	Columnar	None	0/2						0	
	B			1/2						19	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=25   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=25 Inspection access="-" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=25 Inspection access=Both sides

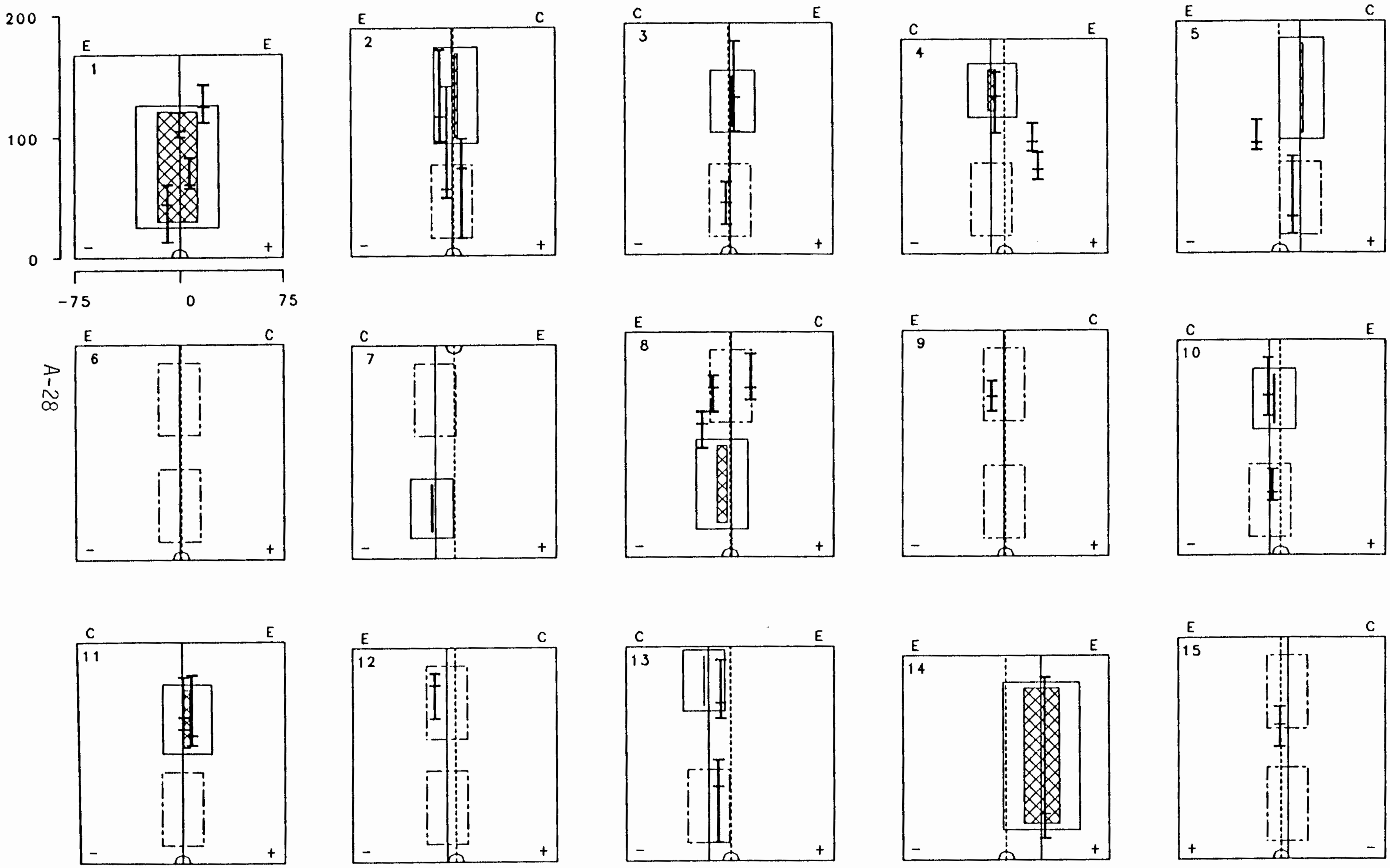
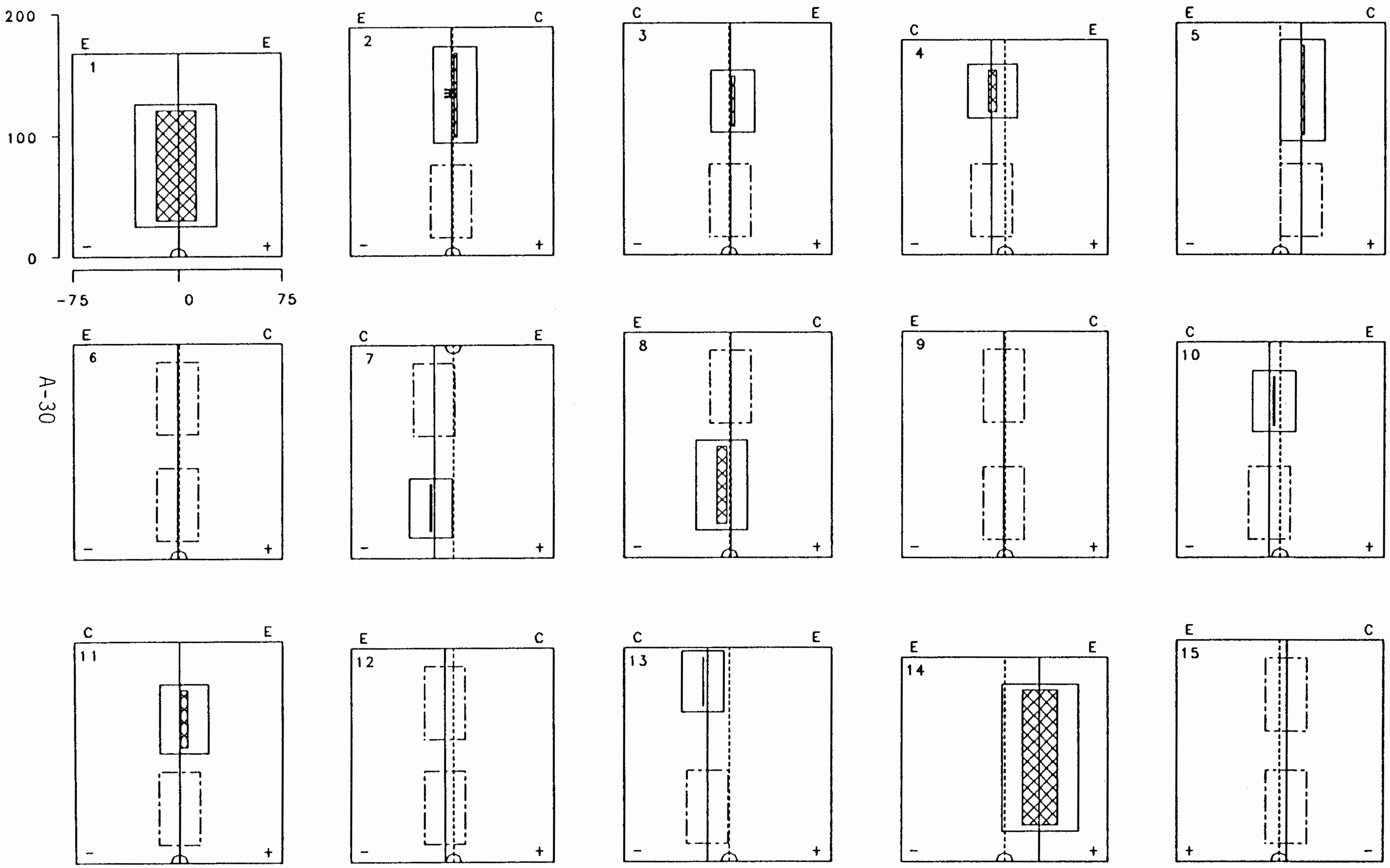


TABLE A.9 Basic Inspection Performance Results for Technique 28

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
2	+	Columnar	Near	0/1	Yes	-4	2	-63	5	0	10
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	1/1	No	.	.	.	.	5	0
4	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	29
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
8	+	Columnar	Far	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
11	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
12	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=28   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=28   Inspection access="-" side

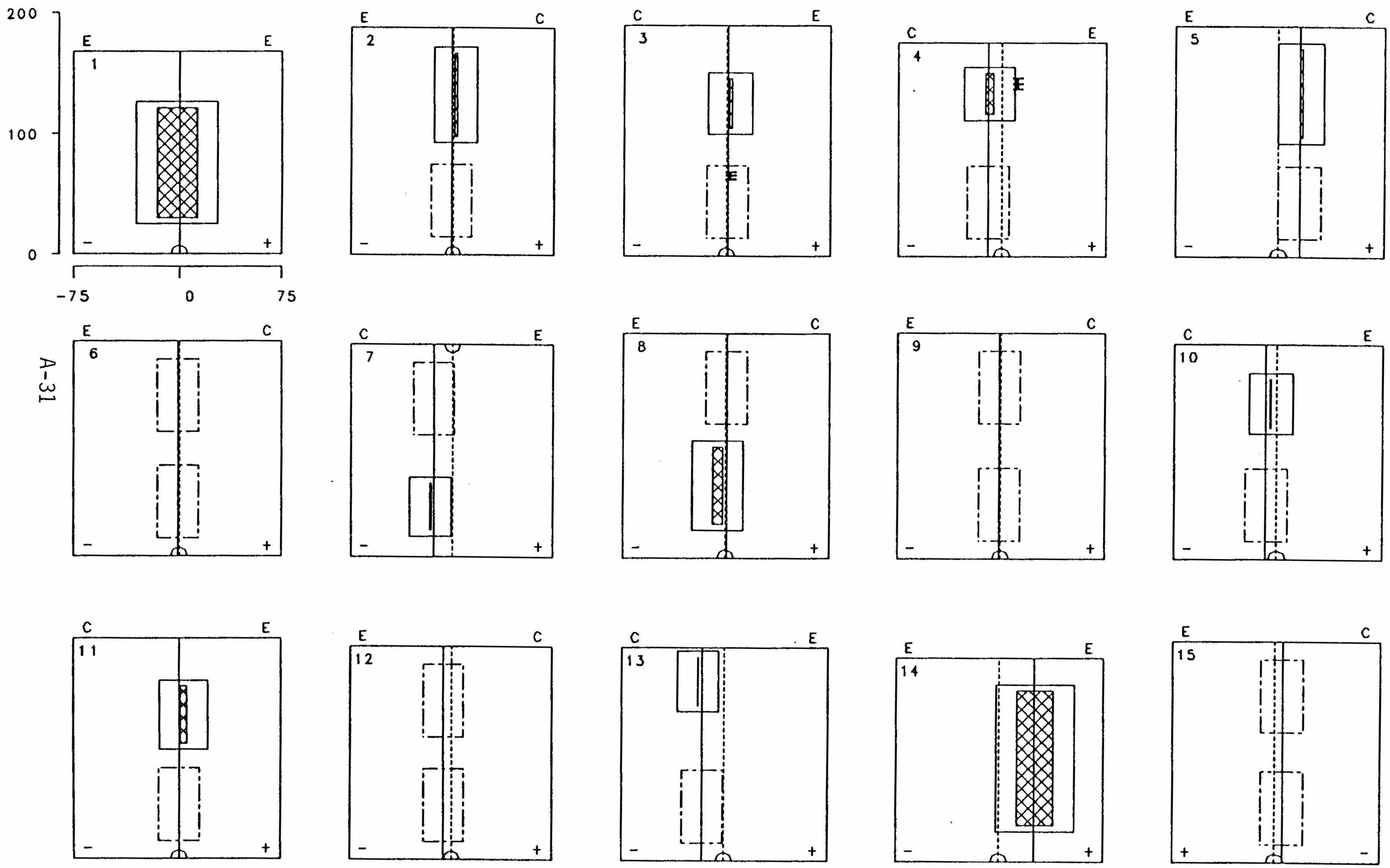
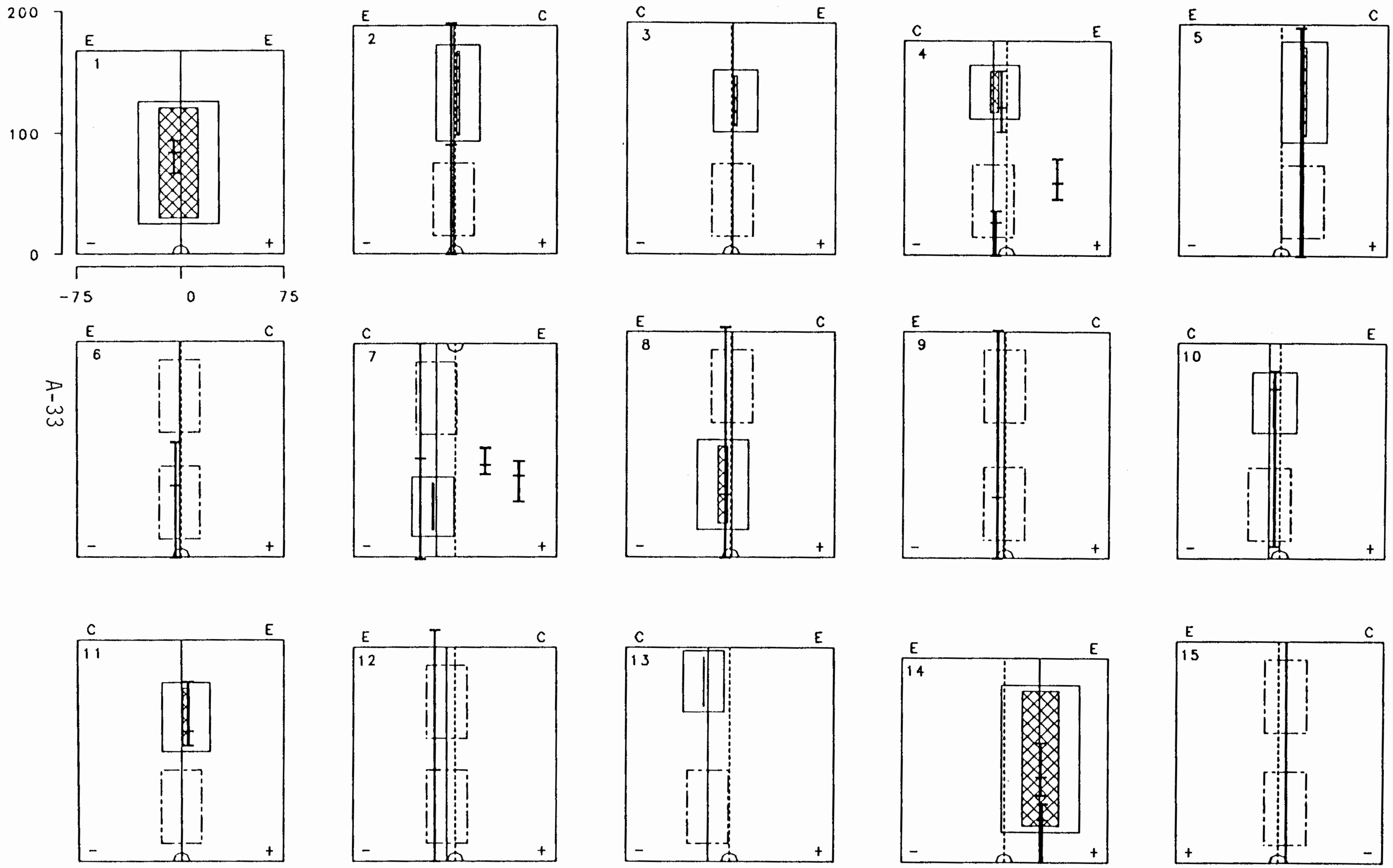


TABLE A.10 Basic Inspection Performance Results for Technique 29

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	-4	5	-64	.	0	30
	-	Equiaxed	Far		No	.	.	.	.	0	0
2	+	Columnar	Near	1/1	Yes	-5	-38	121	-20	100	100
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	1	23	40	.	29	93
4	+	Equiaxed	Far	1/1	Yes	5	-8	16	.	61	100
	-	Columnar	Near	1/1	Yes	11	-40	156	.	100	100
5	+	Columnar	Near	1/1	Yes	-3	-42	115	.	97	100
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	1/2						53	
	-	Equiaxed	None	2/2						40	
7	+	Equiaxed	Far	1/1	Yes	-10	46	139	.	100	100
	-	Columnar	Near	1/1	Yes	13	32	110	.	79	100
8	+	Columnar	Far	1/1	Yes	2	35	126	-3	100	100
	-	Equiaxed	Near	1/1	No	.	.	.	.	59	0
9	+	Columnar	None	2/2						100	
	-	Equiaxed	None	2/2						87	
10	+	Equiaxed	Near	1/1	Yes	1	-47	105	.	77	100
	-	Columnar	Far	1/1	Yes	1	-41	137	.	99	100
11	+	Equiaxed	Near	0/1	Yes	2	3	6	.	4	100
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
12	+	Columnar	None	2/2						100	
	-	Equiaxed	None	2/2						100	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	Yes	9	-18	2	.	14	59
14	+	Equiaxed	Near		Yes	1	-62	-63	.	52	56
	-	Equiaxed	Far		Yes	-18	-15	-65	.	0	42
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	2/2						100	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=29   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=29   Inspection access="-" side

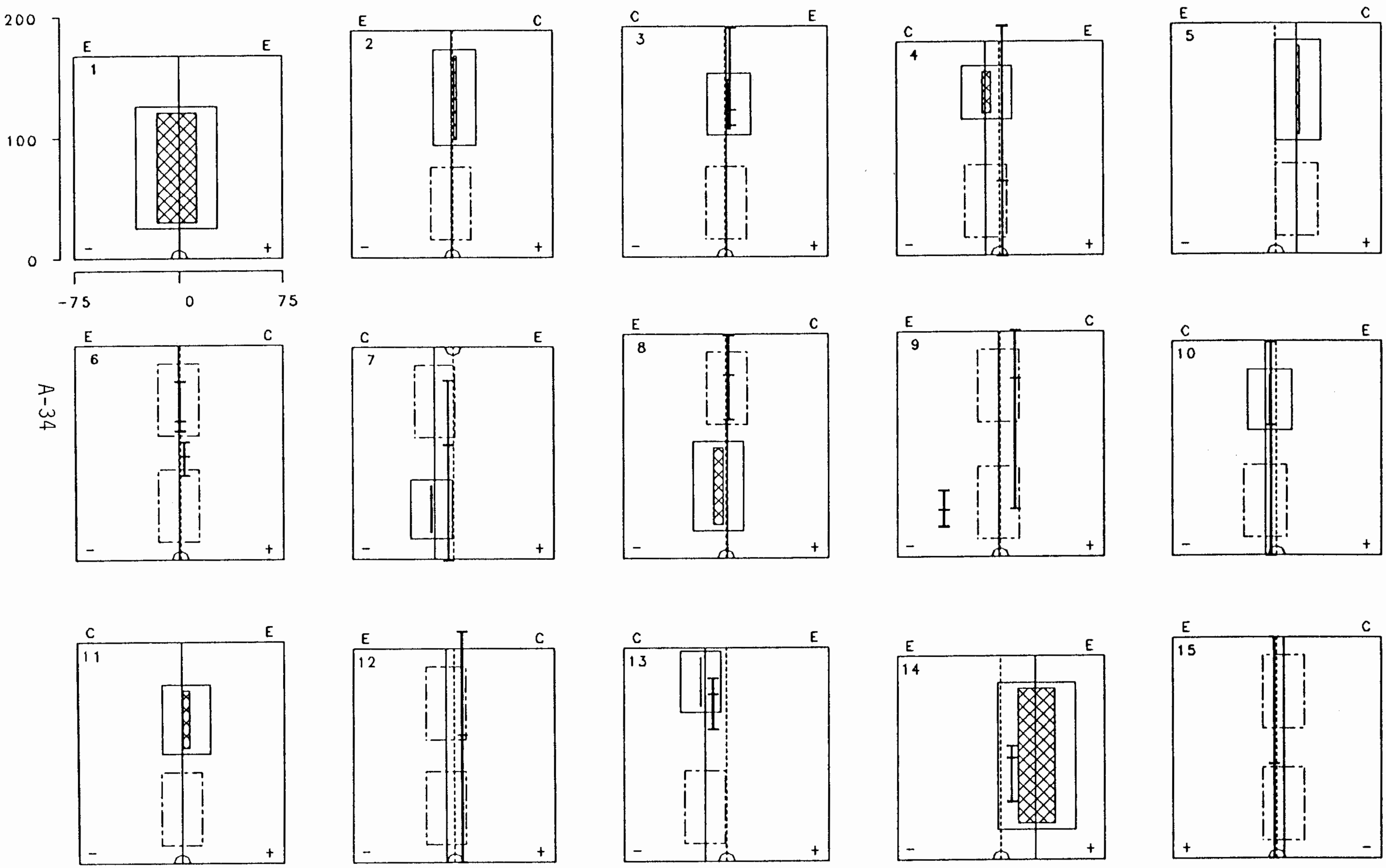
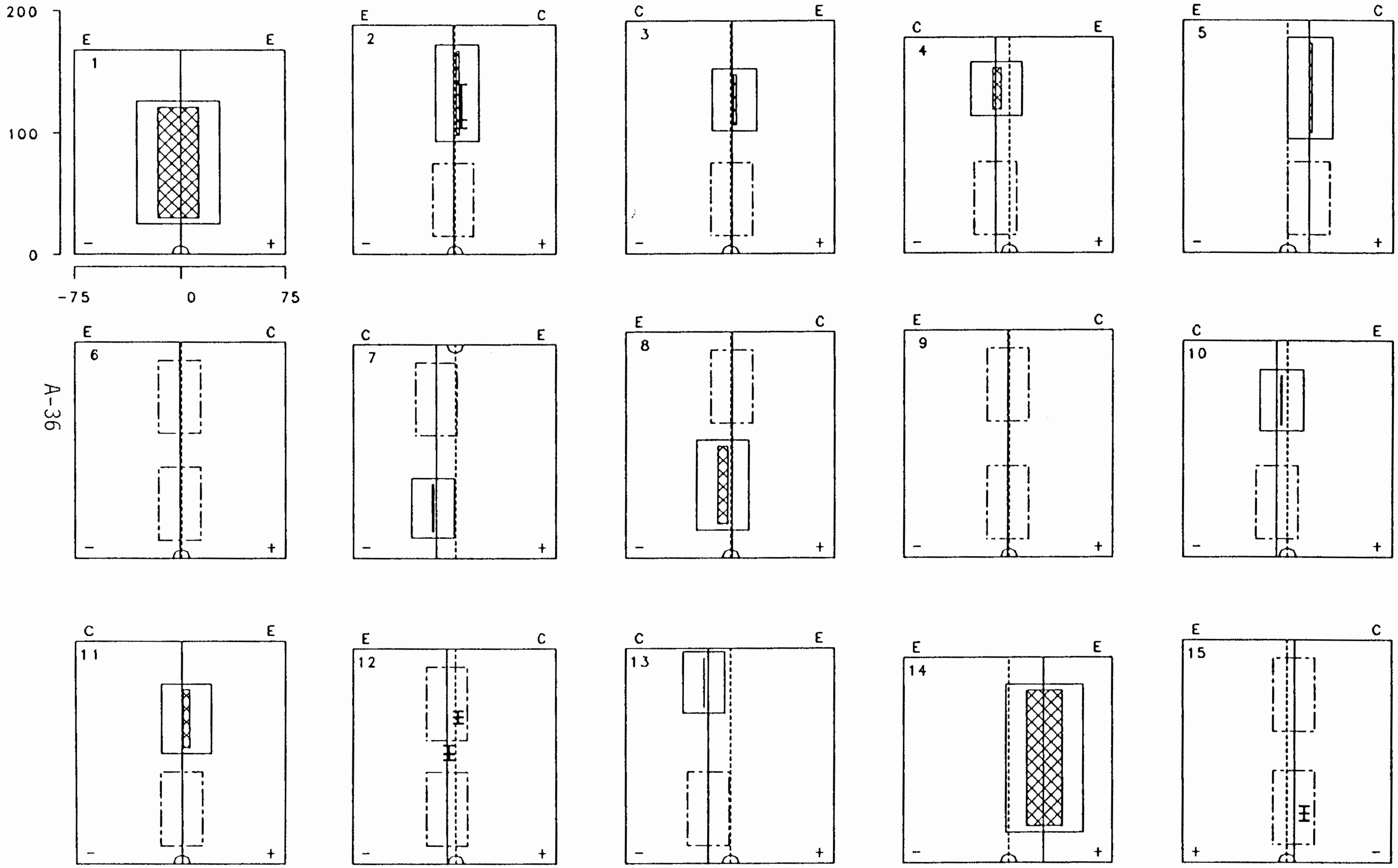


TABLE A.11 Basic Inspection Performance Results for Technique 33

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors: Offset mm	Correctly Classified Cracks: Location Errors: Center mm	Correctly Classified Cracks: Sizing Errors: Length mm	Correctly Classified Cracks: Sizing Errors: Depth XT-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		Yes	-7	2	-66	.	0	28
2	+	Columnar	Near	0/1	Yes	3	-11	-33	.	0	53
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	-1	-24	-16	.	11	24
4	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	18	0
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	0/2						0	
	-	Equiaxed	None	1/2						29	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	8	0
8	+	Columnar	Far	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	1/2						14	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	12	-17	-30	.	1	22
11	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	-6	-4	-17	.	0	65
12	+	Columnar	None	1/2						14	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	21	0
14	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
15	+	Equiaxed	None	1/2						7	
	-	Columnar	None	0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=33   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=33 Inspection access="-" side

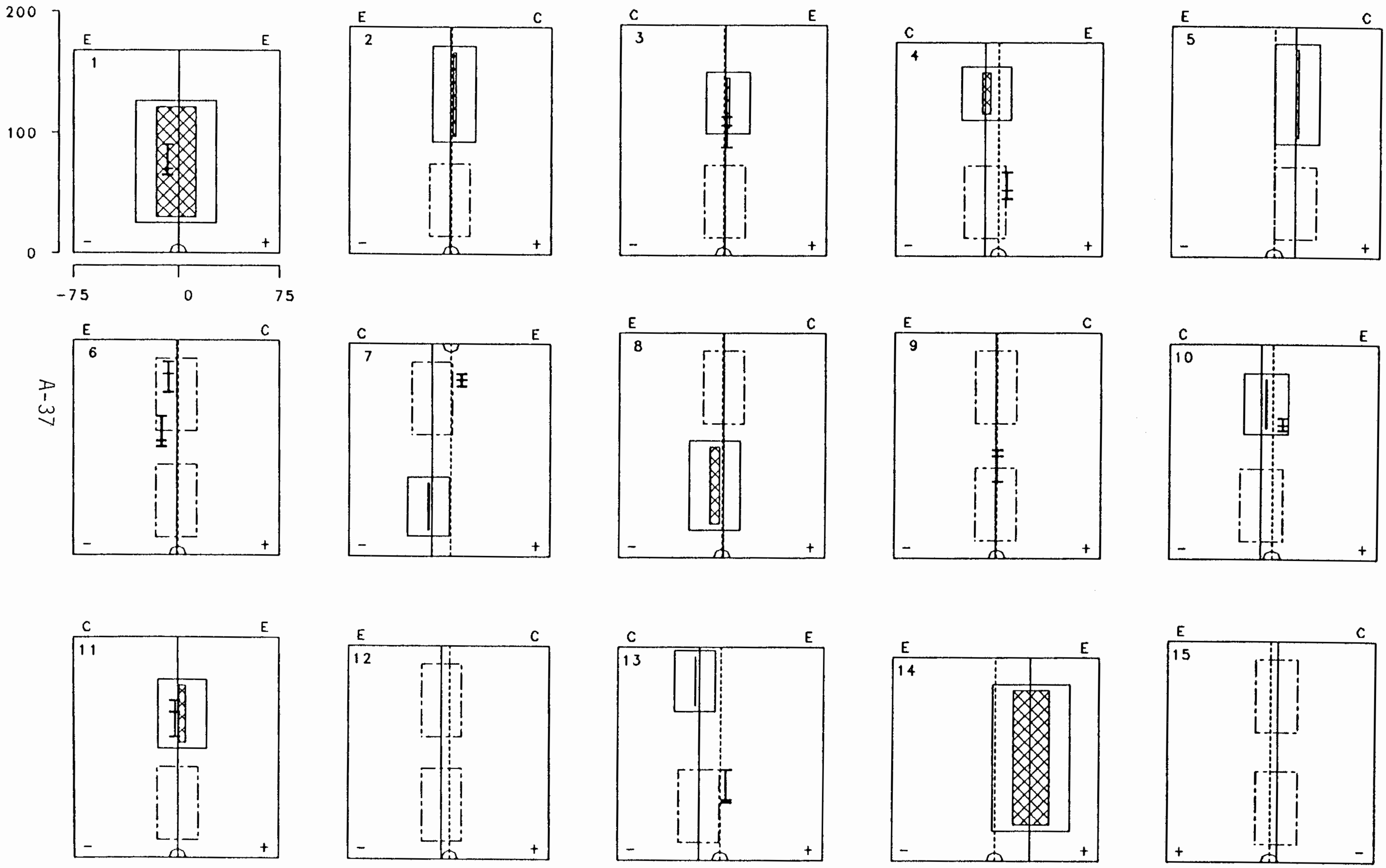
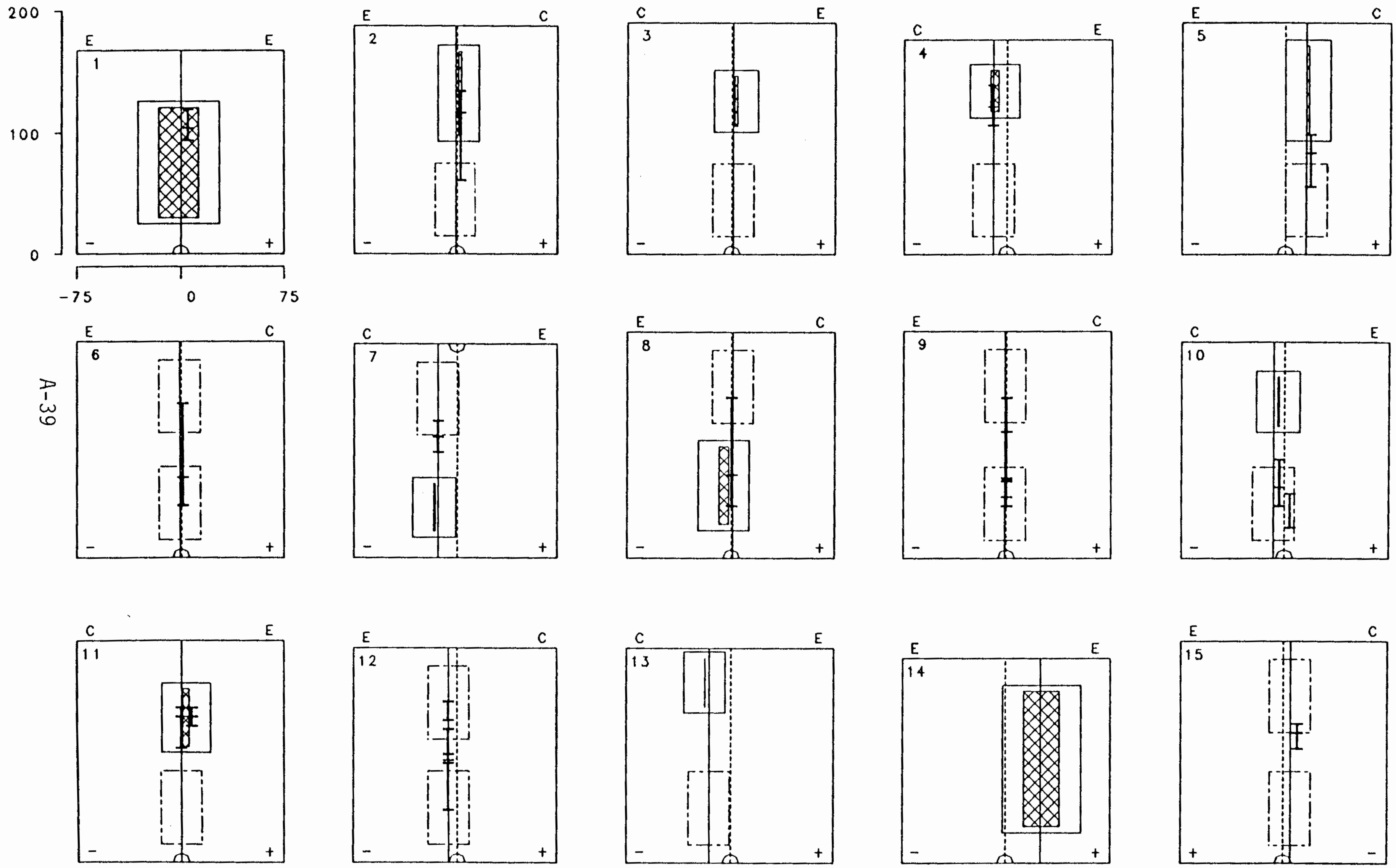


TABLE A.12 Basic Inspection Performance Results for Technique 35

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	7	31	-66	.	0	29
	-	Equiaxed	Far		Yes	-4	-8	-63	.	0	32
2	+	Columnar	Near	1/1	Yes	1	-35	5	.	31	54
	-	Equiaxed	Far	1/1	No	.	.	.	.	14	0
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	-6	-8	-8	.	3	71
4	+	Equiaxed	Far	0/1	Yes	-1	-12	-1	.	8	66
	-	Columnar	Near	1/1	Yes	-1	-40	55	.	47	66
5	+	Columnar	Near	1/1	Yes	2	-58	-30	.	37	3
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	2/2						47	
	-	Equiaxed	None	1/2						29	
7	+	Equiaxed	Far	1/1	No	.	.	.	.	19	0
	-	Columnar	Near	1/1	Yes	3	47	50	.	53	45
8	+	Columnar	Far	1/1	Yes	6	28	25	.	34	75
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	2/2						47	
	-	Equiaxed	None	1/2						22	
10	+	Equiaxed	Near	1/1	No	.	.	.	.	42	0
	-	Columnar	Far	1/1	Yes	-3	-29	23	.	41	61
11	+	Equiaxed	Near	0/1	Yes	-4	-8	-14	.	1	69
	-	Columnar	Far	0/1	Yes	-4	1	-22	.	0	56
12	+	Columnar	None	2/2						47	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	Yes	1	-25	-22	.	10	15
14	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		Yes	-1	38	-98	.	0	13
15	+	Equiaxed	None	1/2						12	
	-	Columnar	None	2/2						47	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=35   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=35   Inspection access="-" side

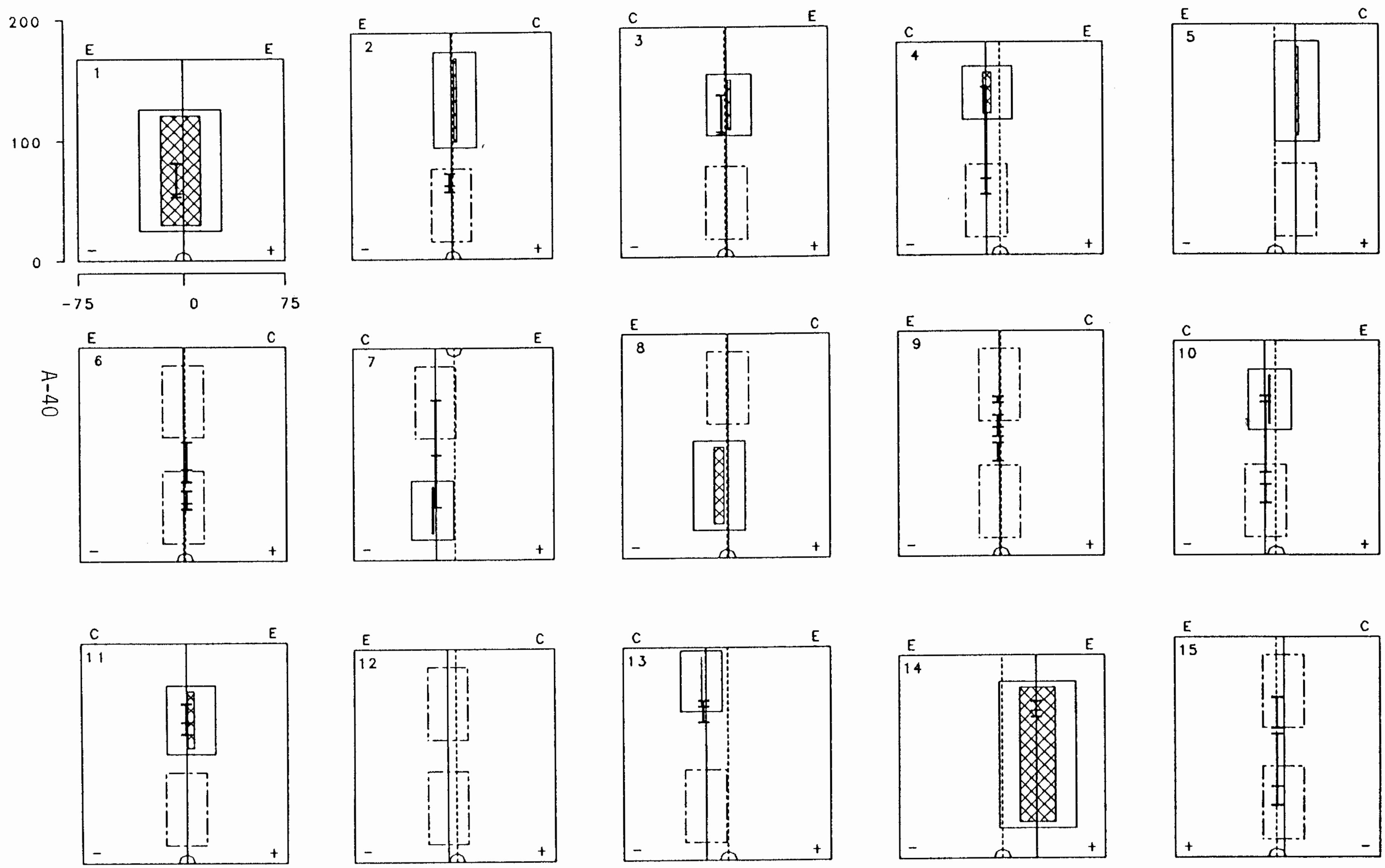


TABLE A.13 Basic Inspection Performance Results for Technique 36

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	B				Yes	-11	-38	-65	.	7	24
2	B			0/1	Yes	6	27	-54	.	12	40
3	B			1/1	Yes	-3	-14	-23	.	17	40
4	B			0/1	No	.	.	.	.	0	0
5	B			0/1	No	.	.	.	.	0	0
6	B			0/2						25	
7	B			1/1	No	.	.	.	.	18	0
8	B			0/1	No	.	.	.	.	0	0
9	B			0/2						0	
10	B			0/1	Yes	-3	-8	-18	.	0	56
11	B			0/1	Yes	-8	12	-20	.	1	54
12	B			2/2						79	
13	B			1/1	No	.	.	.	.	13	0
14	B				Yes	5	8	6	.	20	96
15	B			0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=36 Inspection access=Both sides

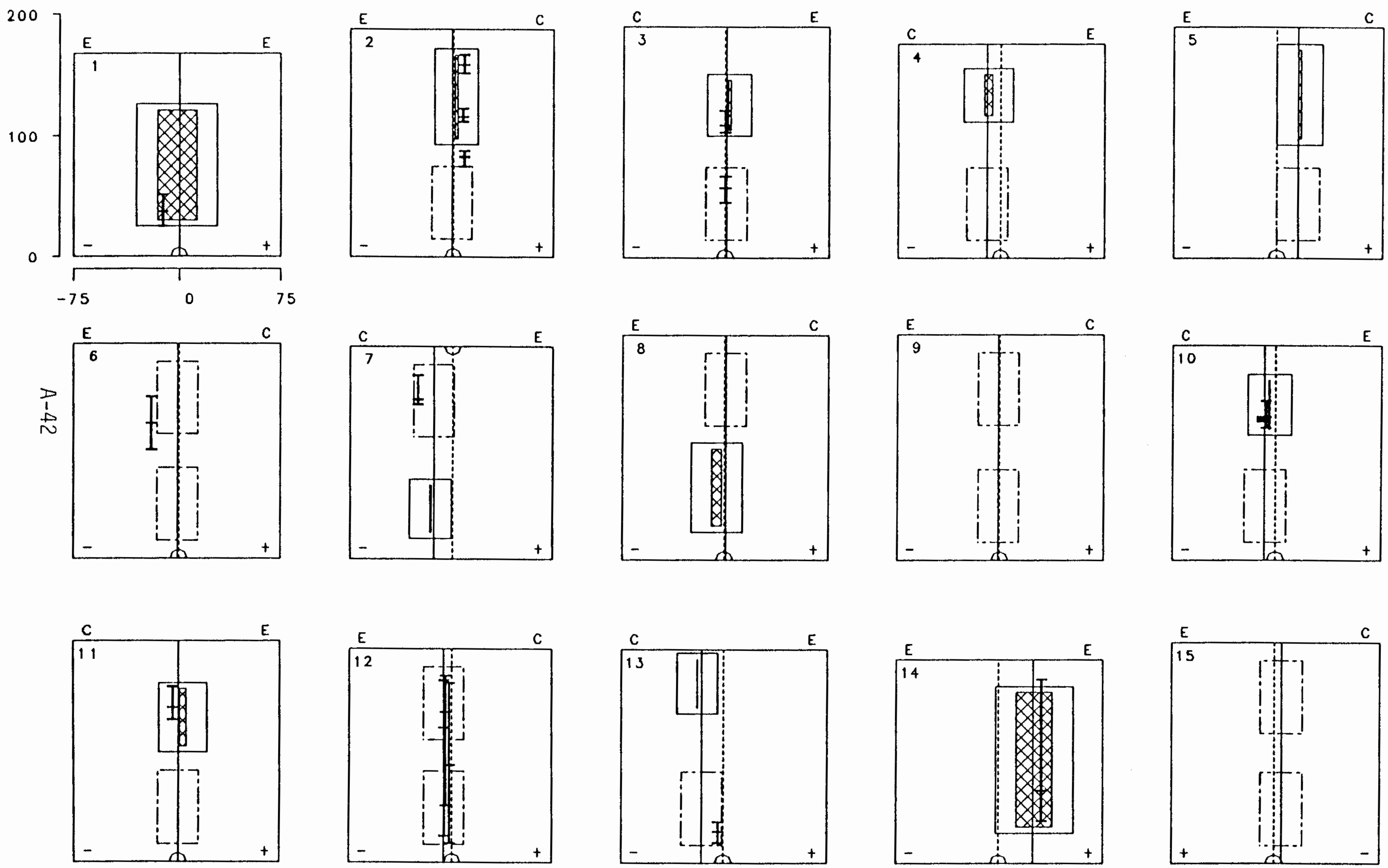
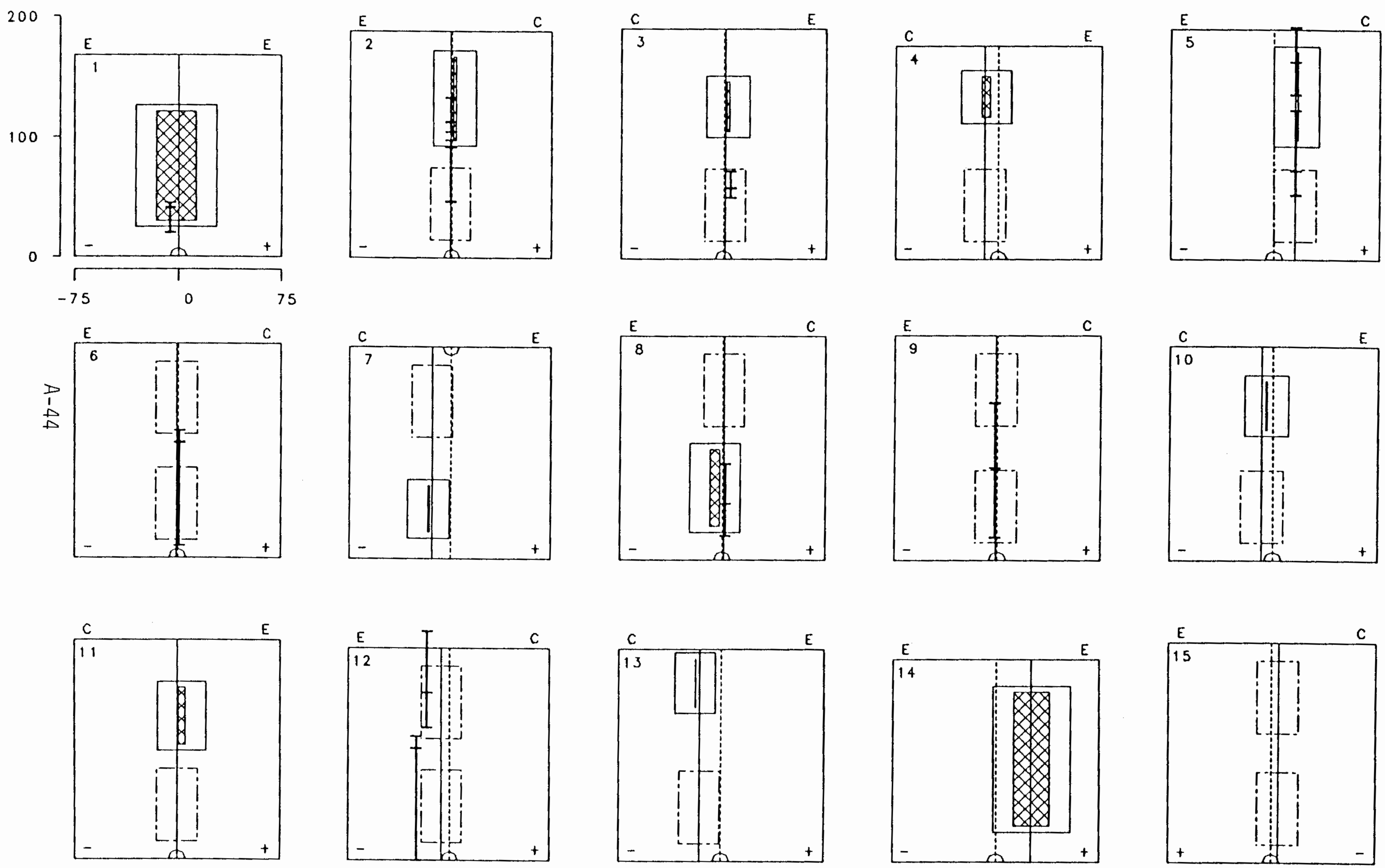


TABLE A.14 Basic Inspection Performance Results for Technique 39

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	-5	-43	-66	.	13	17
	-	Equiaxed	Far		No	.	.	.	.	0	0
2	+	Columnar	Near	1/1	Yes	-3	-14	-41	.	43	43
	-	Equiaxed	Far	1/1	No	.	.	.	.	15	0
3	+	Equiaxed	Near	1/1	No	.	.	.	.	15	0
	-	Columnar	Far	0/1	Yes	-2	-3	-2	.	26	90
4	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	-2	-34	119	.	83	100
5	+	Columnar	Near	1/1	Yes	-1	-47	-3	.	55	84
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	2/2						54	
	-	Equiaxed	None	0/2						0	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	11	46	139	.	100	100
8	+	Columnar	Far	0/1	Yes	8	-10	-4	.	7	82
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	2/2						60	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	1/1	Yes	-1	-53	112	.	81	100
11	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
12	+	Columnar	None	1/2						97	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=39   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=39   Inspection access="-" side

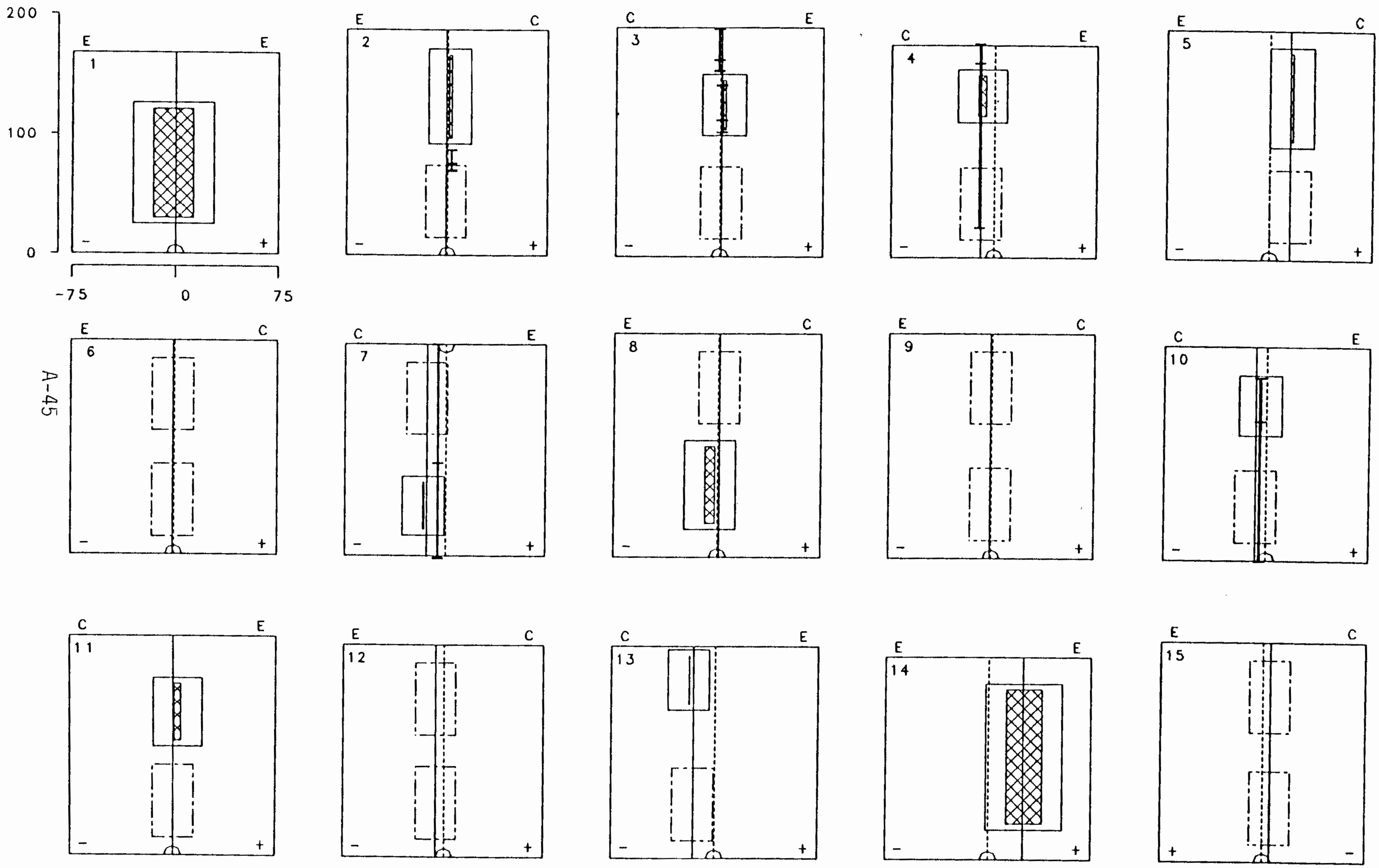
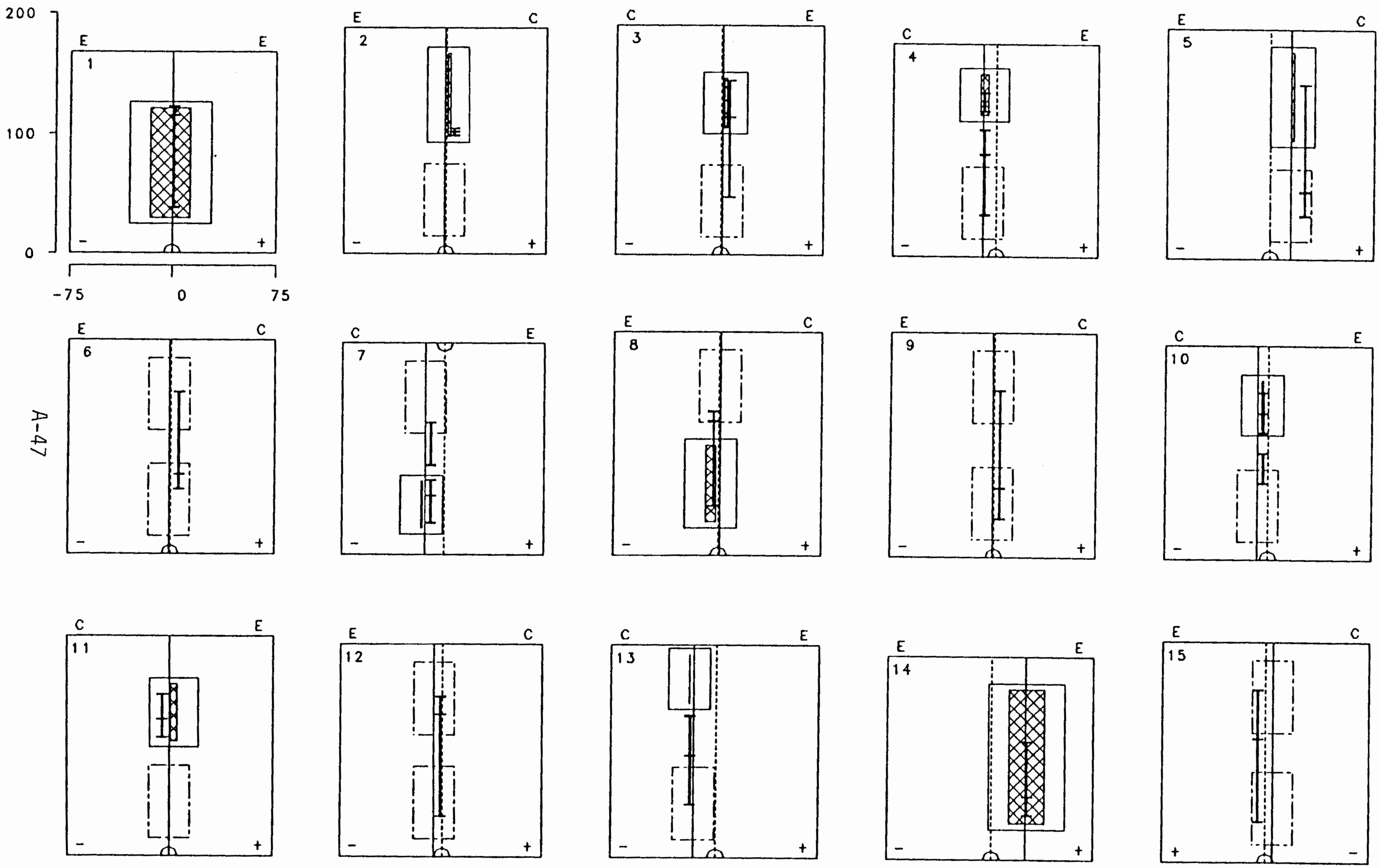


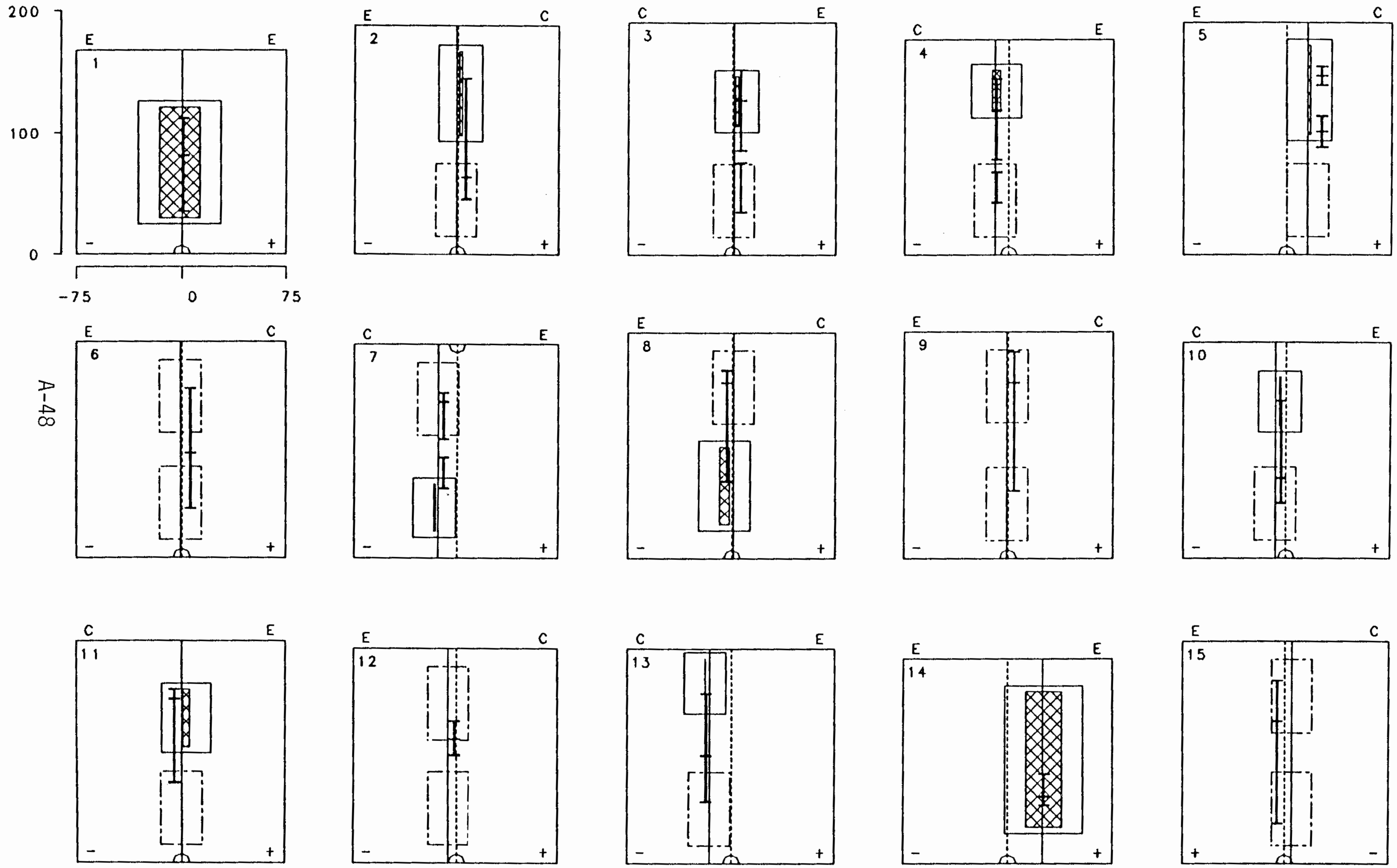
TABLE A.15 Basic Inspection Performance Results for Technique 40

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Blank	Percent Weld Length Classified Cracked
1	+	Equiaxed	Near		Yes	3	5	-7	.	3	90
	-	Equiaxed	Far		Yes	3	-2	-15	.	0	84
	B				Yes	3	-0	-18	.	0	80
2	+	Columnar	Near	0/1	Yes	4	-31	-63	.	0	10
	-	Equiaxed	Far	1/1	Yes	4	-37	30	.	44	69
	B			0/1	Yes	4	-31	-63	.	0	10
3	+	Equiaxed	Near	1/1	Yes	3	-29	55	.	38	98
	-	Columnar	Far	1/1	Yes	3	-7	25	.	45	100
	B			1/1	Yes	3	-29	55	.	38	98
4	+	Equiaxed	Far	1/1	Yes	0	-6	-19	.	51	46
	-	Columnar	Near	1/1	Yes	0	-23	32	.	46	80
	B			1/1	Yes	0	-45	59	.	52	57
5	+	Columnar	Near	1/1	Yes	9	-45	36	.	53	65
	-	Equiaxed	Far	0/1	Yes	9	12	-58	.	9	45
	B			0/1	Yes	9	-18	-17	.	9	65
6	+	Columnar	None	2/2						46	
	-	Equiaxed	None	2/2						56	
	B			2/2						46	
7	+	Equiaxed	Far	1/1	Yes	7	2	-4	.	27	88
	-	Columnar	Near	1/1	Yes	7	29	-14	.	46	10
	B			1/1	Yes	7	42	14	.	36	10
8	+	Columnar	Far	1/1	Yes	2	21	15	.	23	78
	-	Equiaxed	Near	1/1	Yes	2	49	27	.	52	45
	B			1/1	Yes	2	32	-8	.	23	45
9	+	Columnar	None	2/2						57	
	-	Equiaxed	None	2/2						62	
	B			2/2						45	
10	+	Equiaxed	Near	1/1	Yes	1	-7	-7	.	21	76
	-	Columnar	Far	1/1	Yes	1	-41	44	.	46	54
	B			1/1	Yes	1	-32	26	.	33	54
11	+	Equiaxed	Near	0/1	Yes	-9	-3	-11	.	0	75
	-	Columnar	Far	1/1	Yes	-9	-14	29	.	22	100
	B			0/1	Yes	-9	-3	-11	.	0	75
12	+	Columnar	None	2/2						57	
	-	Equiaxed	None	1/2						16	
	B			1/2						16	
13	+	Equiaxed	Far	1/1	No	.	.	.	.	56	0
	-	Columnar	Near	1/1	Yes	1	-53	49	.	57	32
	B			1/1	No	.	.	.	.	50	0
14	+	Equiaxed	Near		Yes	0	-18	-50	.	0	55
	-	Equiaxed	Far		Yes	0	-25	-86	.	0	23
	B				Yes	0	-25	-86	.	0	23
15	+	Equiaxed	None	2/2						60	
	-	Columnar	None	2/2						65	
	B			2/2						60	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=40   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=40   Inspection access="-" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=40   Inspection access=Both sides

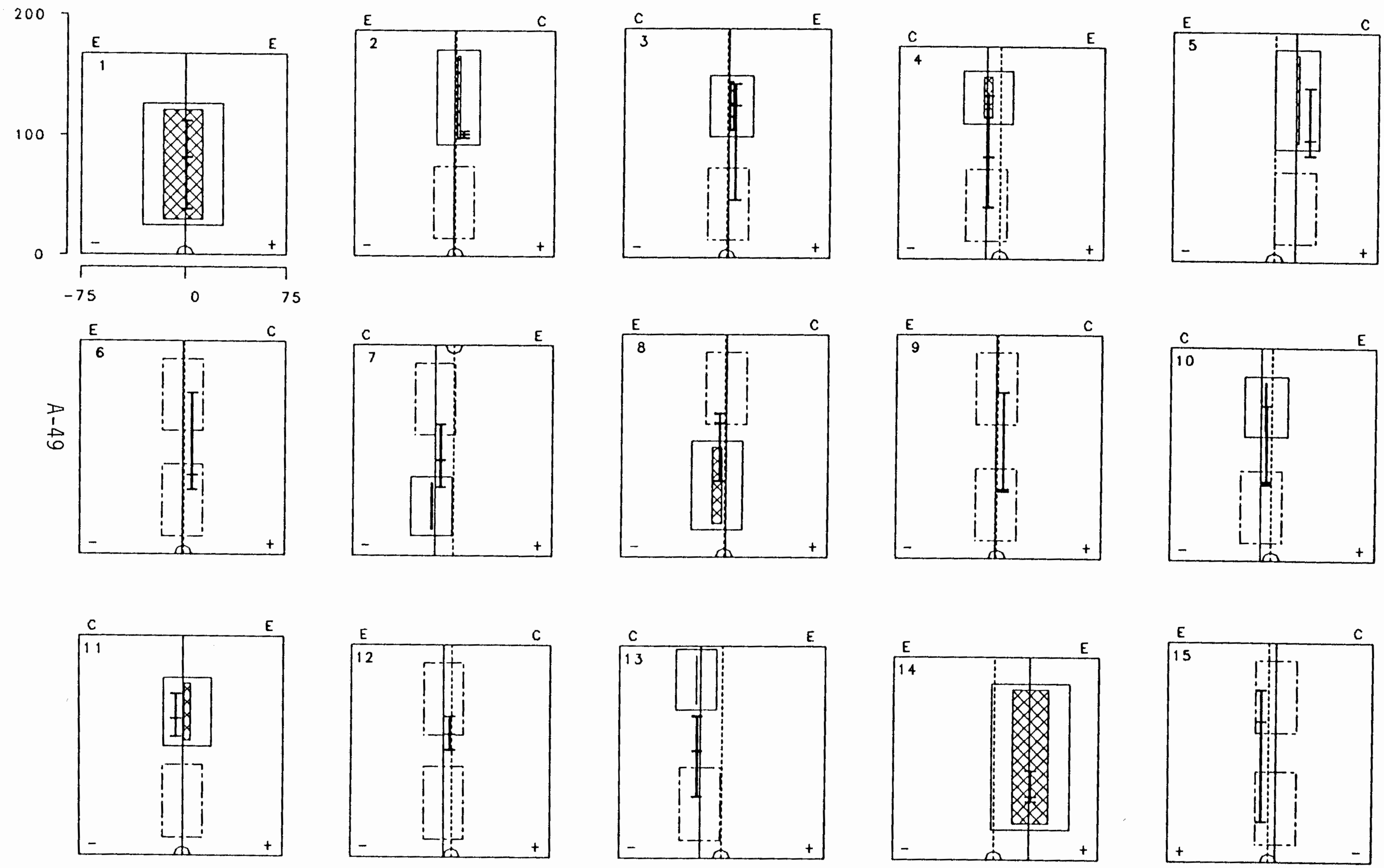
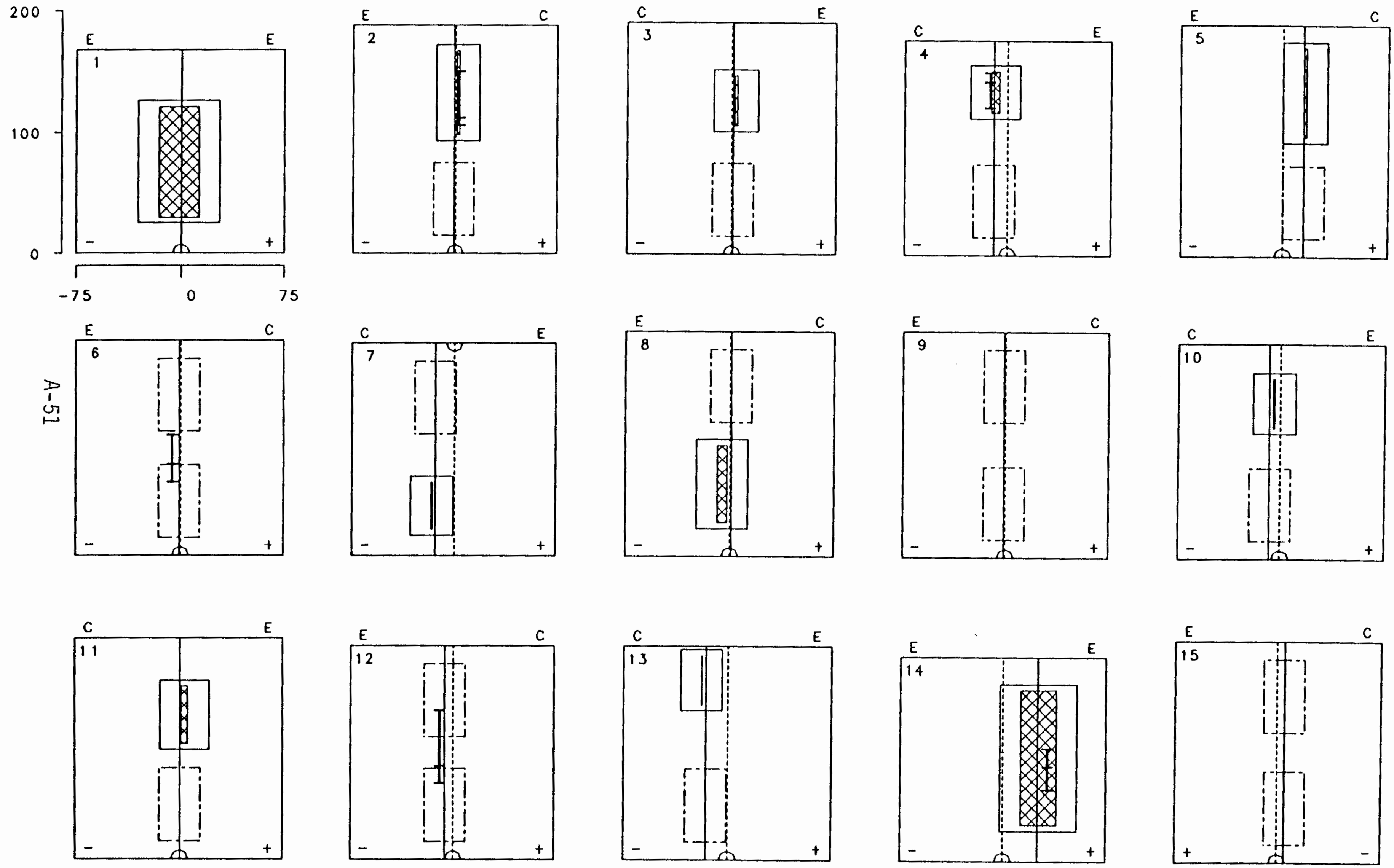


TABLE A.16 Basic Inspection Performance Results for Technique 46

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
2	+	Columnar	Near	0/1	Yes	1	-5	-25	.	0	64
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
4	+	Equiaxed	Far	0/1	Yes	-4	2	-5	.	0	86
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	1/2						22	
	-	Equiaxed	None	0/2						0	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
8	+	Columnar	Far	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
11	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
12	+	Columnar	None	2/2						35	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		Yes	6	-10	-77	.	0	31
	-	Equiaxed	Far		No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=46   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=46   Inspection access="-" side

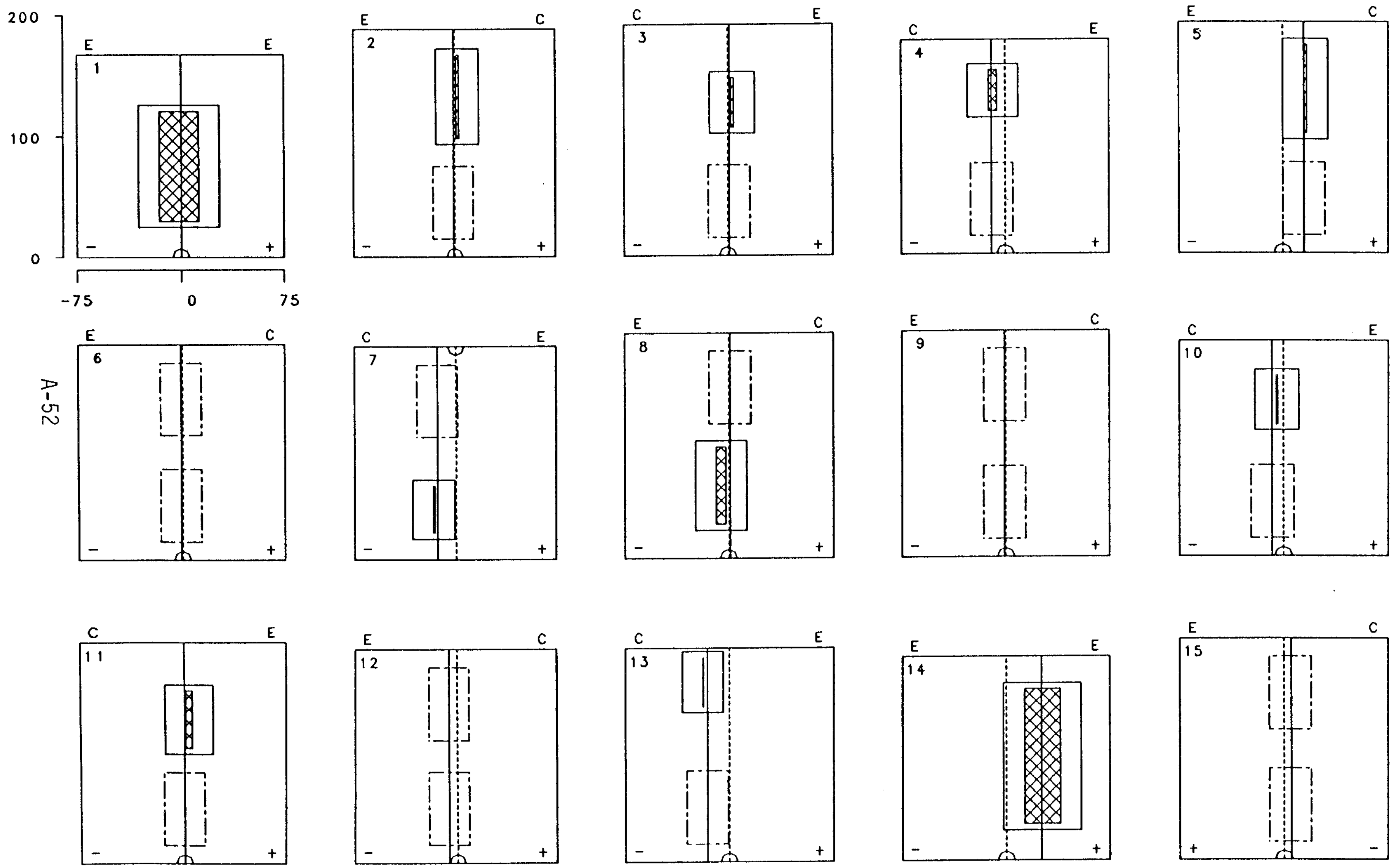
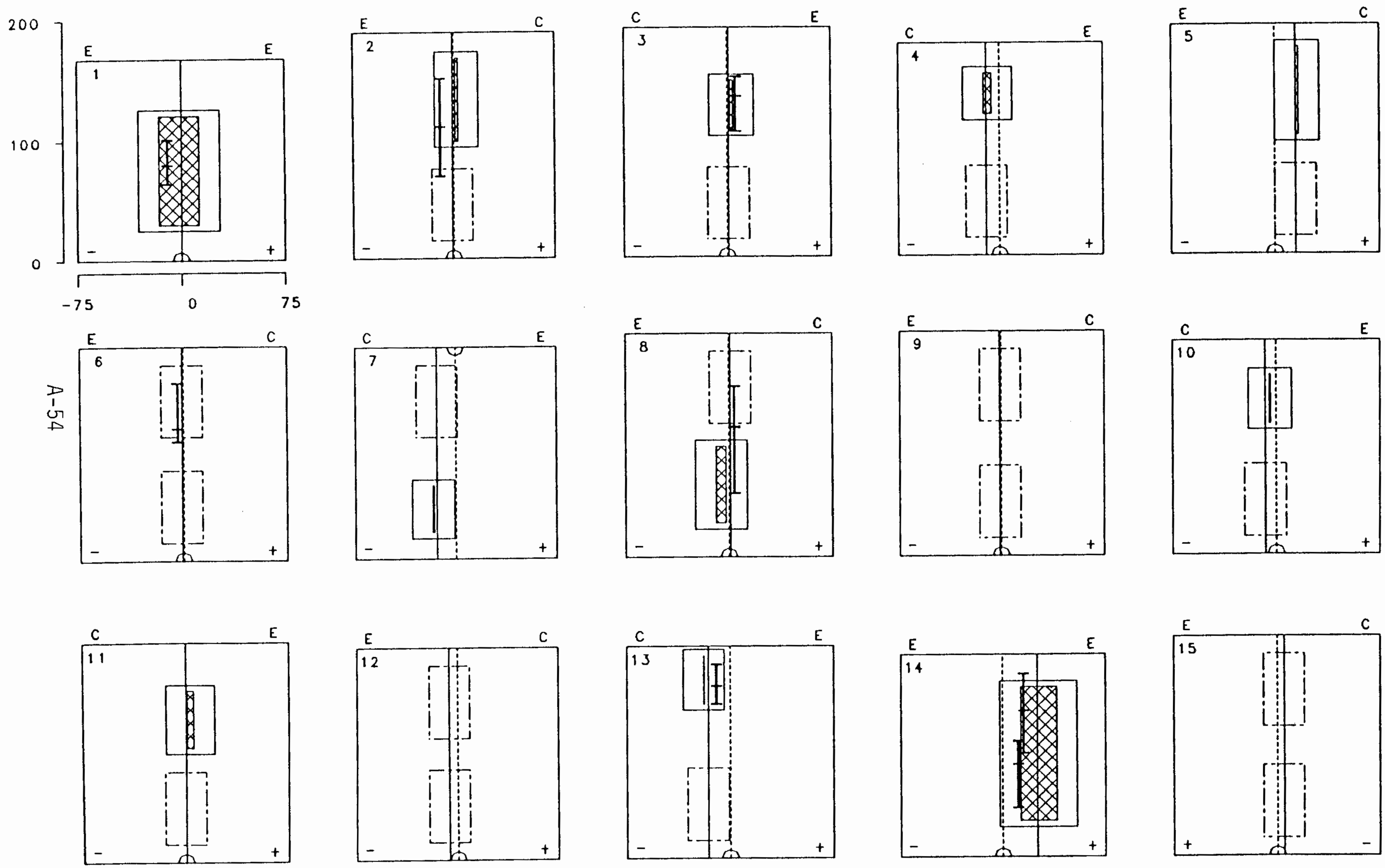


TABLE A.17 Basic Inspection Performance Results for Technique 48

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	-9	7	-54	.	0	41
	-	Equiaxed	Far		Yes	-15	5	-44	.	0	52
2	+	Columnar	Near	1/1	Yes	-12	-23	12	3	25	76
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	0/1	Yes	3	1	4	-5	3	100
	-	Columnar	Far	0/1	Yes	8	11	2	1	8	76
4	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	1/2						28	
	-	Equiaxed	None	0/2						0	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
8	+	Columnar	Far	1/1	Yes	10	38	25	-18	41	62
	-	Equiaxed	Near	0/1	Yes	7	-33	-31	-13	14	26
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
11	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
12	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	Yes	9	-4	-7	.	0	83
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		Yes	-15	-17	-56	.	20	90
	-	Equiaxed	Far		No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	1/2						27	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=48   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=48 Inspection access="-" side

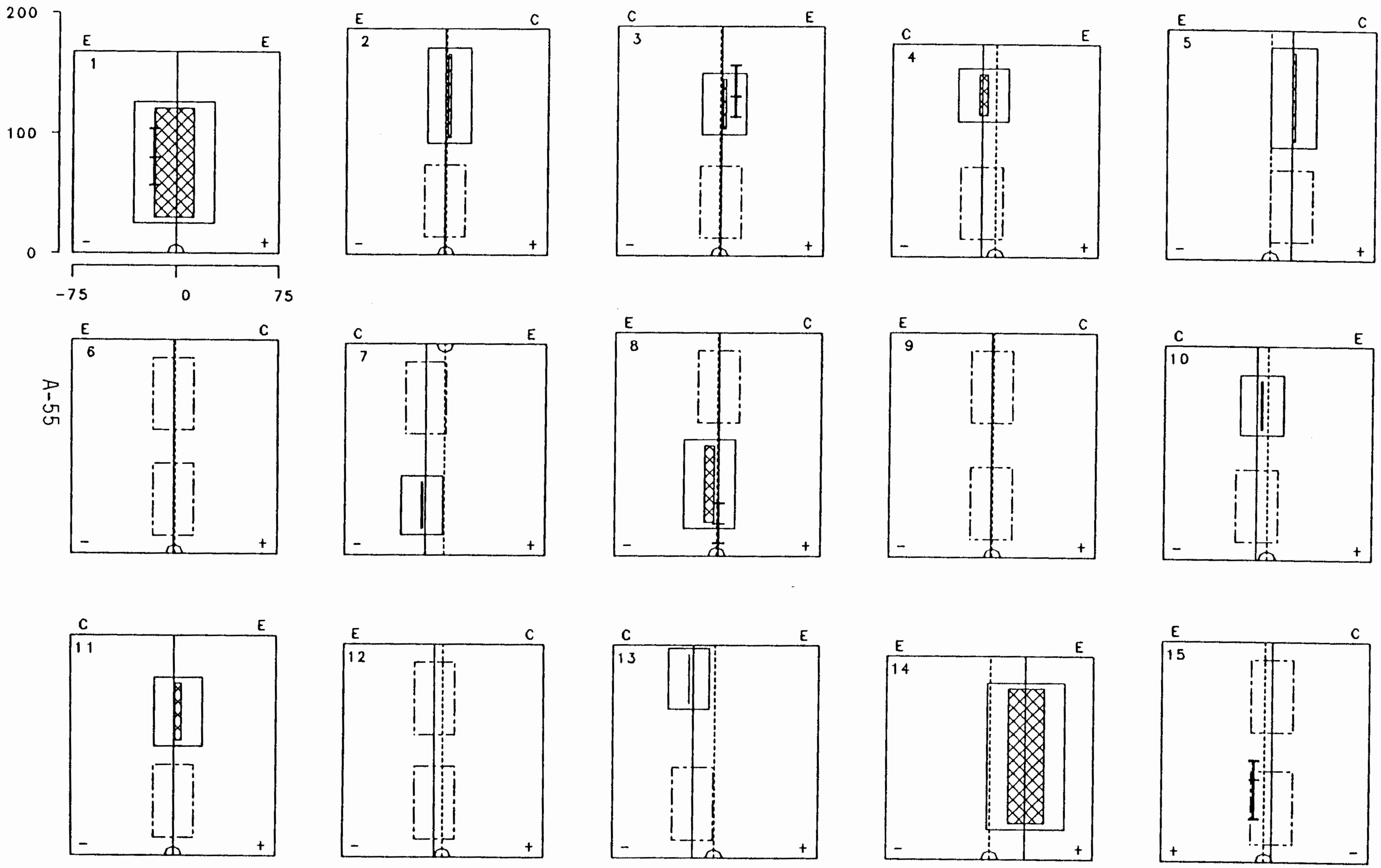
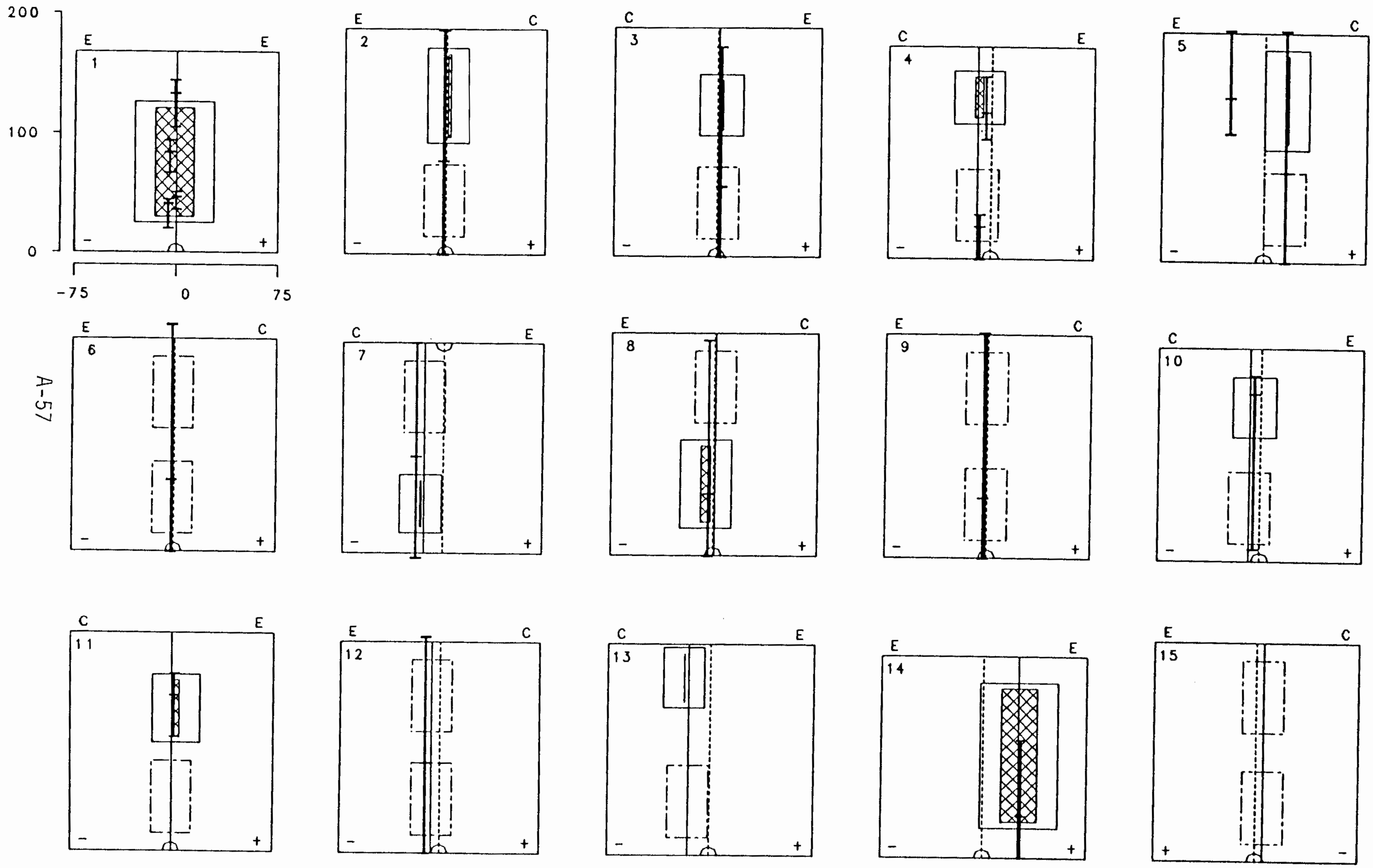


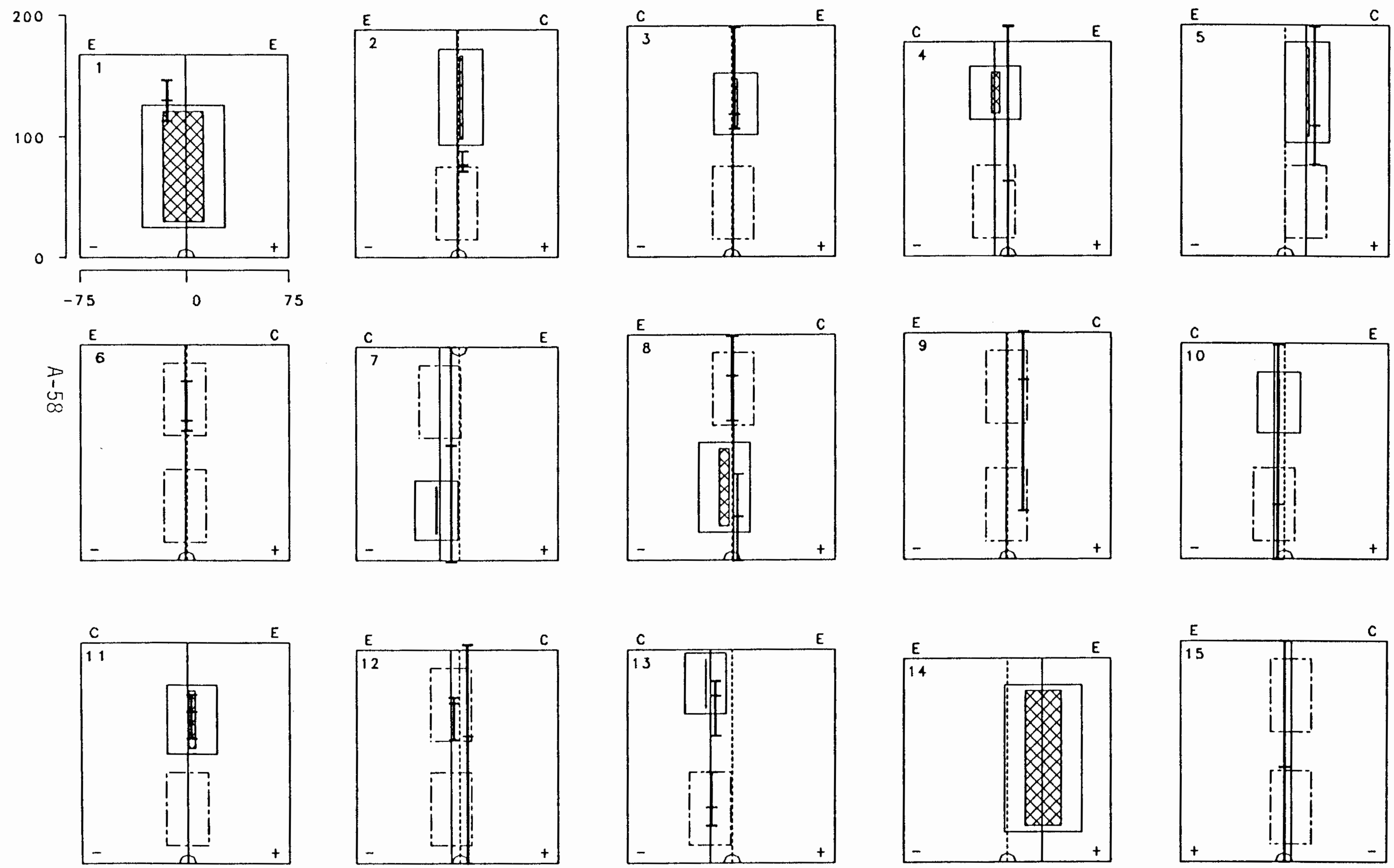
TABLE A.18 Basic Inspection Performance Results for Technique 51

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	-5	-43	-68	.	43	73
	-	Equiaxed	Far		Yes	-12	55	-57	.	34	10
	B				Yes	-2	-40	-60	.	58	84
2	+	Columnar	Near	1/1	Yes	-4	-39	118	-15	99	100
	-	Equiaxed	Far	1/1	No	.	.	.	.	15	0
	B			1/1	Yes	-2	-39	118	-15	99	100
3	+	Equiaxed	Near	1/1	Yes	0	-39	134	.	89	100
	-	Columnar	Far	0/1	Yes	-1	22	43	.	29	100
	B			1/1	Yes	0	-32	149	.	99	100
4	+	Equiaxed	Far	1/1	Yes	5	-9	18	.	39	100
	-	Columnar	Near	1/1	Yes	9	-40	156	.	100	100
	B			1/1	Yes	5	-40	156	.	100	100
5	+	Columnar	Near	1/1	Yes	-1	-39	120	.	100	100
	-	Equiaxed	Far	0/1	Yes	5	-3	41	.	35	100
	B			1/1	Yes	1	-39	120	.	100	100
6	+	Columnar	None	2/2						100	
	-	Equiaxed	None	1/2						24	
	B			2/2						100	
7	+	Equiaxed	Far	1/1	Yes	-4	45	141	.	100	100
	-	Columnar	Near	1/1	Yes	11	46	138	.	100	100
	B			1/1	Yes	3	45	141	.	100	100
8	+	Columnar	Far	1/1	Yes	2	30	116	.	95	100
	-	Equiaxed	Near	1/1	Yes	10	-25	7	.	81	68
	B			1/1	Yes	6	30	116	.	95	100
9	+	Columnar	None	2/2						100	
	-	Equiaxed	None	2/2						79	
	B			2/2						100	
10	+	Equiaxed	Near	1/1	Yes	-1	-47	105	.	77	100
	-	Columnar	Far	1/1	Yes	-1	-41	137	.	99	100
	B			1/1	Yes	-1	-41	137	.	99	100
11	+	Equiaxed	Near	0/1	Yes	-2	3	6	.	4	100
	-	Columnar	Far	0/1	Yes	-1	3	-11	.	0	77
	B			0/1	Yes	-2	3	6	.	4	100
12	+	Columnar	None	2/2						100	
	-	Equiaxed	None	2/2						100	
	B			2/2						100	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	7	-21	5	.	50	58
	B			0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		Yes	1	-37	-13	.	52	62
	-	Equiaxed	Far		No	.	.	.	.	0	42
	B				Yes	1	-37	-13	.	52	62
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	2/2						100	
	B			2/2						100	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=51   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=51   Inspection access="-" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=51   Inspection access=Both sides

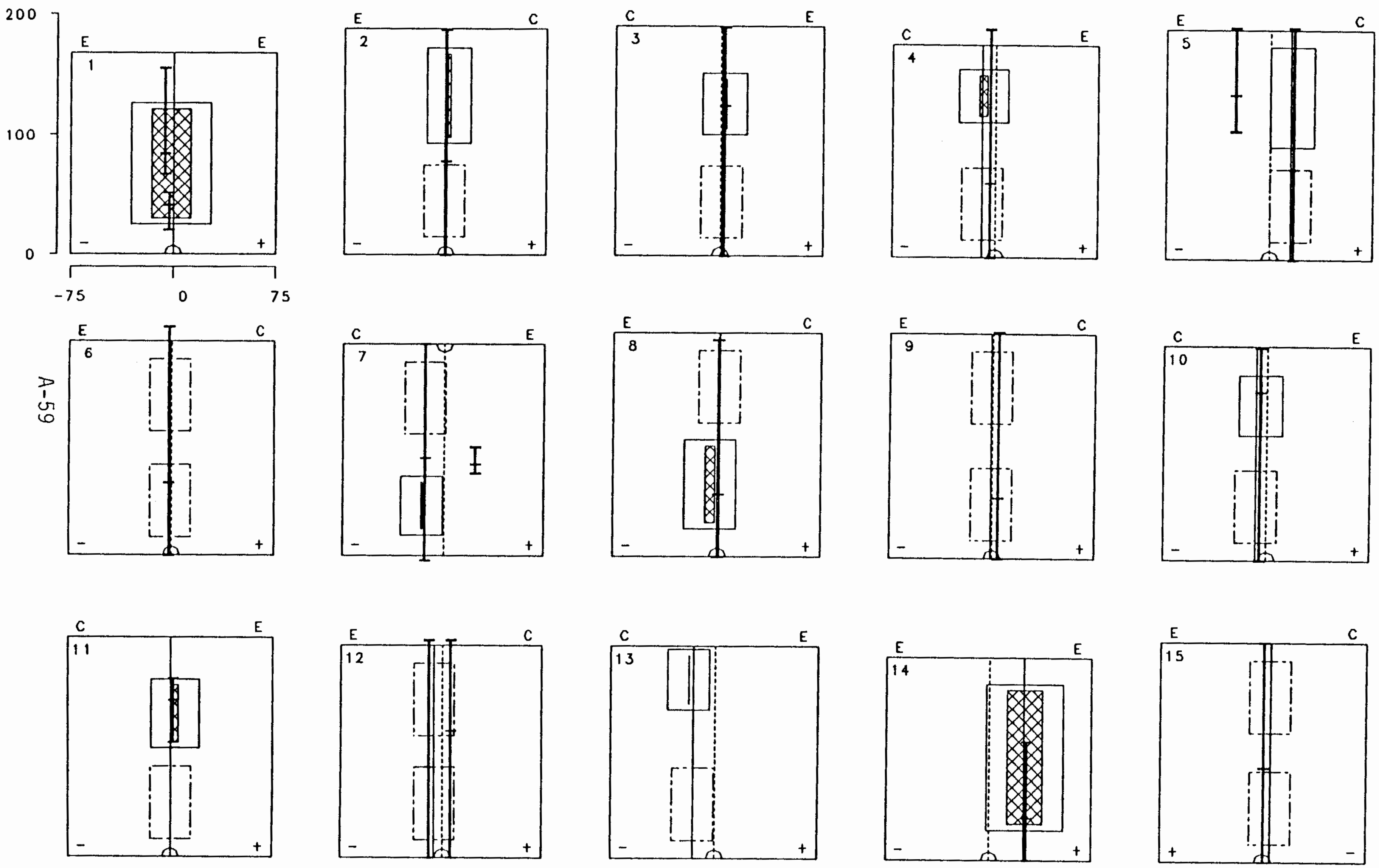


TABLE A.19 Basic Inspection Performance Results for Technique 52

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	B				No	.	.	.	.	0	0
2	B			0/1	No	.	.	.	.	0	0
3	B			0/1	No	.	.	.	.	0	0
4	B			0/1	No	.	.	.	.	0	0
5	B			0/1	No	.	.	.	.	0	0
6	B			0/2		$				0	
7	B			0/1	No	.	.	.	.	0	0
8	B			0/1	No	.	.	.	.	0	0
9	B			0/2						0	
10	B			0/1	No	.	.	.	.	0	0
11	B			0/1	Yes	-7	14	-27	32	0	44
12	B			0/2						0	
13	B			0/1	No	.	.	.	.	0	0
14	B				No	.	.	.	.	0	0
15	B			0/2						8	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=52 Inspection access=Both sides

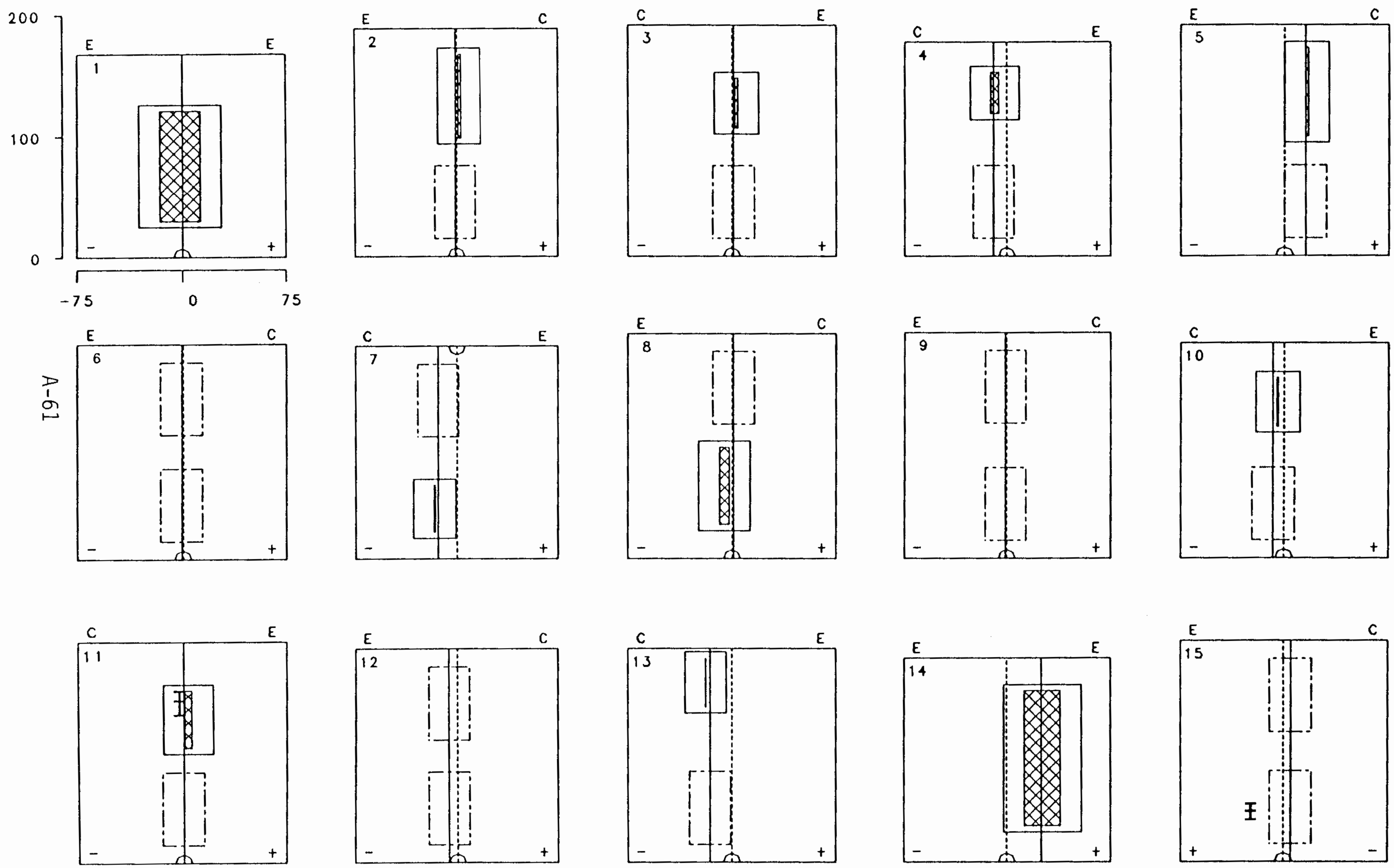
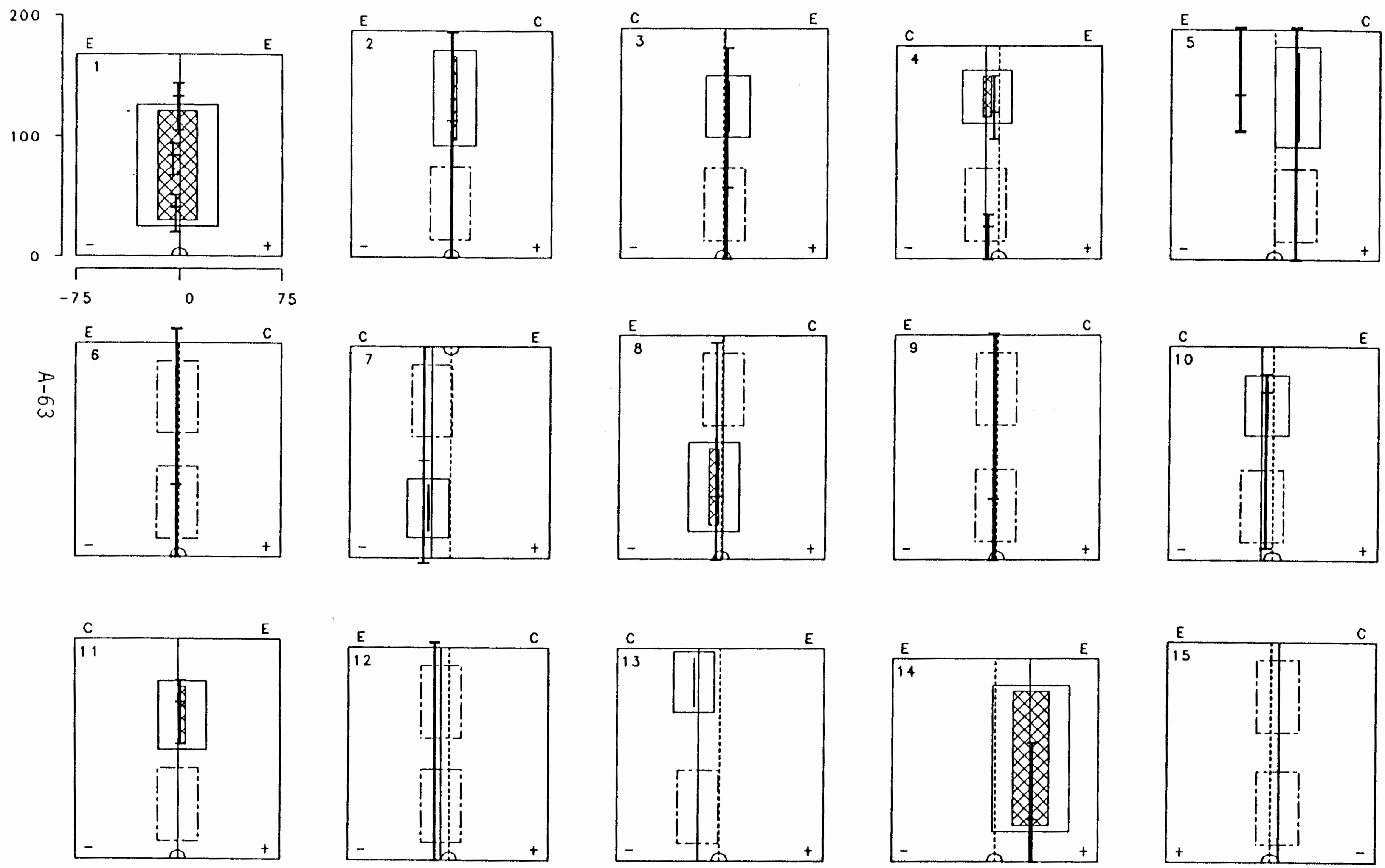


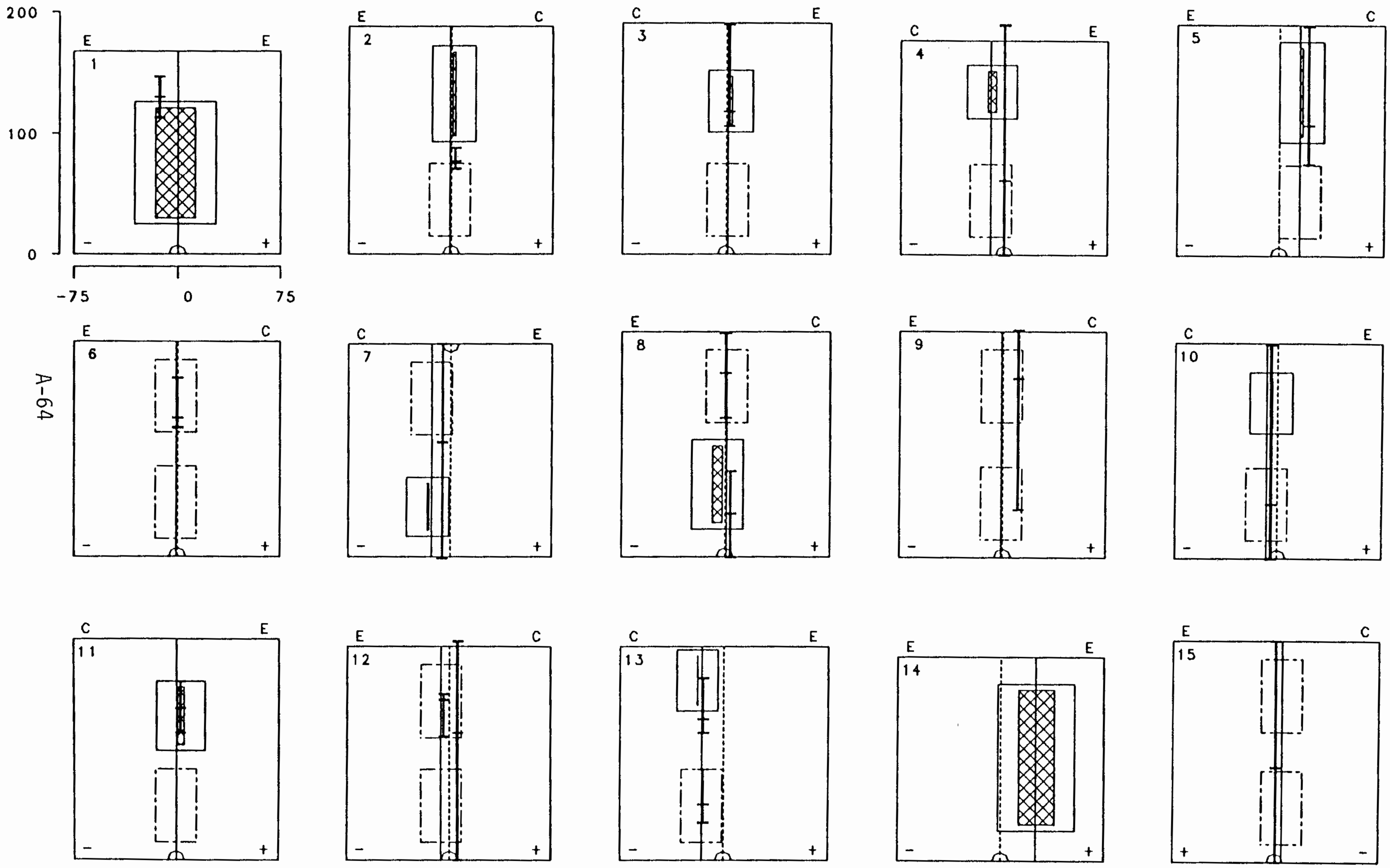
TABLE A.20 Basic Inspection Performance Results for Technique 53

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	-2	-40	-60	.	43	73
	-	Equiaxed	Far		Yes	-12	55	-57	.	34	10
	B				Yes	-4	36	-3	.	58	84
2	+	Columnar	Near	1/1	Yes	-2	-39	118	5	99	100
	-	Equiaxed	Far	1/1	No	.	.	.	.	15	0
	B			1/1	Yes	-2	-39	118	5	99	100
3	+	Equiaxed	Near	1/1	Yes	0	-39	134	.	89	100
	-	Columnar	Far	0/1	Yes	-1	22	43	.	29	100
	B			1/1	Yes	-1	-32	149	.	99	100
4	+	Equiaxed	Far	1/1	Yes	5	-9	18	19	39	100
	-	Columnar	Near	1/1	Yes	9	-40	156	19	100	100
	B			1/1	Yes	5	-40	156	19	100	100
5	+	Columnar	Near	1/1	Yes	-1	-39	120	12	100	100
	-	Equiaxed	Far	0/1	Yes	5	-3	41	.	35	100
	B			1/1	Yes	1	-39	120	12	100	100
6	+	Columnar	None	2/2						100	
	-	Equiaxed	None	1/2						24	
	B			2/2						100	
7	+	Equiaxed	Far	1/1	Yes	-4	45	141	.	100	100
	-	Columnar	Near	1/1	Yes	11	46	138	.	100	100
	B			1/1	Yes	3	45	141	.	100	100
8	+	Columnar	Far	1/1	Yes	2	30	116	12	95	100
	-	Equiaxed	Near	1/1	Yes	10	-25	7	.	81	68
	B			1/1	Yes	6	33	121	12	99	100
9	+	Columnar	None	2/2						100	
	-	Equiaxed	None	2/2						79	
	B			2/2						100	
10	+	Equiaxed	Near	1/1	Yes	-1	-47	105	.	77	100
	-	Columnar	Far	1/1	Yes	-1	-41	137	.	99	100
	B			1/1	Yes	-1	-41	137	.	99	100
11	+	Equiaxed	Near	0/1	Yes	-2	3	6	.	4	100
	-	Columnar	Far	0/1	Yes	-1	8	-5	12	4	79
	B			0/1	Yes	-2	3	6	12	4	100
12	+	Columnar	None	2/2						100	
	-	Equiaxed	None	2/2						100	
	B			2/2						100	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	4	-21	5	.	50	56
	B			0/1	Yes	4	-21	5	.	17	56
14	+	Equiaxed	Near		Yes	1	-37	-13	.	52	62
	-	Equiaxed	Far		No	.	.	.	.	0	42
	B				Yes	1	-37	-13	.	52	62
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	2/2						100	
	B			2/2						100	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=53   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=53 Inspection access="-" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=53 Inspection access=Both sides

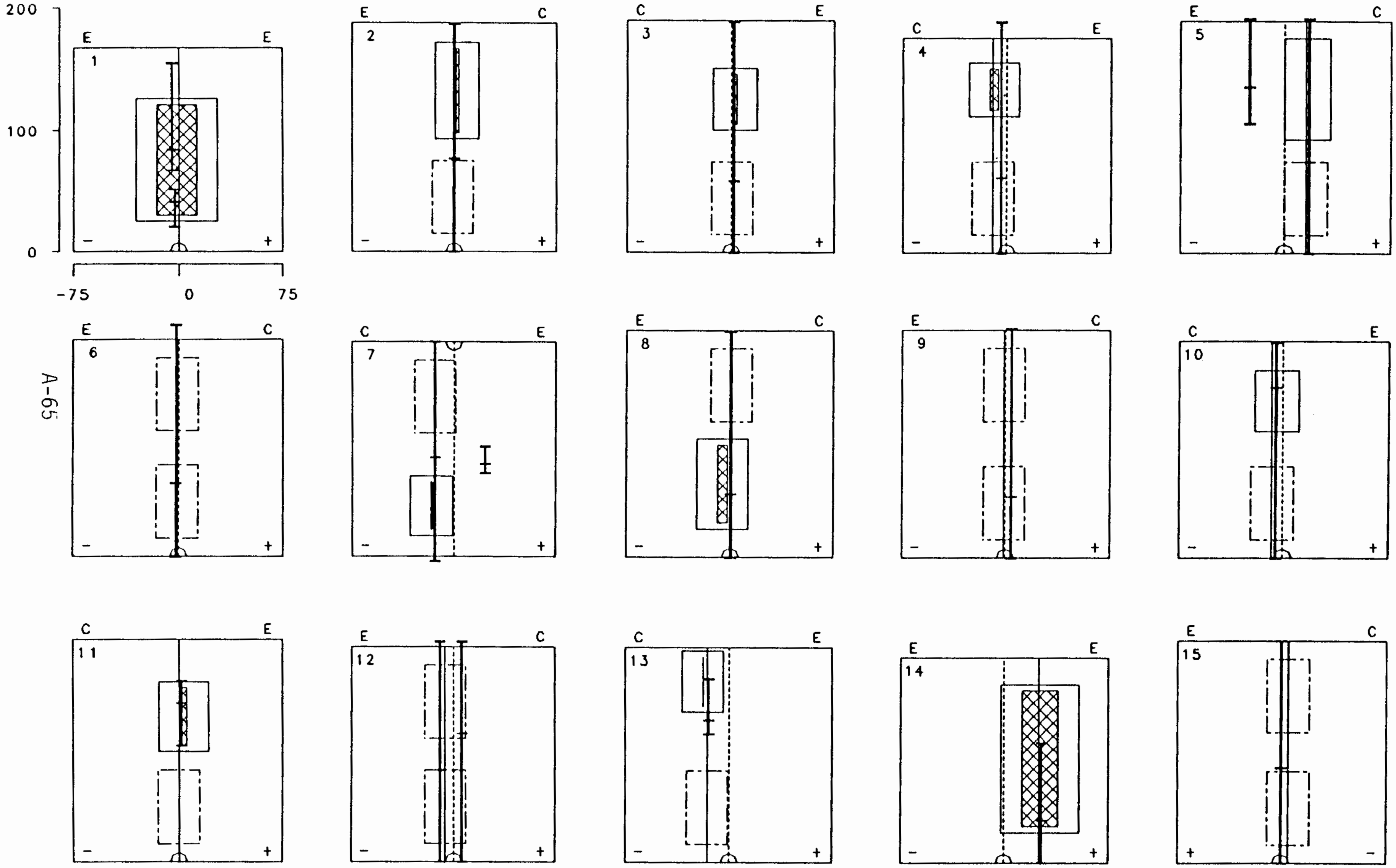


TABLE A.21 Basic Inspection Performance Results for Technique 56

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	B				Yes	2	-15	-60	.	0	35
2	B			0/1	Yes	0	-8	-46	.	0	34
3	B			0/1	Yes	3	-12	-11	.	17	60
4	B			1/1	Yes	-2	-22	-24	.	32	3
5	B			0/1	Yes	2	35	-23	.	16	38
6	B			1/2						16	
7	B			0/1	No	.	.	.	.	0	0
8	B			1/1	No	.	.	.	.	26	55
9	B			1/2						24	
10	B			0/1	No	.	.	.	.	0	0
11	B			0/1	Yes	-9	9	-12	.	2	69
12	B			0/2						0	
13	B			0/1	No	.	.	.	.	0	0
14	B				Yes	-11	47	-86	.	7	20
15	B			2/2						31	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=56   Inspection access=Both sides

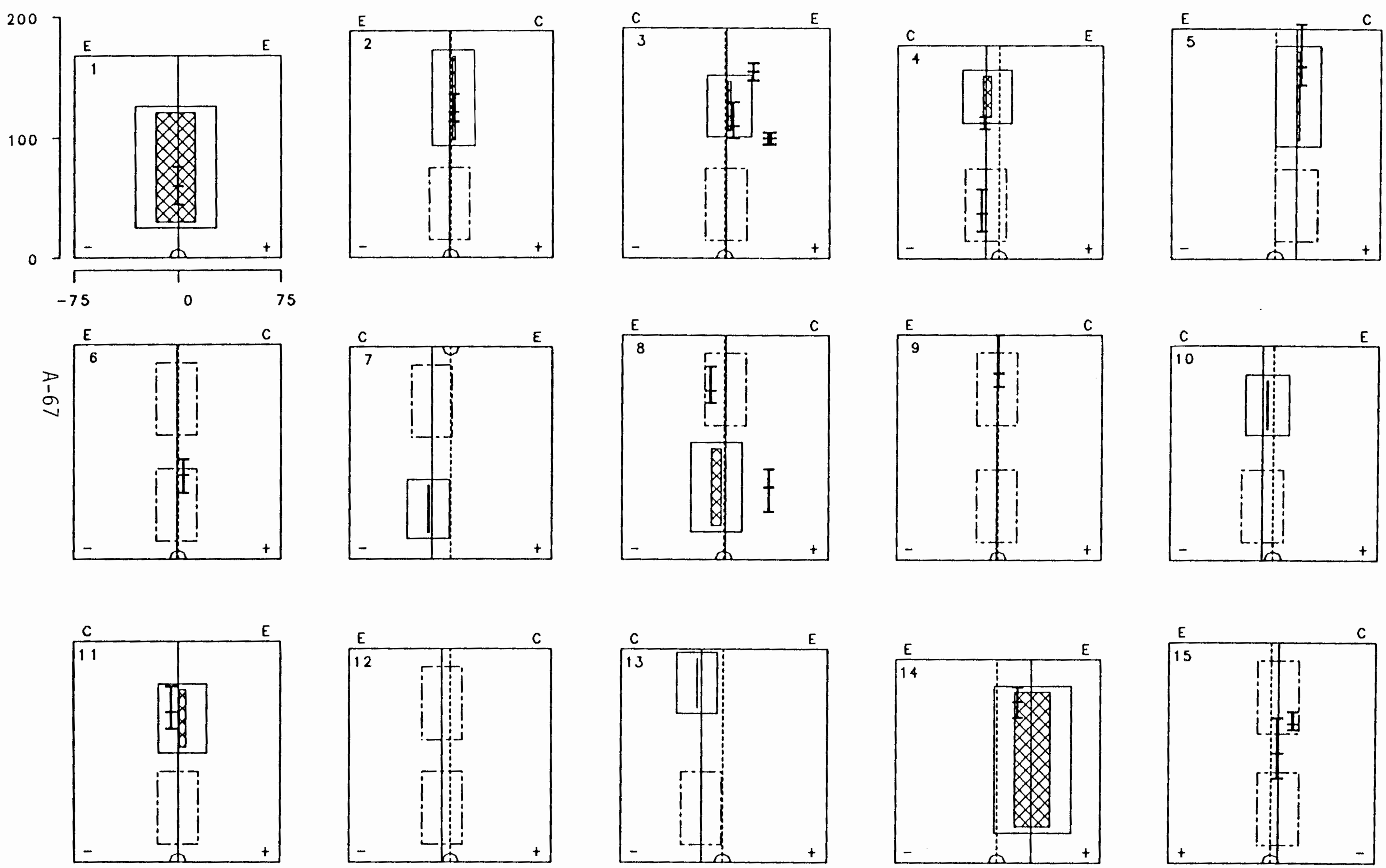
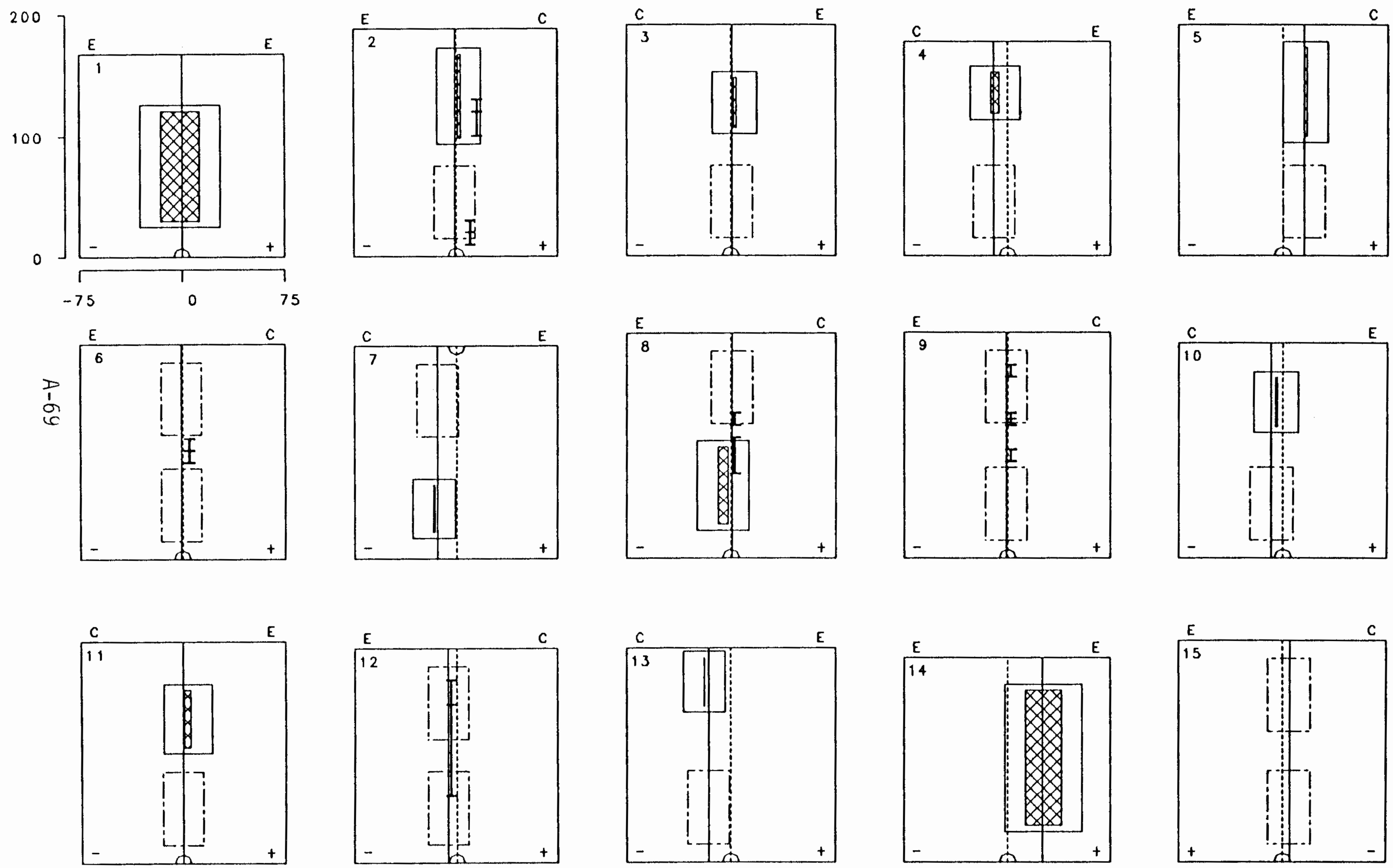


TABLE A.22 Basic Inspection Performance Results for Technique 71

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
2	+	Columnar	Near	1/1	Yes	13	-18	-39	.	18	44
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	1/1	Yes	-7	-12	-11	.	18	60
4	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	-1	-55	66	.	62	37
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	0/2						12	
	-	Equiaxed	None	0/2						0	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	4	10	-9	.	34	65
8	+	Columnar	Far	1/1	Yes	9	25	-34	.	16	35
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	1/2						18	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	-6	-14	-30	.	0	27
11	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	-4	12	-37	.	0	23
12	+	Columnar	None	2/2						55	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	2/2						42	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=71   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=71   Inspection access="-" side

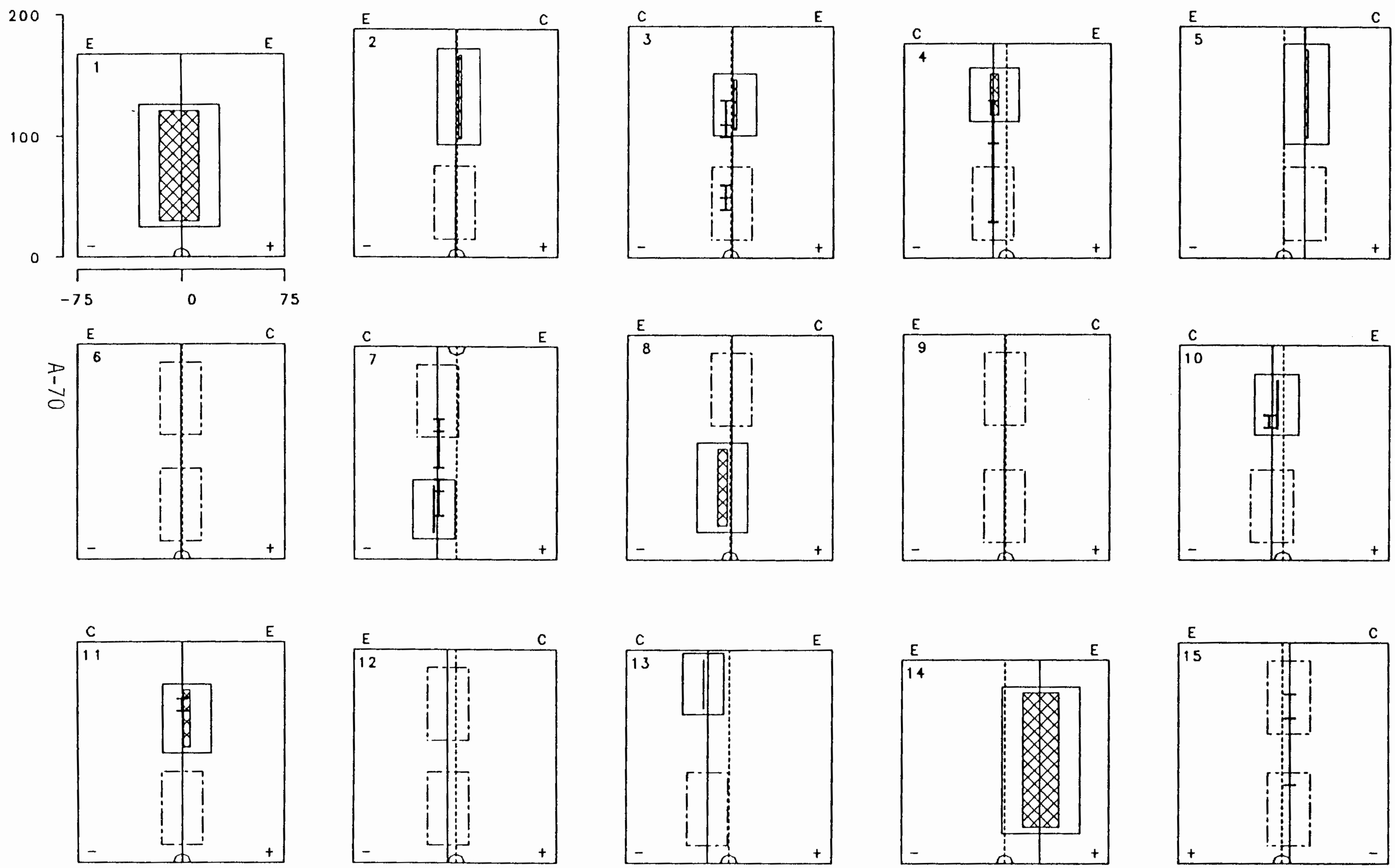
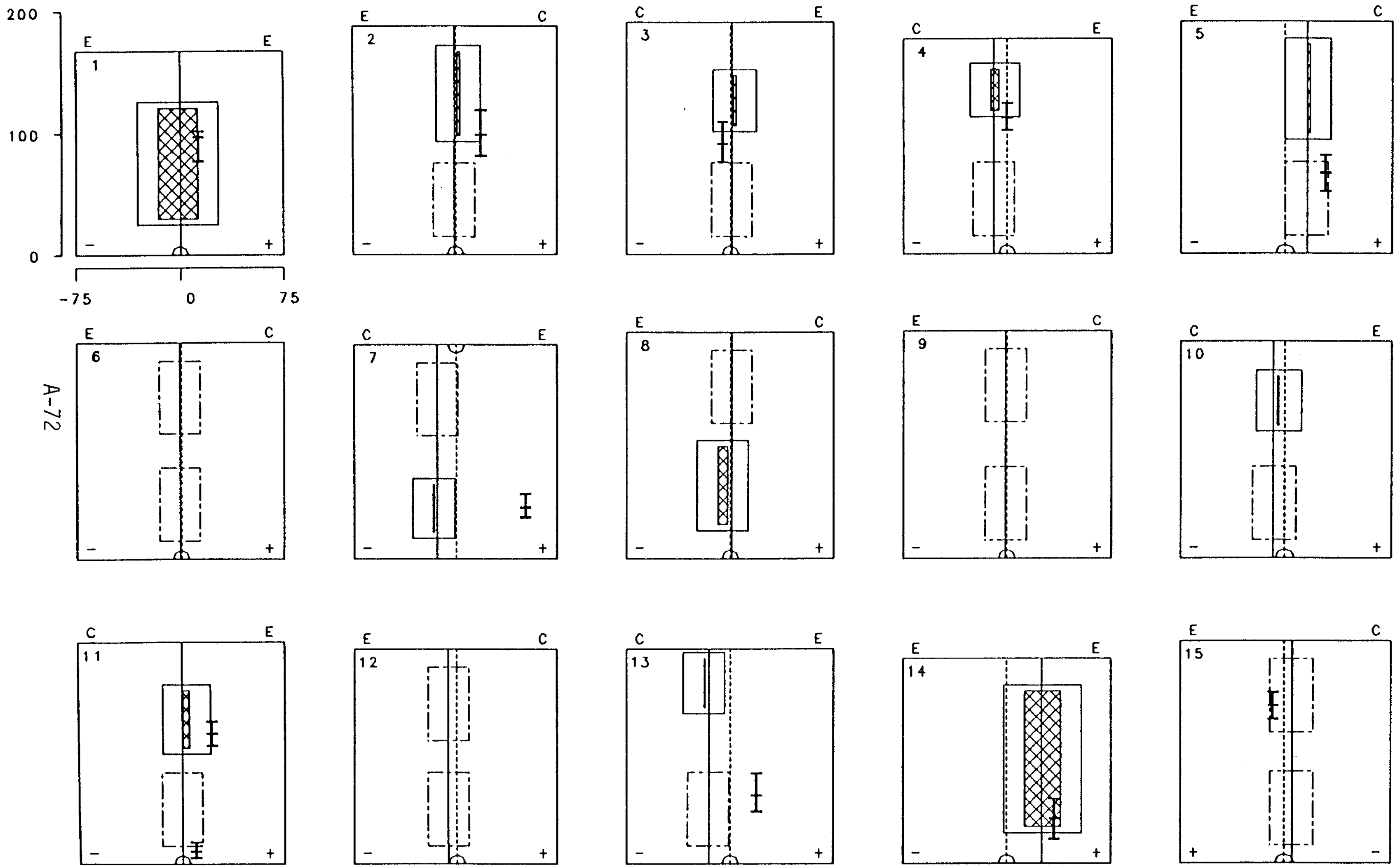


TABLE A.23 Basic Inspection Performance Results for Technique 75

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	15	14	-66	.	0	28
	-	Equiaxed	Far		Yes	-9	3	-56	.	0	39
2	+	Columnar	Near	0/1	Yes	16	-33	-31	-25	14	31
	-	Equiaxed	Far	1/1	No	.	.	.	.	35	0
3	+	Equiaxed	Near	0/1	Yes	-9	-34	-8	-13	20	10
	-	Columnar	Far	0/1	Yes	-8	-16	2	-13	11	64
4	+	Equiaxed	Far	0/1	Yes	9	-22	-12	-11	11	20
	-	Columnar	Near	0/1	No	.	.	.	.	19	37
5	+	Columnar	Near	1/1	No	.	.	.	.	26	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						11	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	50
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
8	+	Columnar	Far	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Near	1/1	Yes	-13	7	-41	-18	20	37
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						12	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	1	51
11	+	Equiaxed	Near	1/1	No	.	.	.	.	10	44
	-	Columnar	Far	0/1	Yes	-10	2	-7	-19	0	85
12	+	Columnar	None	0/2						0	
	-	Equiaxed	None	1/2						15	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	24	0
	-	Columnar	Near	0/1	Yes	-7	-8	-19	.	0	54
14	+	Equiaxed	Near		Yes	8	-49	-78	.	18	21
	-	Equiaxed	Far		No	.	.	.	.	0	25
15	+	Equiaxed	None	1/2						13	
	-	Columnar	None	1/2						13	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=75 Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=75   Inspection access="-" side

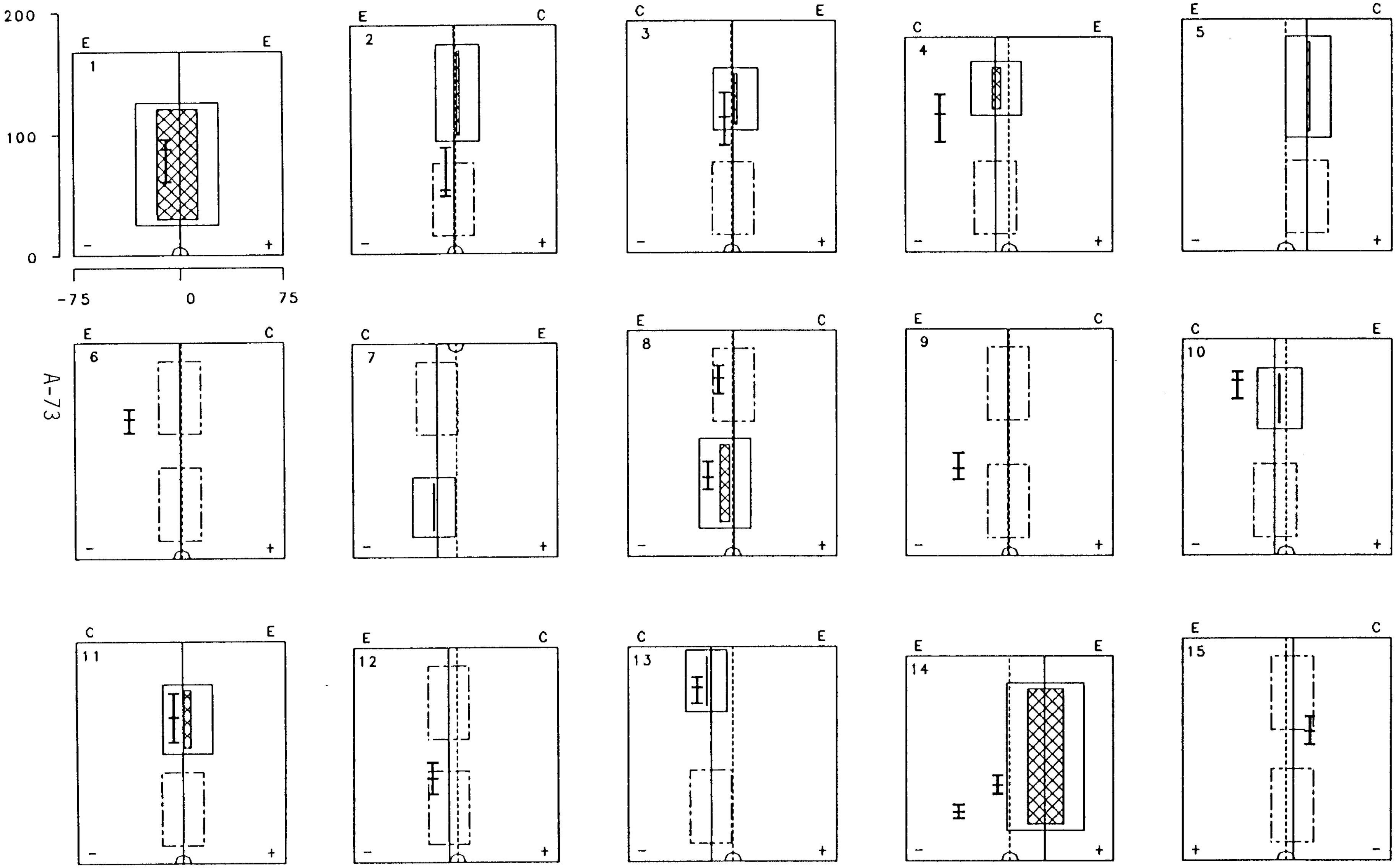


TABLE A.24 Basic Inspection Performance Results for Technique 81

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	B				No	.	.	.	.	0	0
2	B			1/1	Yes	8	18	-59	.	18	16
3	B			1/1	No	.	.	.	.	21	0
4	B			0/1	No	.	.	.	.	0	0
5	B			0/1	Yes	4	-1	-23	.	0	69
6	B			0/2						0	
7	B			0/1	No	.	.	.	.	15	3
8	B			0/1	No	.	.	.	.	2	89
9	B			0/2						17	
10	B			0/1	Yes	-13	-4	0	.	3	90
11	B			0/1	Yes	1	7	-7	.	2	79
12	B			0/2						0	
13	B			0/1	No	.	.	.	.	16	0
14	B				No	.	.	.	.	7	29
15	B			1/2						14	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=81   Inspection access=Both sides

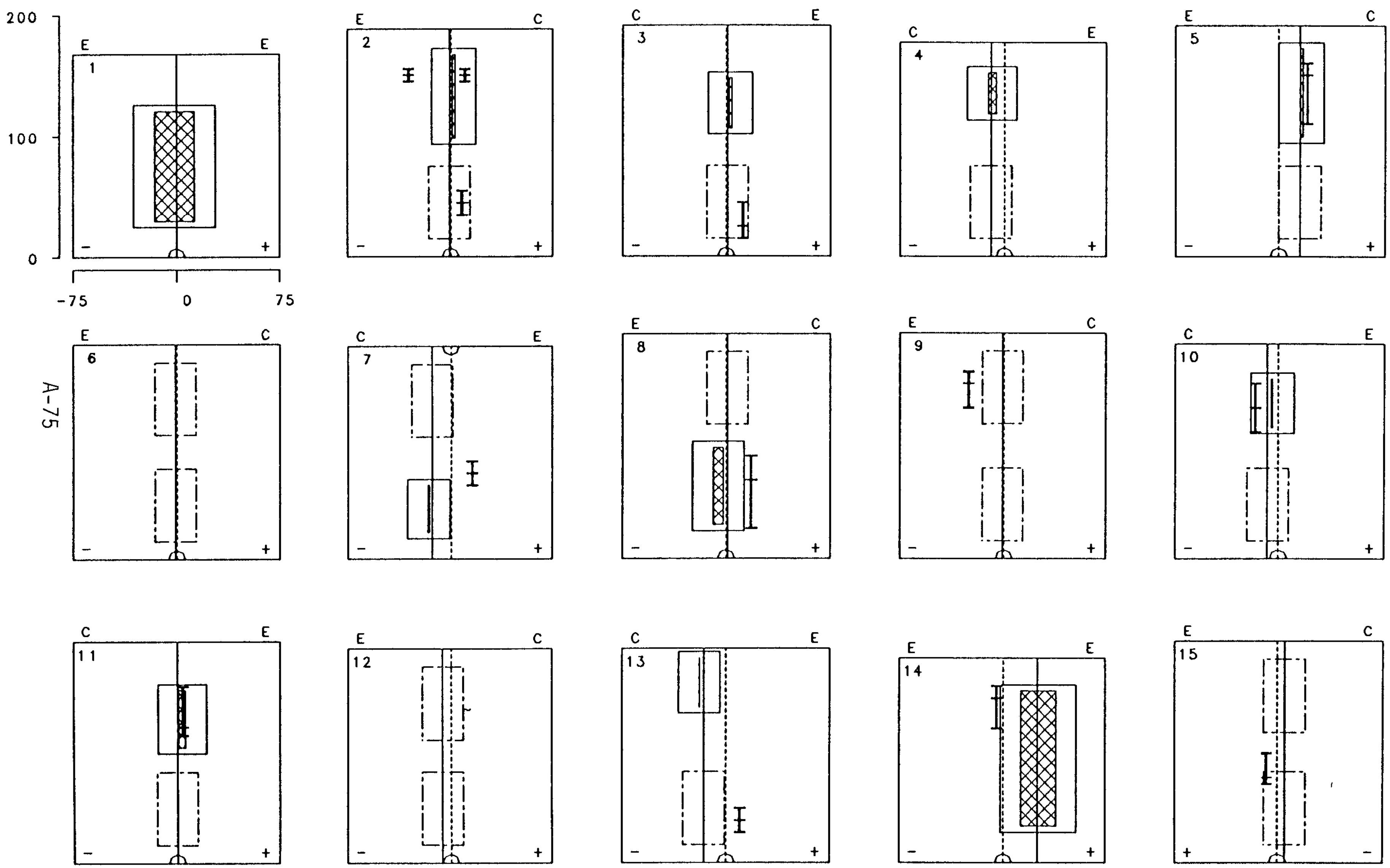
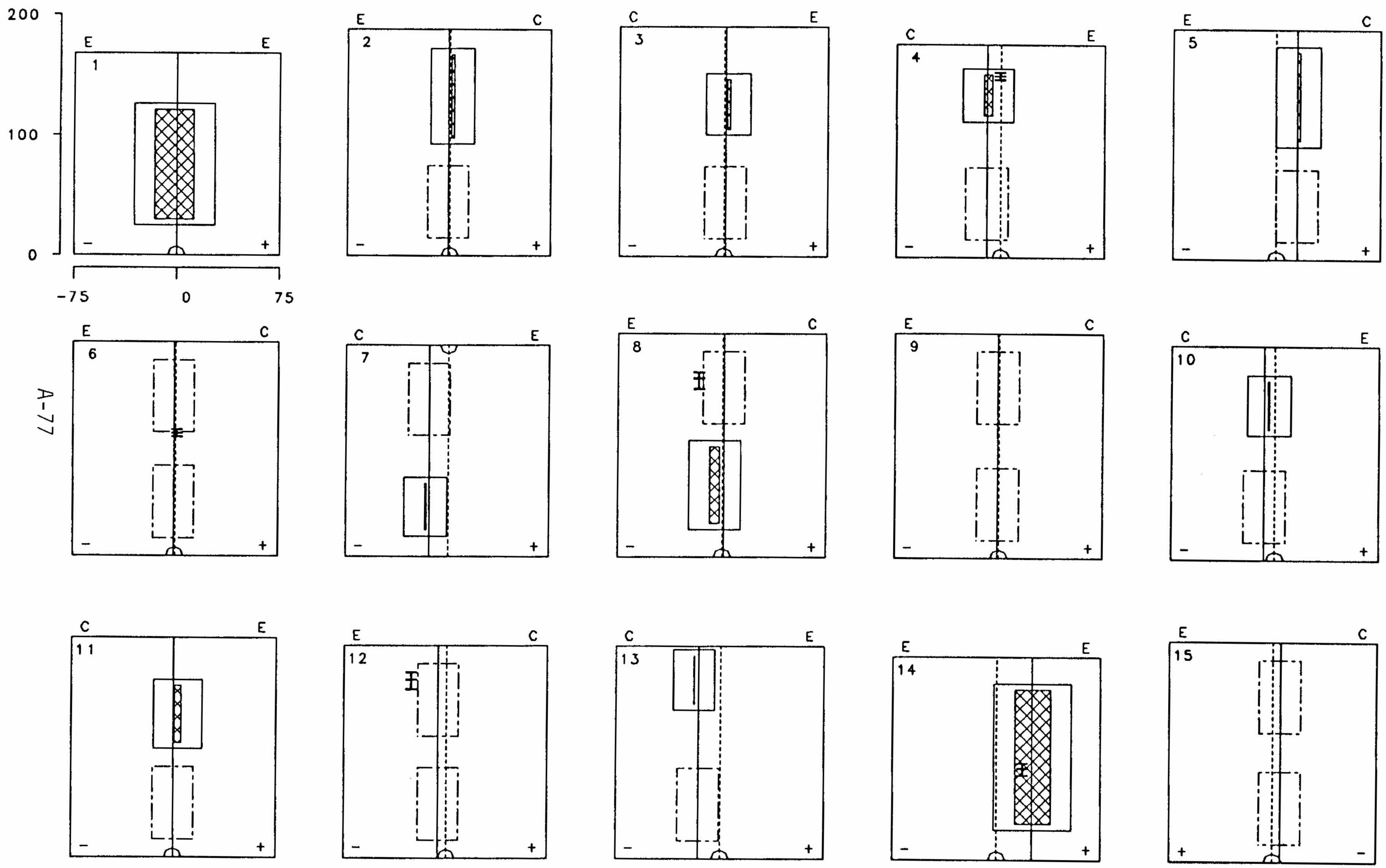


TABLE A.25 Basic Inspection Performance Results for Technique 85

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		No	.	.	.	.	0	0
2	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
4	+	Equiaxed	Far	0/1	Yes	8	16	-28	19	1	14
	-	Columnar	Near	1/1	Yes	-9	8	-24	19	5	31
5	+	Columnar	Near	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	1/2						4	
	-	Equiaxed	None	0/2						0	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
8	+	Columnar	Far	0/1	No	.	.	.	.	12	0
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
11	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	8	24	-38	12	4	10
12	+	Columnar	None	0/2						9	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		Yes	-8	-11	***	.	0	10
	-	Equiaxed	Far		No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	0/2						4	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=85   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=85   Inspection access="-" side

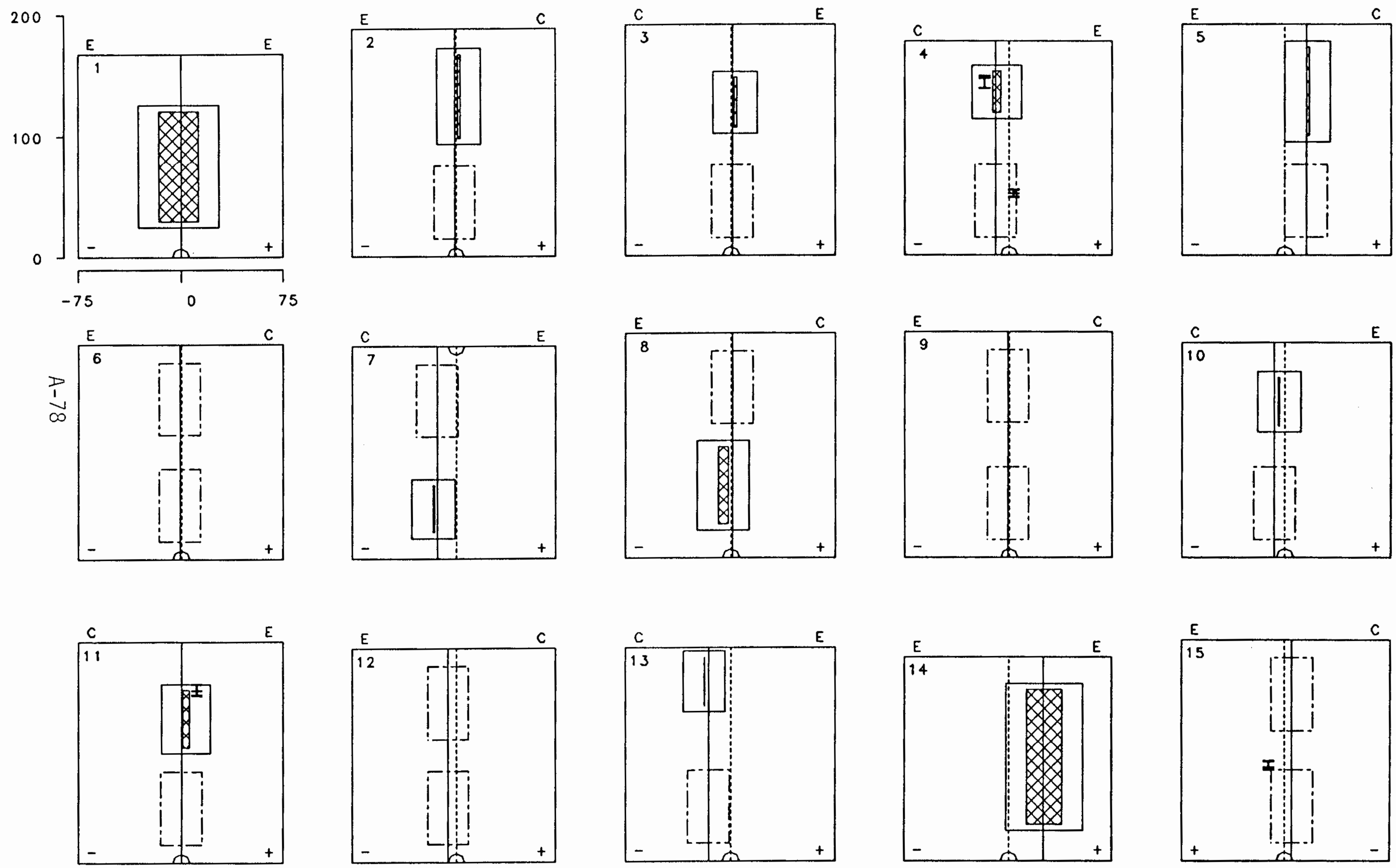


TABLE A.26 Basic Inspection Performance Results for Technique 87

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	B				Yes	5	1	-37	.	41	79
2	B			0/1	Yes	1	-7	-26	.	0	63
3	B			0/1	Yes	1	5	-2	7	3	86
4	B			0/1	No	.	.	.	.	0	0
5	B			0/1	No	.	.	.	.	0	0
6	B			0/2						21	
7	B			0/1	No	.	.	.	.	0	0
8	B			0/1	No	.	.	.	.	0	0
9	B			1/2						16	
10	B			1/1	Yes	-3	-8	-4	.	28	76
11	B			0/1	Yes	-2	-1	-14	2	0	71
12	B			0/2						0	
13	B			0/1	Yes	0	-5	-6	.	1	80
14	B				Yes	3	-4	-19	.	0	83
15	B			0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=87 Inspection access=Both sides

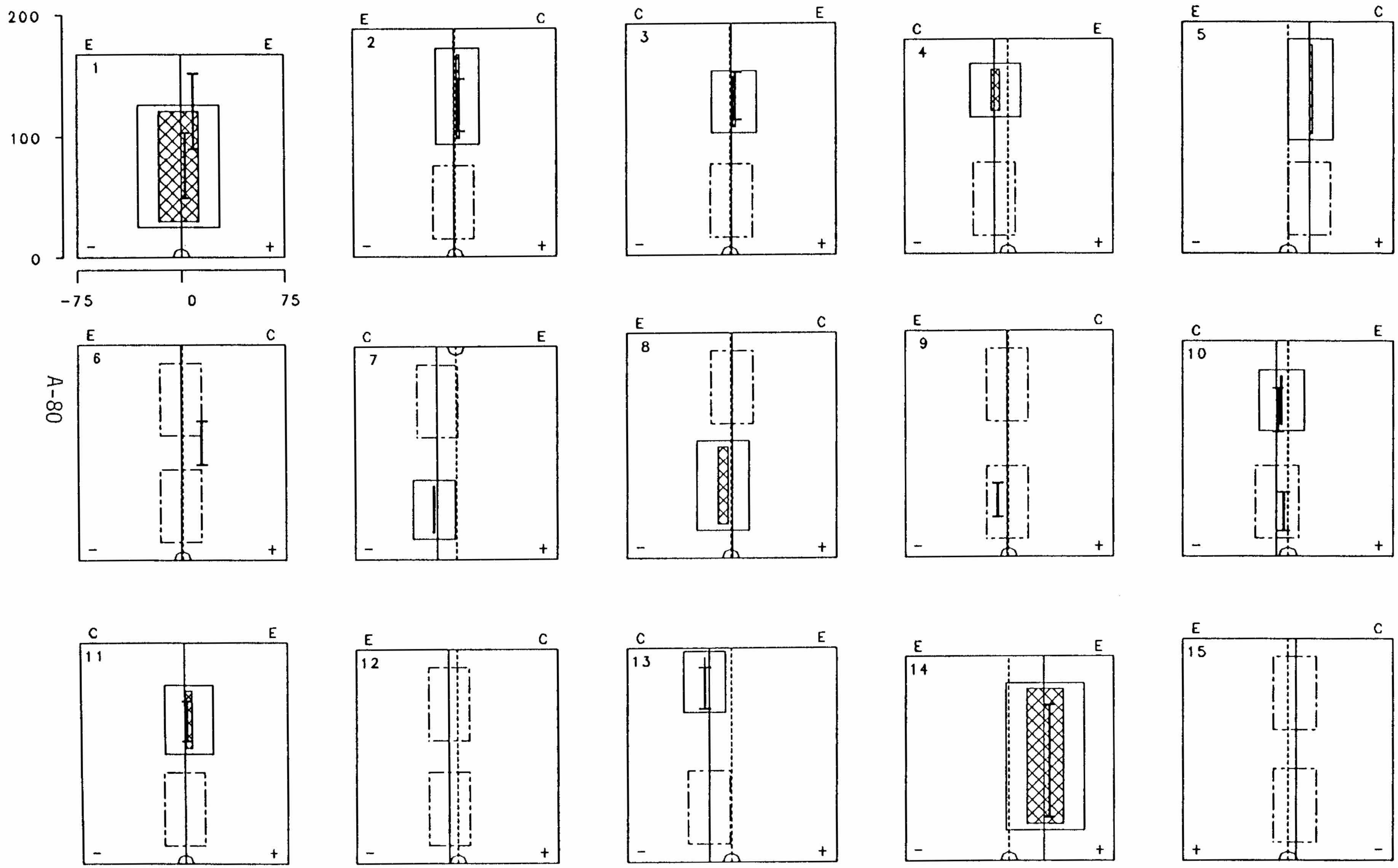
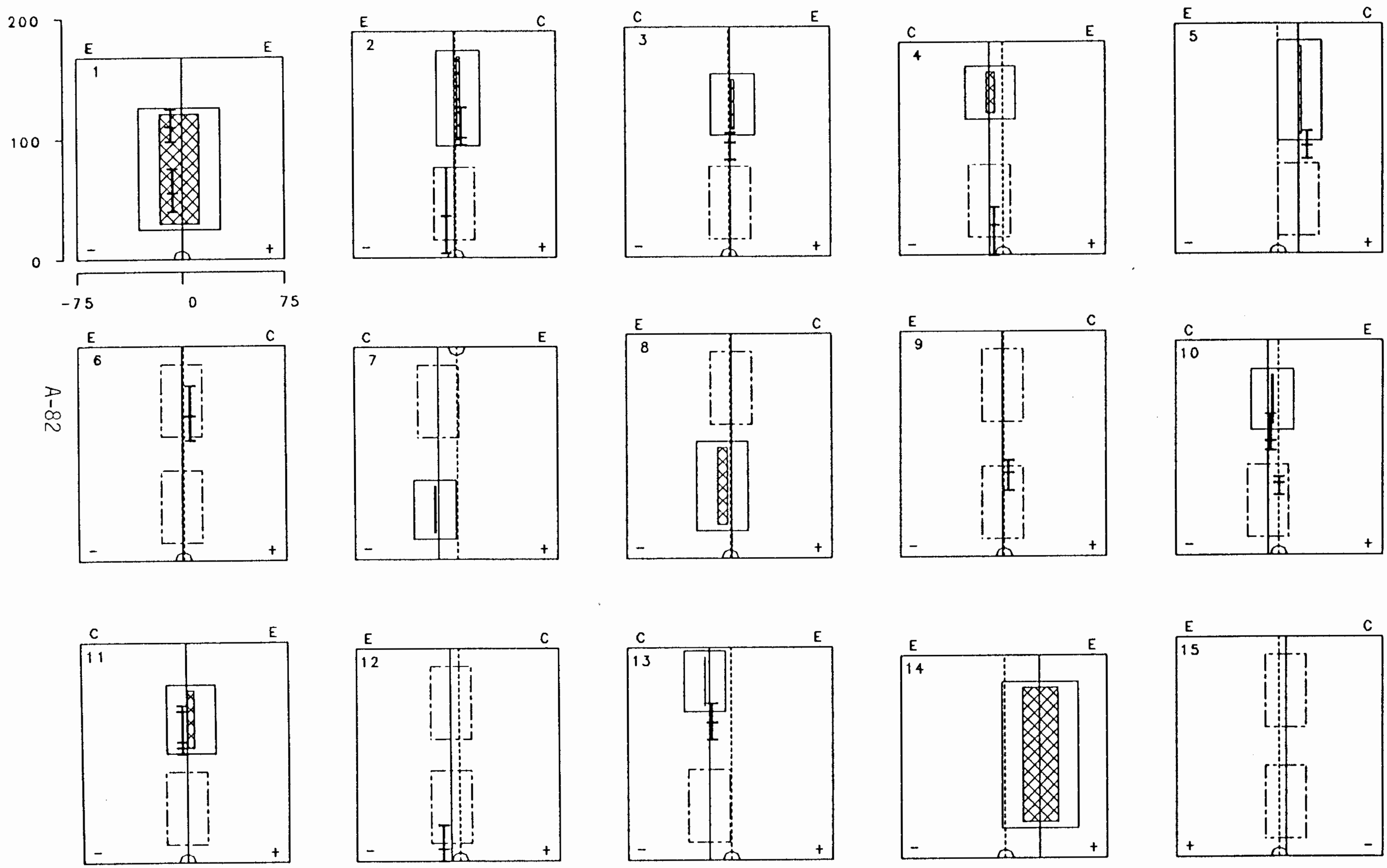


TABLE A.27 Basic Inspection Performance Results for Technique 88

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	-6	-18	-56	.	5	65
	-	Equiaxed	Far		Yes	-6	2	-66	.	0	28
2	+	Columnar	Near	1/1	Yes	2	-23	-38	-25	64	40
	-	Equiaxed	Far	1/1	Yes	-9	-8	-39	-25	19	44
3	+	Equiaxed	Near	0/1	Yes	-2	-35	-19	-13	15	0
	-	Columnar	Far	1/1	Yes	-3	-32	-12	-3	84	10
4	+	Equiaxed	Far	1/1	No	.	.	.	.	28	0
	-	Columnar	Near	1/1	Yes	-4	-5	6	-9	22	94
5	+	Columnar	Near	0/1	Yes	5	-45	-50	-20	17	5
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
6	+	Columnar	None	1/2						26	
	-	Equiaxed	None	0/2						0	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	No	.	.	.	.	45	0
8	+	Columnar	Far	0/1	No	.	.	.	.	0	0
	-	Equiaxed	Near	0/1	No	.	.	.	.	0	0
9	+	Columnar	None	1/2						14	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	1/1	Yes	-2	-27	-10	-9	28	22
	-	Columnar	Far	0/1	Yes	-1	-29	-10	-6	18	17
11	+	Equiaxed	Near	0/1	Yes	-7	-6	-12	-8	4	75
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
12	+	Columnar	None	1/2						17	
	-	Equiaxed	None	0/2						0	
13	+	Equiaxed	Far	0/1	Yes	5	-33	-10	.	21	7
	-	Columnar	Near	0/1	No	.	.	.	.	0	0
14	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		Yes	-3	-46	-71	.	18	28
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	1/2						17	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=88   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=88   Inspection access="-" side

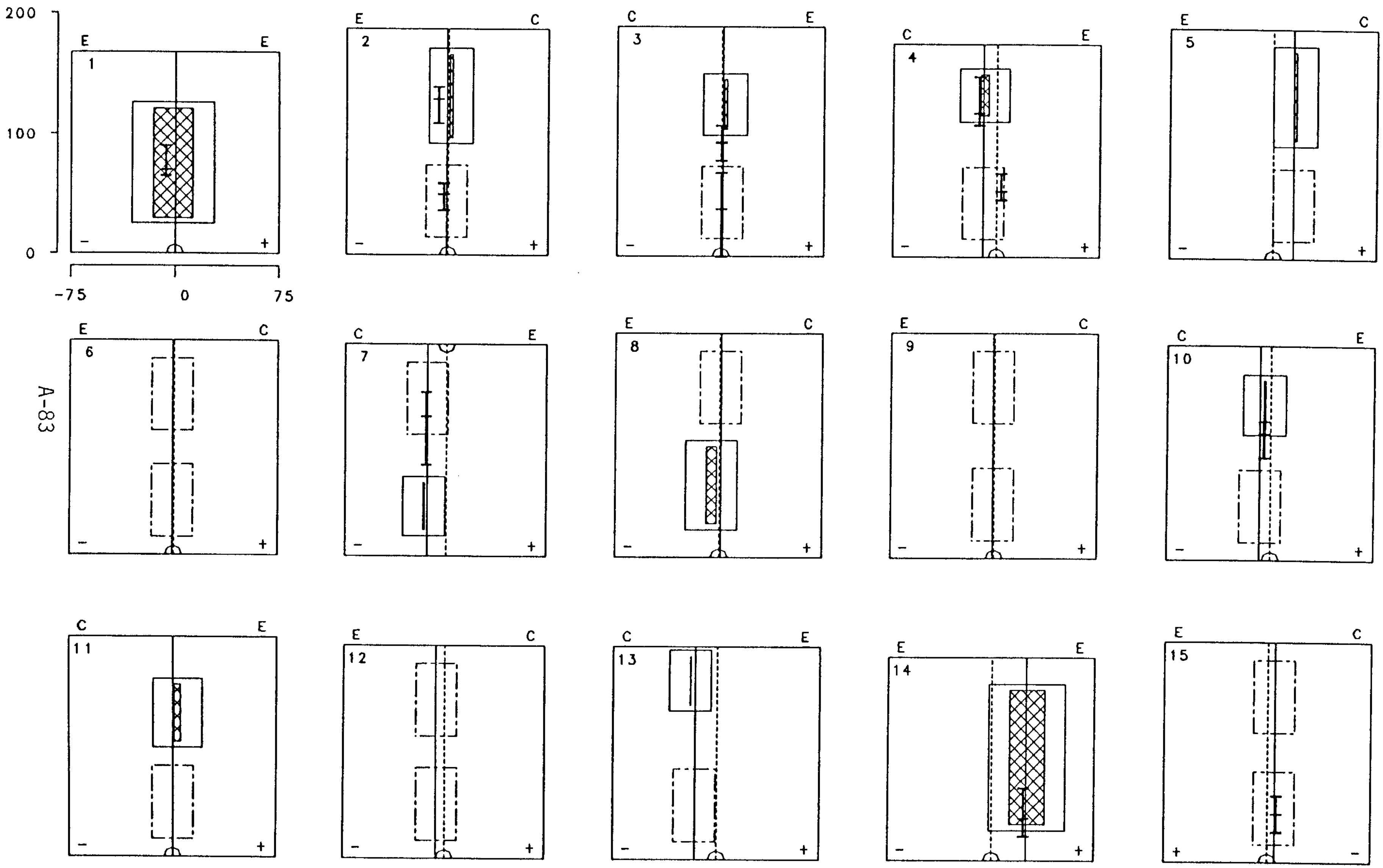
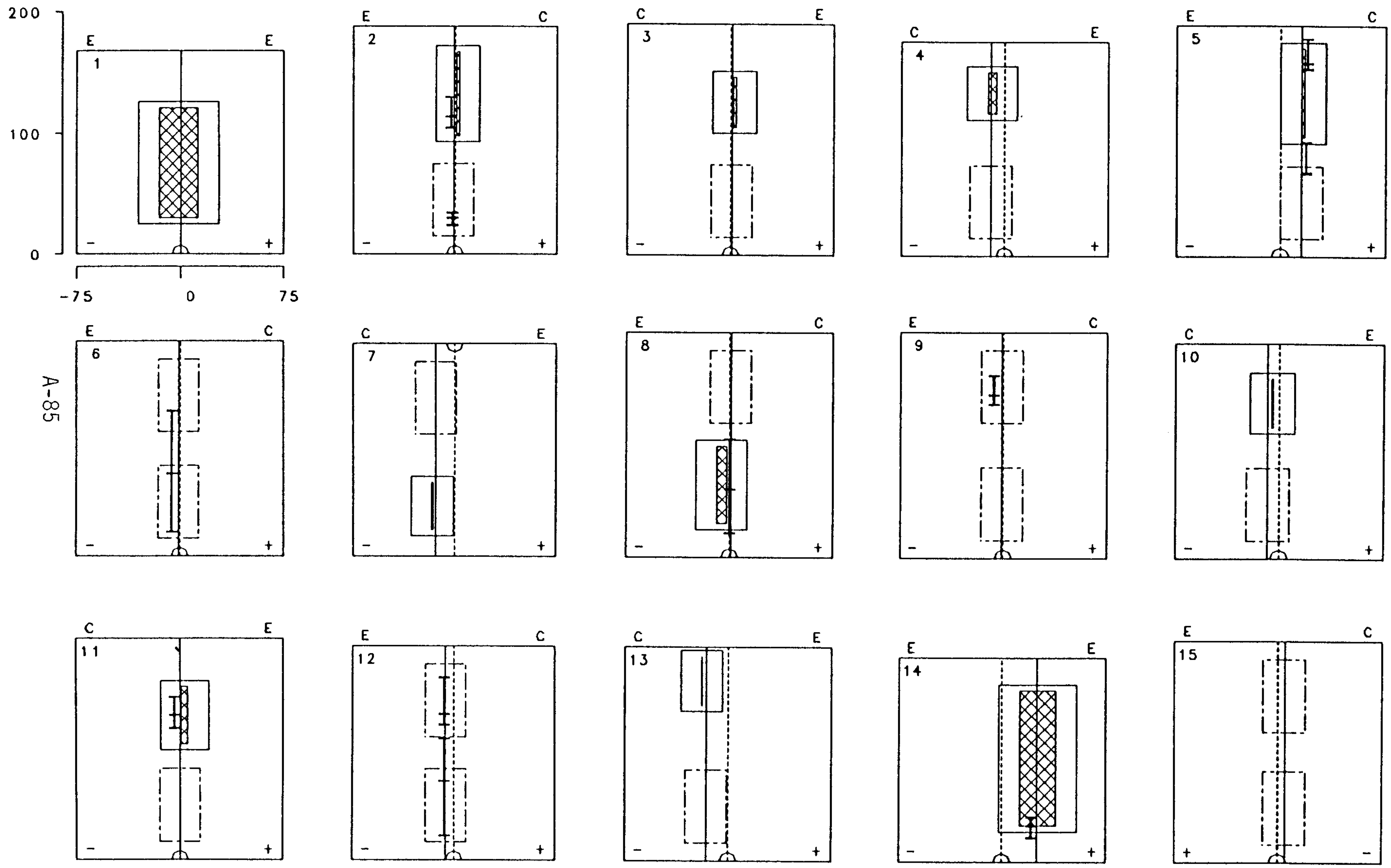


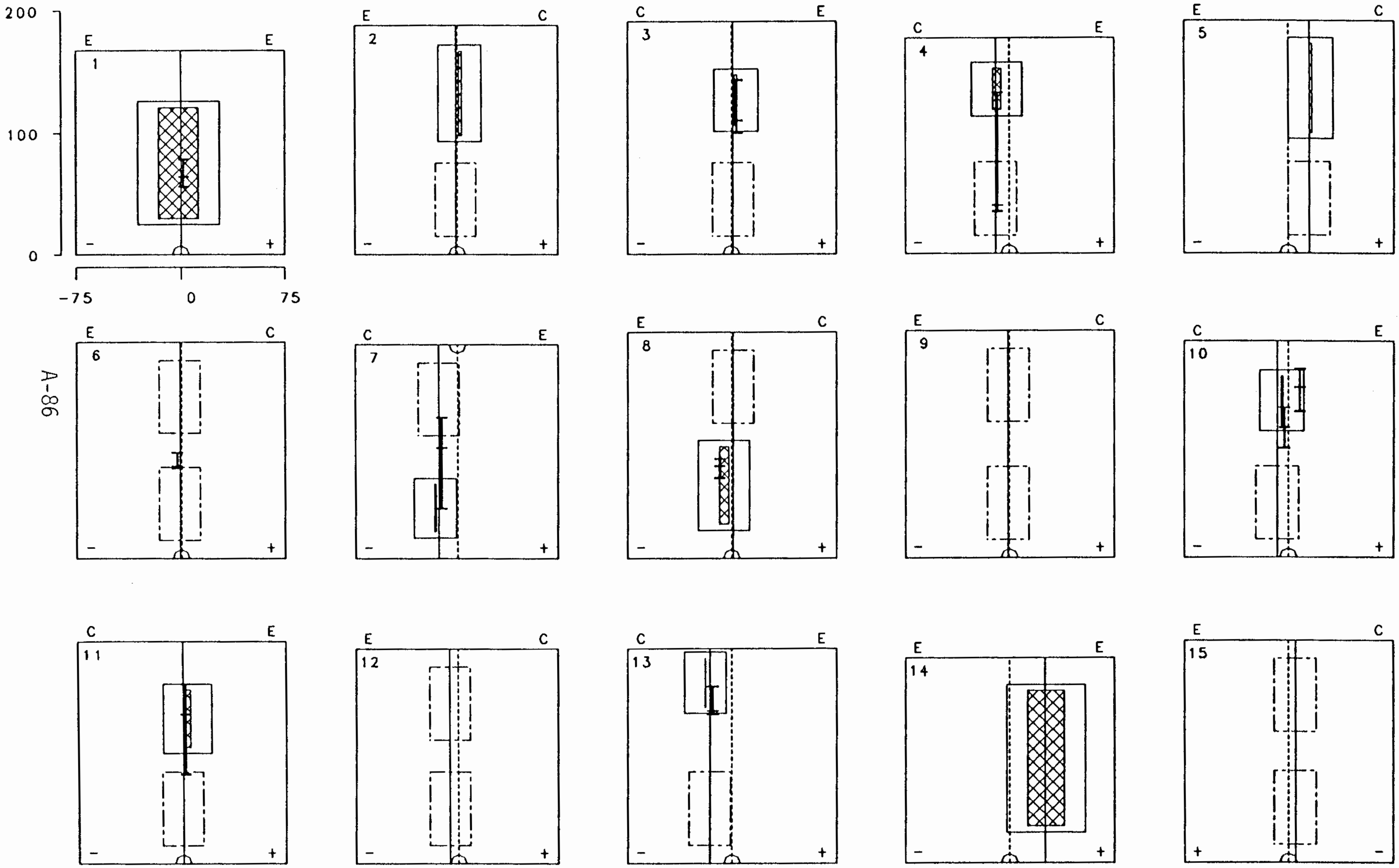
TABLE A.28 Basic Inspection Performance Results for Technique 90

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		No	.	.	.	.	0	0
	-	Equiaxed	Far		Yes	4	-9	-69	.	0	25
	B				Yes	4	-9	-69	.	0	25
2	+	Columnar	Near	1/1	Yes	-5	-15	-44	-23	10	37
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	B			1/1	Yes	-5	-15	-44	-23	10	37
3	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	1	-5	2	-8	4	90
	B			0/1	Yes	1	-5	2	-8	4	90
4	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	0	-52	63	-13	58	43
	B			1/1	Yes	0	-52	63	-13	58	43
5	+	Columnar	Near	1/1	Yes	2	-54	-47	-14	30	24
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	B			1/1	Yes	2	-54	-47	-14	30	24
6	+	Columnar	None	2/2						57	
	-	Equiaxed	None	1/2						8	
	B			2/2						57	
7	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	5	37	36	-11	40	53
	B			1/1	Yes	5	37	36	-11	40	53
8	+	Columnar	Far	0/1	Yes	6	-1	14	-12	12	100
	-	Equiaxed	Near	0/1	Yes	-4	14	-48	-23	0	26
	B			0/1	Yes	6	-1	14	-12	12	100
9	+	Columnar	None	1/2						13	
	-	Equiaxed	None	0/2						0	
	B			1/2						13	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	0/1	Yes	2	-23	-7	-8	18	100
	B			0/1	Yes	2	-23	-7	-8	18	100
11	+	Equiaxed	Near	0/1	Yes	-8	3	-21	-15	0	56
	-	Columnar	Far	1/1	Yes	-2	-9	27	-6	20	100
	B			1/1	Yes	-2	-9	27	-6	20	100
12	+	Columnar	None	2/2						69	
	-	Equiaxed	None	0/2						0	
	B			2/2						69	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	0/1	Yes	5	-15	-17	.	4	44
	B			0/1	Yes	5	-15	-17	.	4	44
14	+	Equiaxed	Near		Yes	-5	-57	-94	.	18	7
	-	Equiaxed	Far		No	.	.	.	.	0	0
	B				Yes	-5	-57	-94	.	18	7
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	0/2						0	
	B			0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=90   Inspection access="+" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=90   Inspection access="-" side



Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=90 Inspection access=Both sides

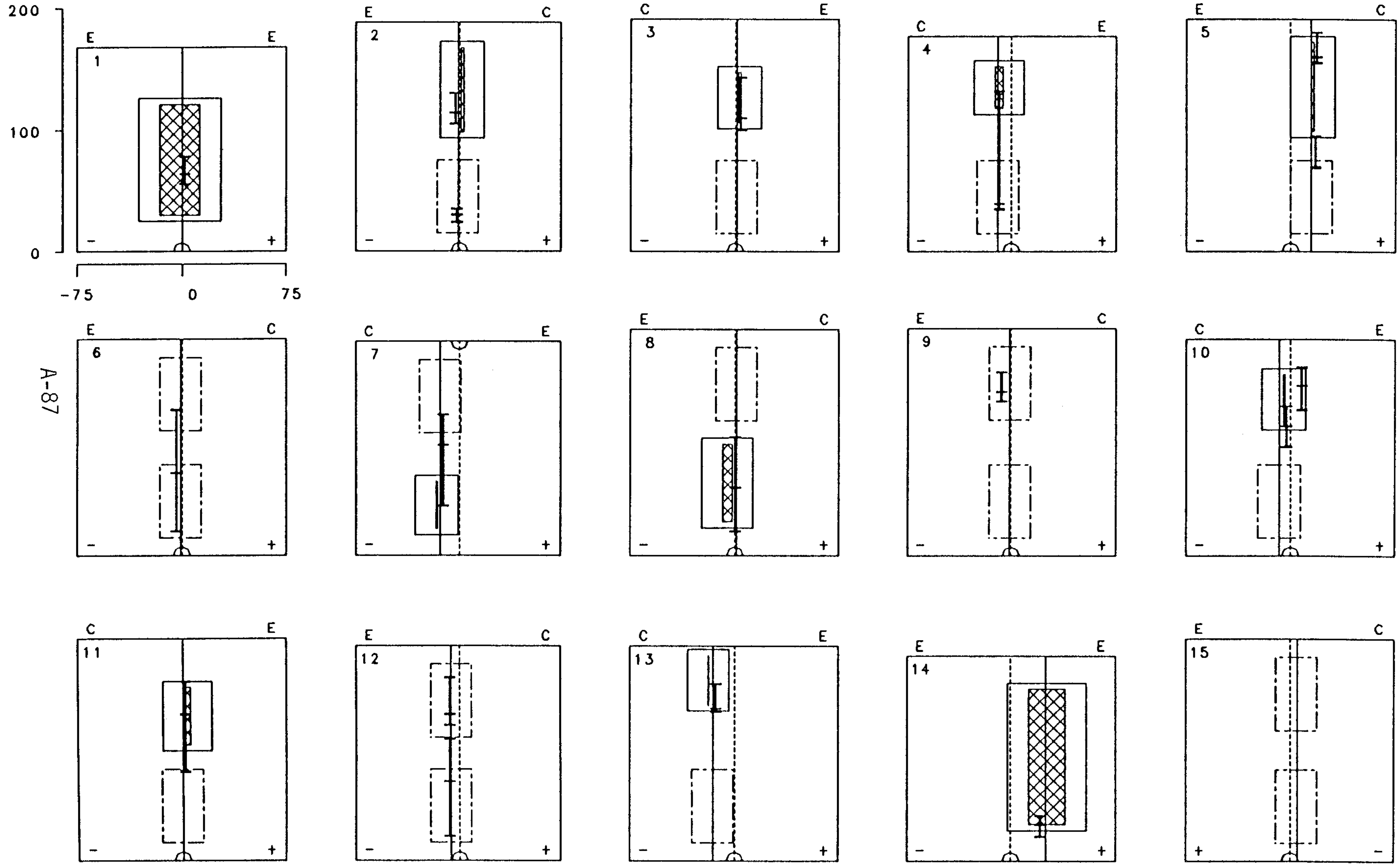


TABLE A.29 Basic Inspection Performance Results for Technique 94

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Location Errors Center mm	Sizing Errors Length mm	Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	B				Yes	5	-2	-3	.	0	97
2	B			0/1	Yes	1	-1	-10	.	0	86
3	B			0/1	Yes	-1	-3	-6	.	0	86
4	B			0/1	Yes	3	-3	-6	.	0	83
5	B			0/1	Yes	-1	-2	-25	.	0	66
6	B			0/2						0	
7	B			0/1	Yes	5	-1	-15	.	0	63
8	B			0/1	Yes	-4	1	-20	.	0	71
9	B			0/2						0	
10	B			0/1	Yes	-1	1	-2	.	0	95
11	B			0/1	Yes	-2	-1	-2	.	0	96
12	B			0/2						0	
13	B			0/1	Yes	0	-4	-8	.	0	80
14	B				Yes	3	-1	-1	.	0	99
15	B			0/2						0	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=94   Inspection access=Both sides

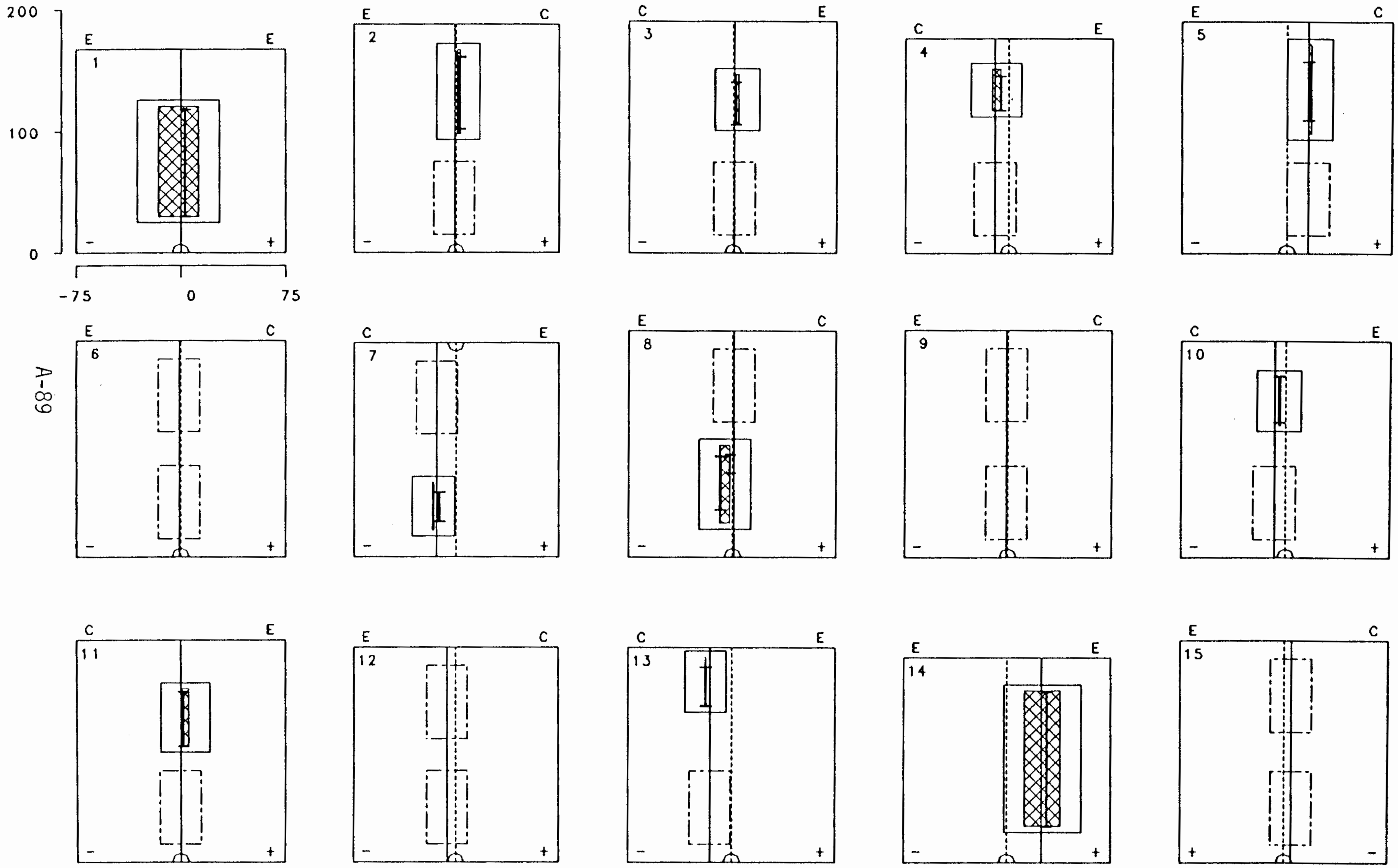
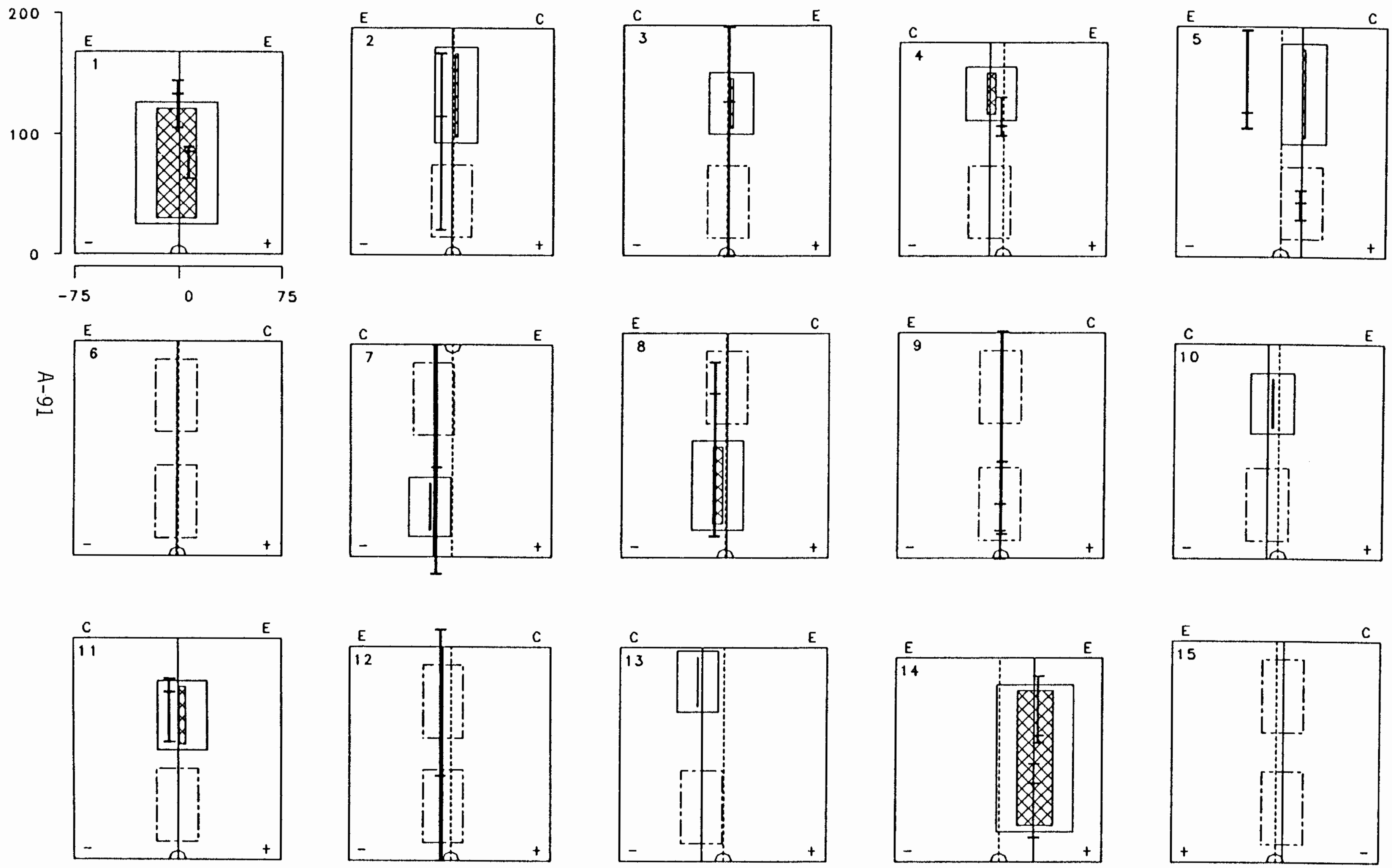


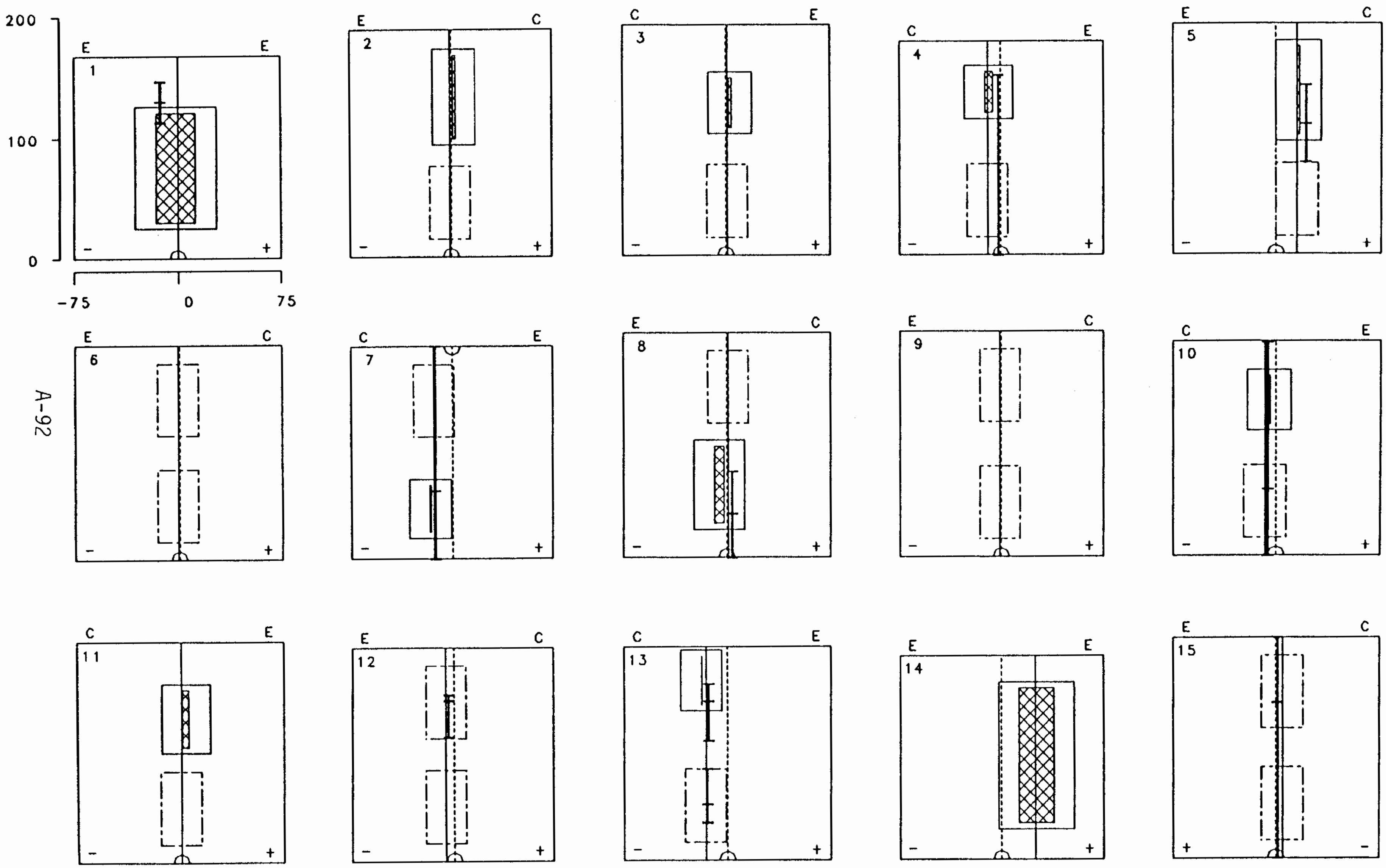
TABLE A.30 Basic Inspection Performance Results for Technique 95

Specimen	Inspection Side	Inpsection Grain	Crack Access	Grading Units: Blanks Classified as Cracked	Grading Units: Cracked Classified as Cracked	Correctly Classified Cracks: Location Errors Offset mm	Correctly Classified Cracks: Location Errors Center mm	Correctly Classified Cracks: Sizing Errors Length mm	Correctly Classified Cracks: Sizing Errors Depth %T-Wall	Percent Weld Length Classified Cracked: Blank	Percent Weld Length Classified Cracked: Cracked
1	+	Equiaxed	Near		Yes	9	1	-65	.	30	48
	-	Equiaxed	Far		Yes	-12	55	-57	.	34	10
2	+	Columnar	Near	1/1	Yes	-11	-39	77	.	65	100
	-	Equiaxed	Far	0/1	No	.	.	.	.	0	0
3	+	Equiaxed	Near	1/1	Yes	-2	-32	149	.	99	100
	-	Columnar	Far	0/1	No	.	.	.	.	30	100
4	+	Equiaxed	Far	0/1	Yes	7	-19	-2	.	13	43
	-	Columnar	Near	1/1	Yes	7	-61	115	.	82	91
5	+	Columnar	Near	1/1	No	.	.	.	.	36	89
	-	Equiaxed	Far	0/1	Yes	5	-28	-9	.	20	57
6	+	Columnar	None	0/2						0	
	-	Equiaxed	None	0/2						0	
7	+	Equiaxed	Far	1/1	Yes	5	40	151	.	100	100
	-	Columnar	Near	1/1	Yes	4	47	137	.	100	100
8	+	Columnar	Far	1/1	Yes	-3	30	80	.	66	100
	-	Equiaxed	Near	0/1	Yes	10	-25	7	.	22	68
9	+	Columnar	None	2/2						100	
	-	Equiaxed	None	0/2						0	
10	+	Equiaxed	Near	0/1	No	.	.	.	.	0	0
	-	Columnar	Far	1/1	Yes	-2	-41	137	.	99	100
11	+	Equiaxed	Near	0/1	Yes	-10	5	5	.	5	96
	-	Columnar	Far	0/1	No	.	.	.	.	0	0
12	+	Columnar	None	2/2						100	
	-	Equiaxed	None	1/2						20	
13	+	Equiaxed	Far	0/1	No	.	.	.	.	0	0
	-	Columnar	Near	1/1	Yes	5	-27	7	.	56	44
14	+	Equiaxed	Near		Yes	-1	-35	-50	.	39	86
	-	Equiaxed	Far		No	.	.	.	.	0	0
15	+	Equiaxed	None	0/2						0	
	-	Columnar	None	2/2						100	

Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=95 Inspection access="+" side



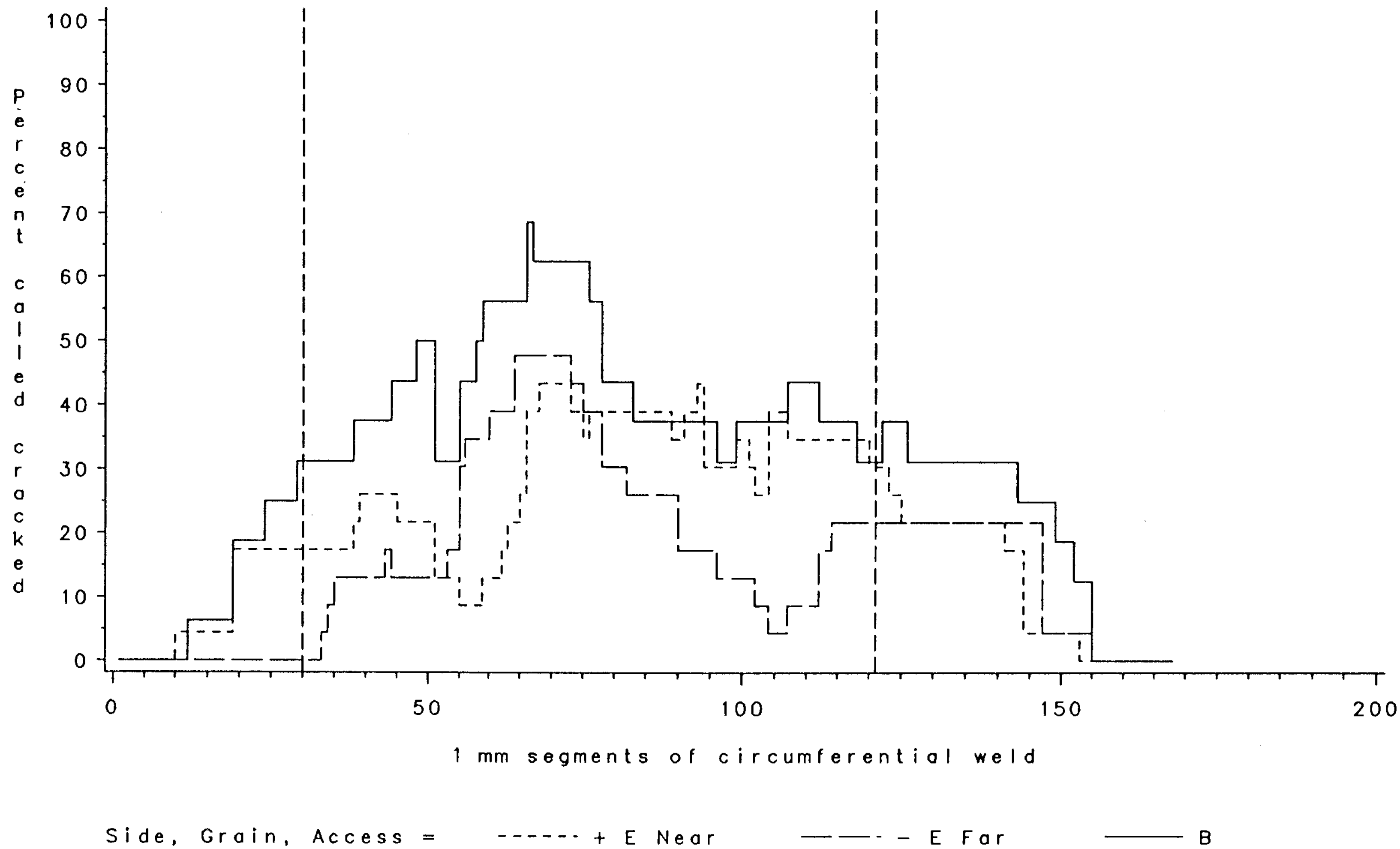
Cast Stainless Steel Round Robin Test Inspection Results
Inspection Technique=95   Inspection access="-" side



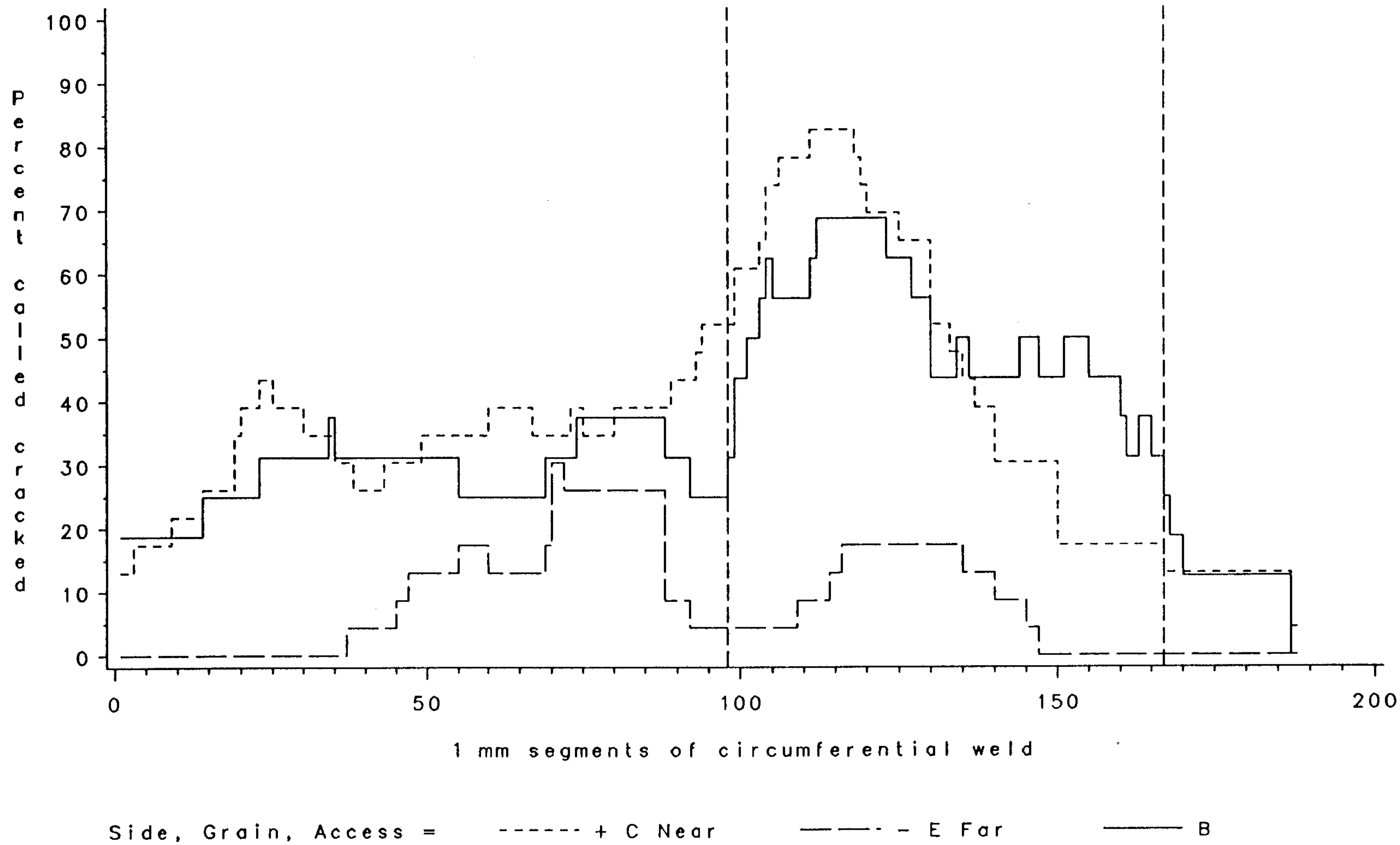
APPENDIX B

Summary of Crack Calls for Specimens 1 through 15

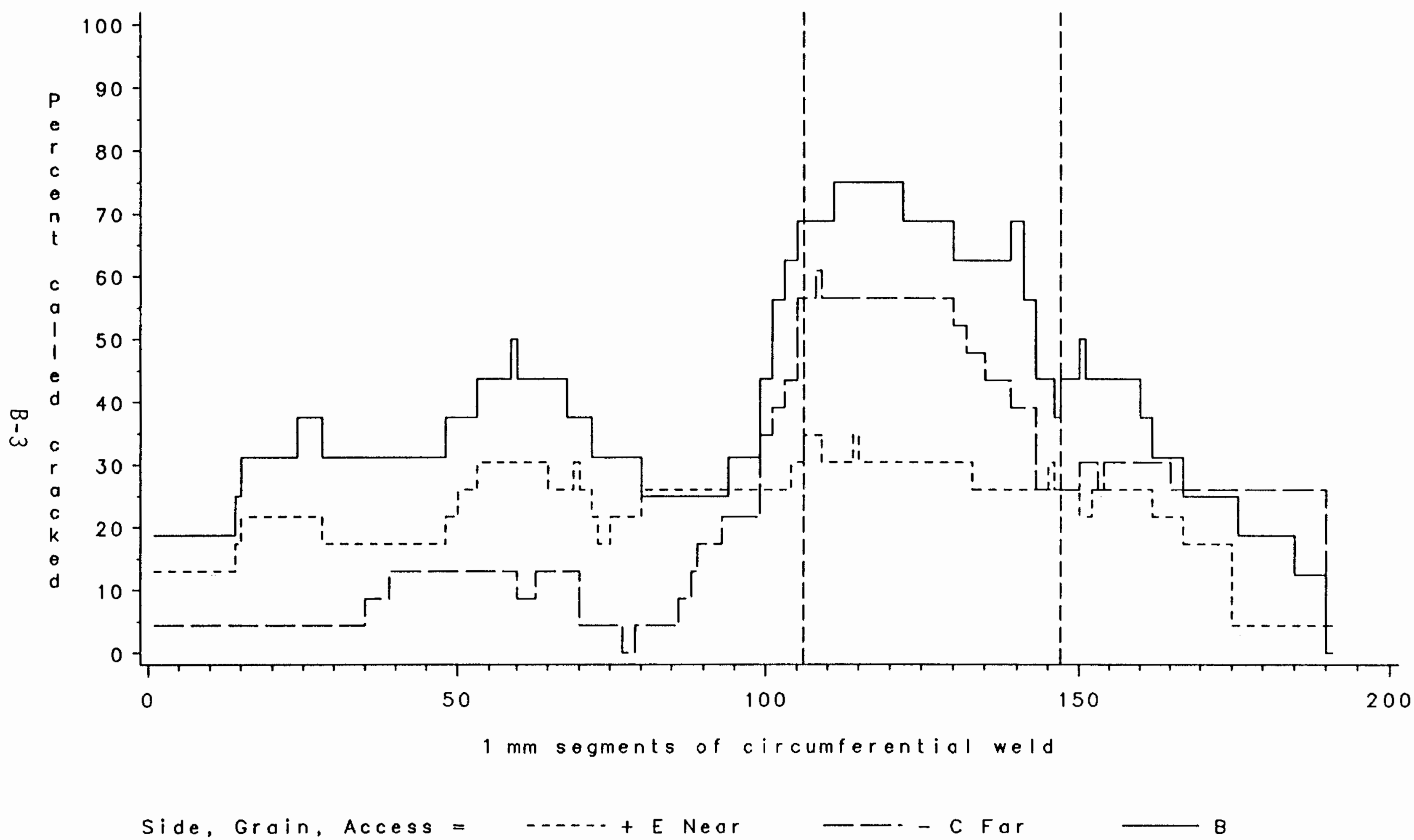
This Appendix contains the crack call profiles for each specimen used in the CCSSRRT. See Section 6.2 for a complete description of the information contained in these plots.



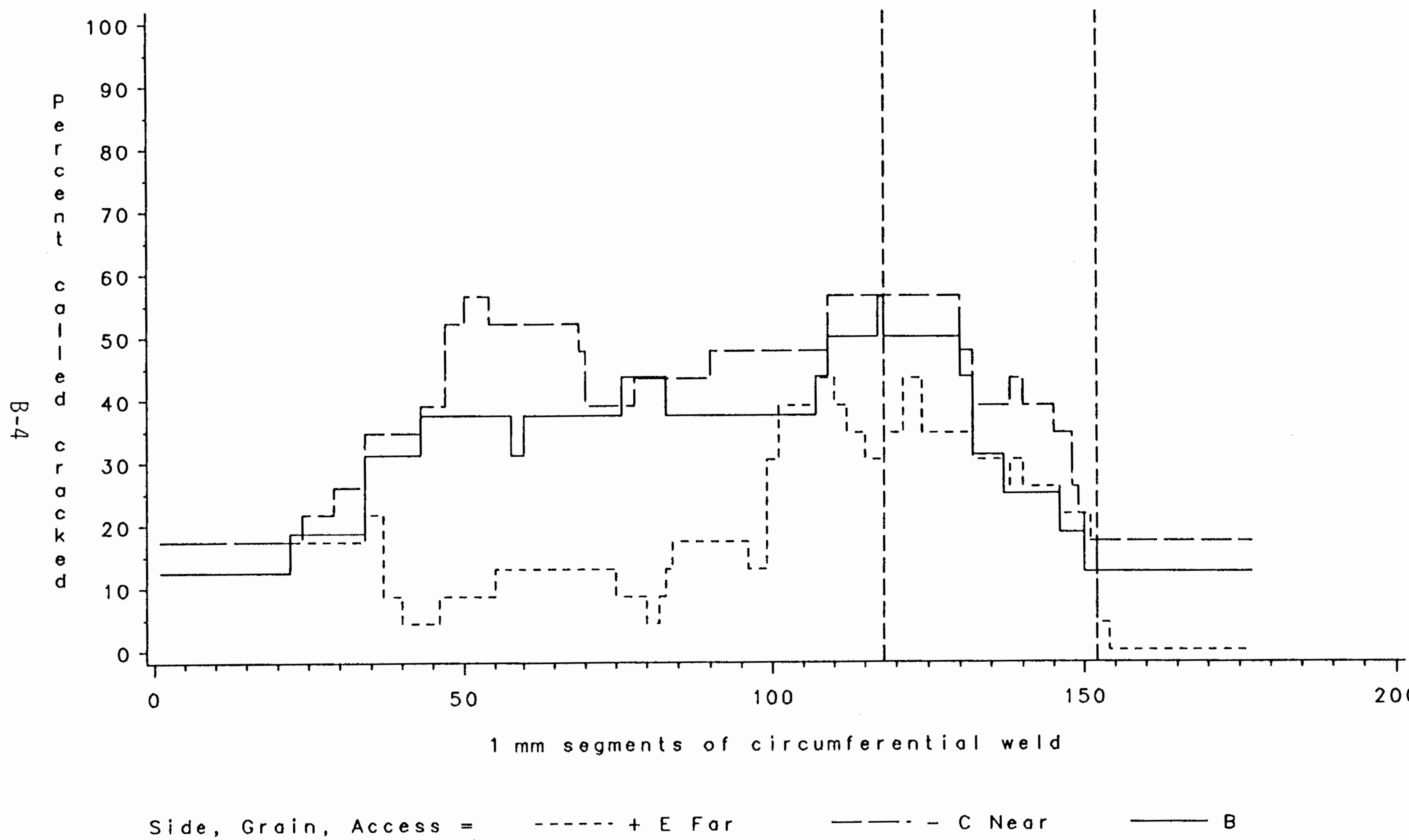
Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.1 Summary of Crack Calls for Specimen 1



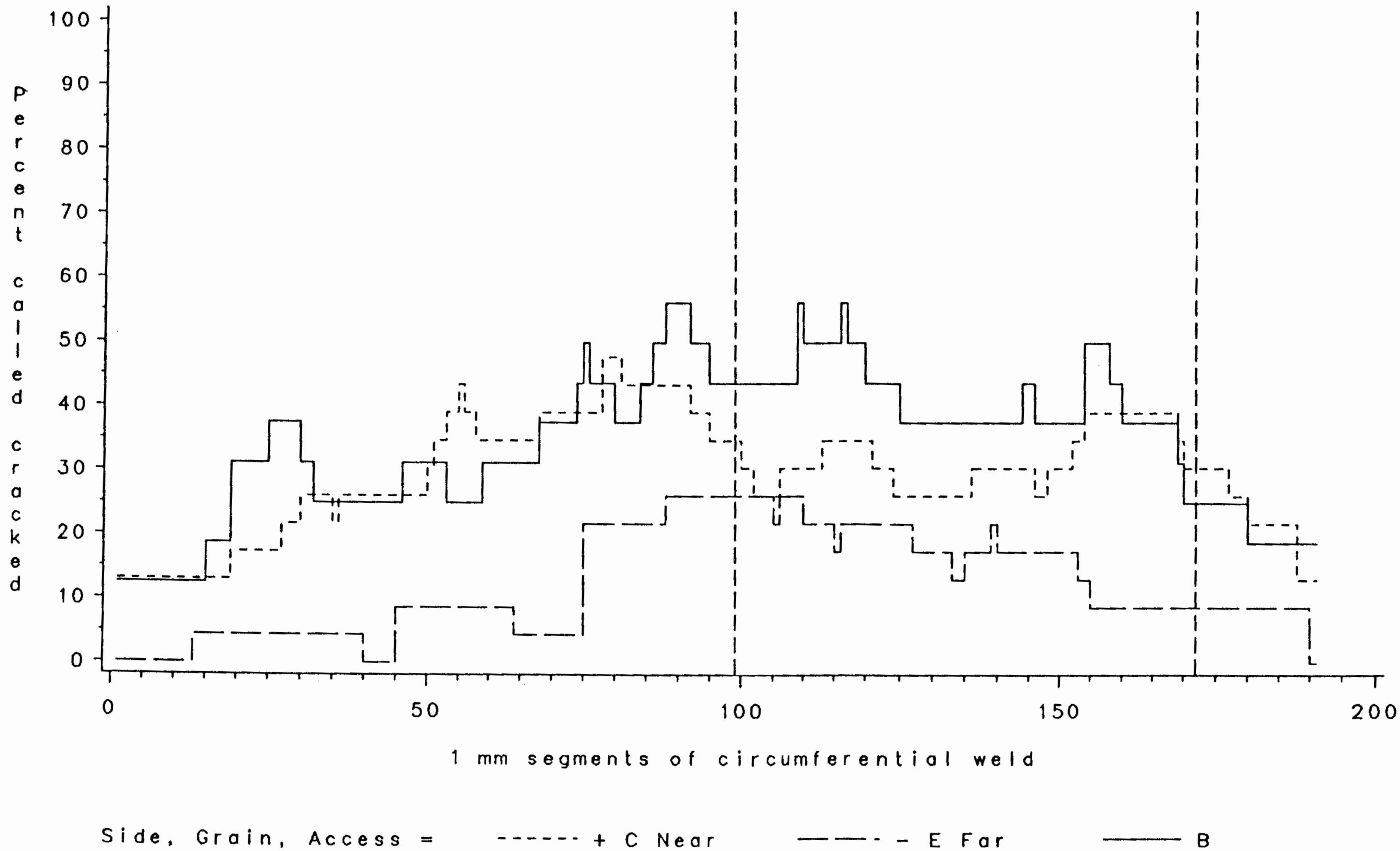
Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.2 Summary of Crack Calls for Specimen 2



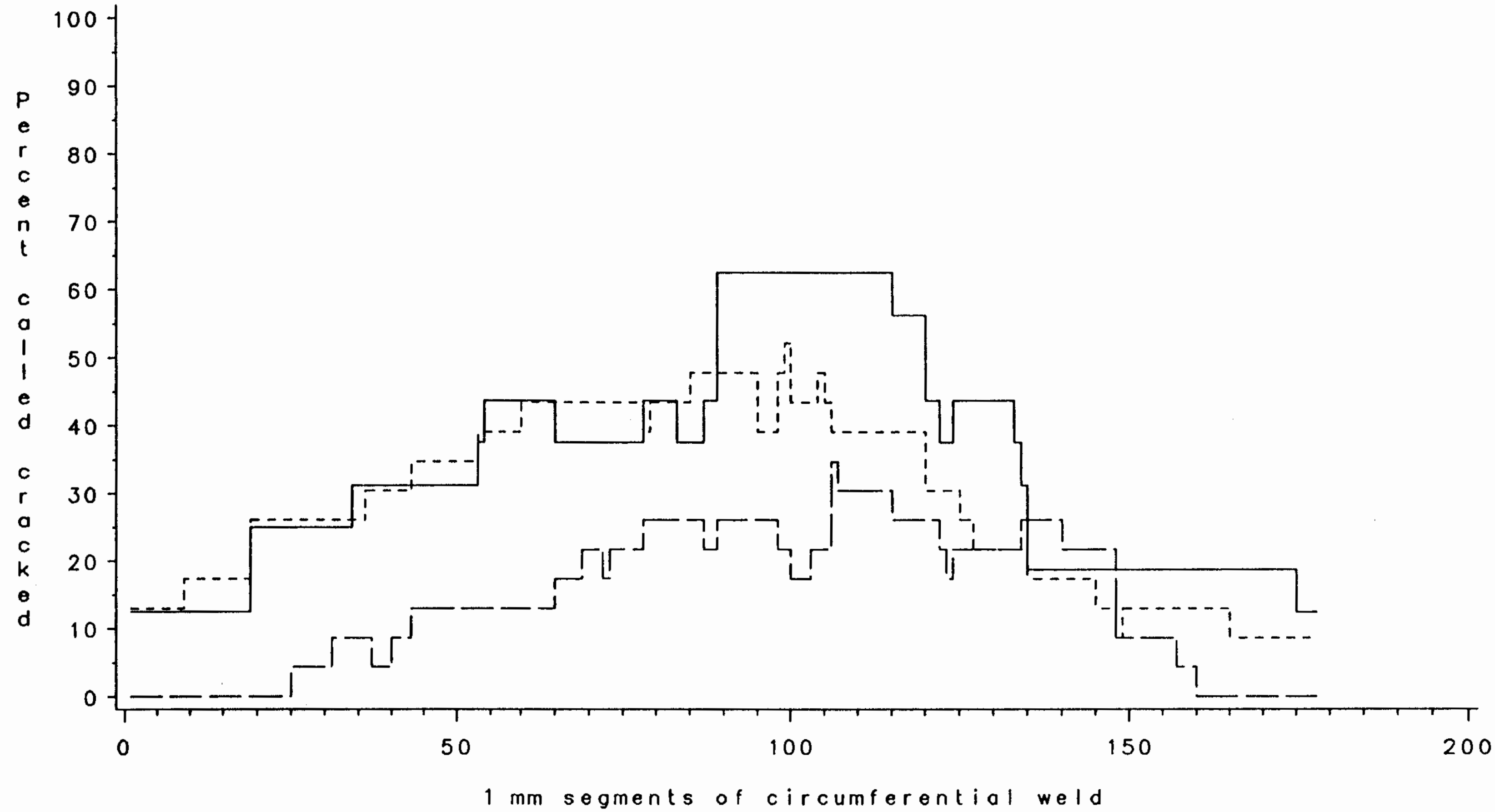
Vertical broken lines are boundaries of crack
23 Single-side inspections, 16 Both-side inspections
FIGURE B.3 Summary of Crack Calls for Specimen 3



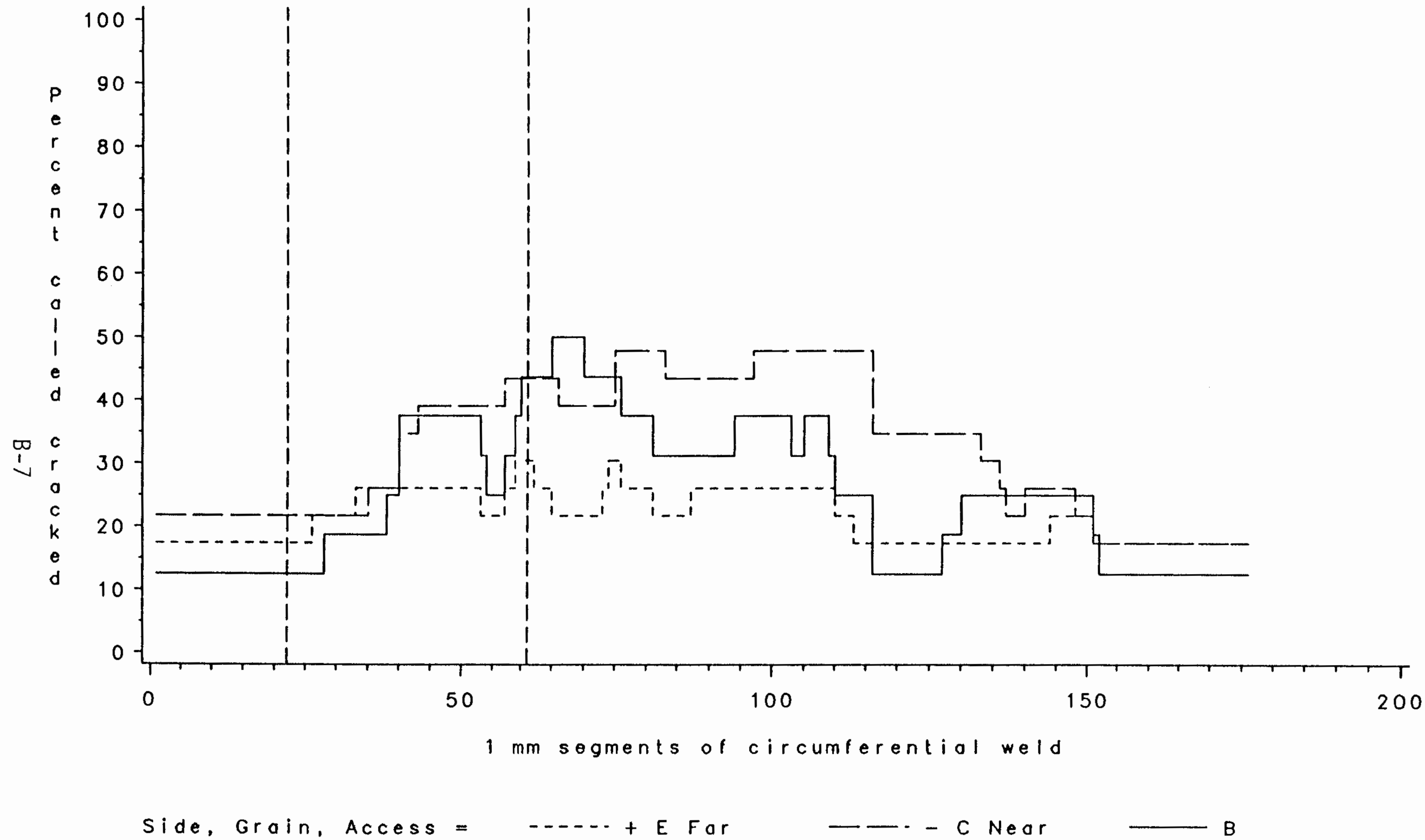
Vertical broken lines are boundaries of crack
23 Single−side inspections, 16 Both−side inspections
FIGURE B.4 Summary of Crack Calls for Specimen 4



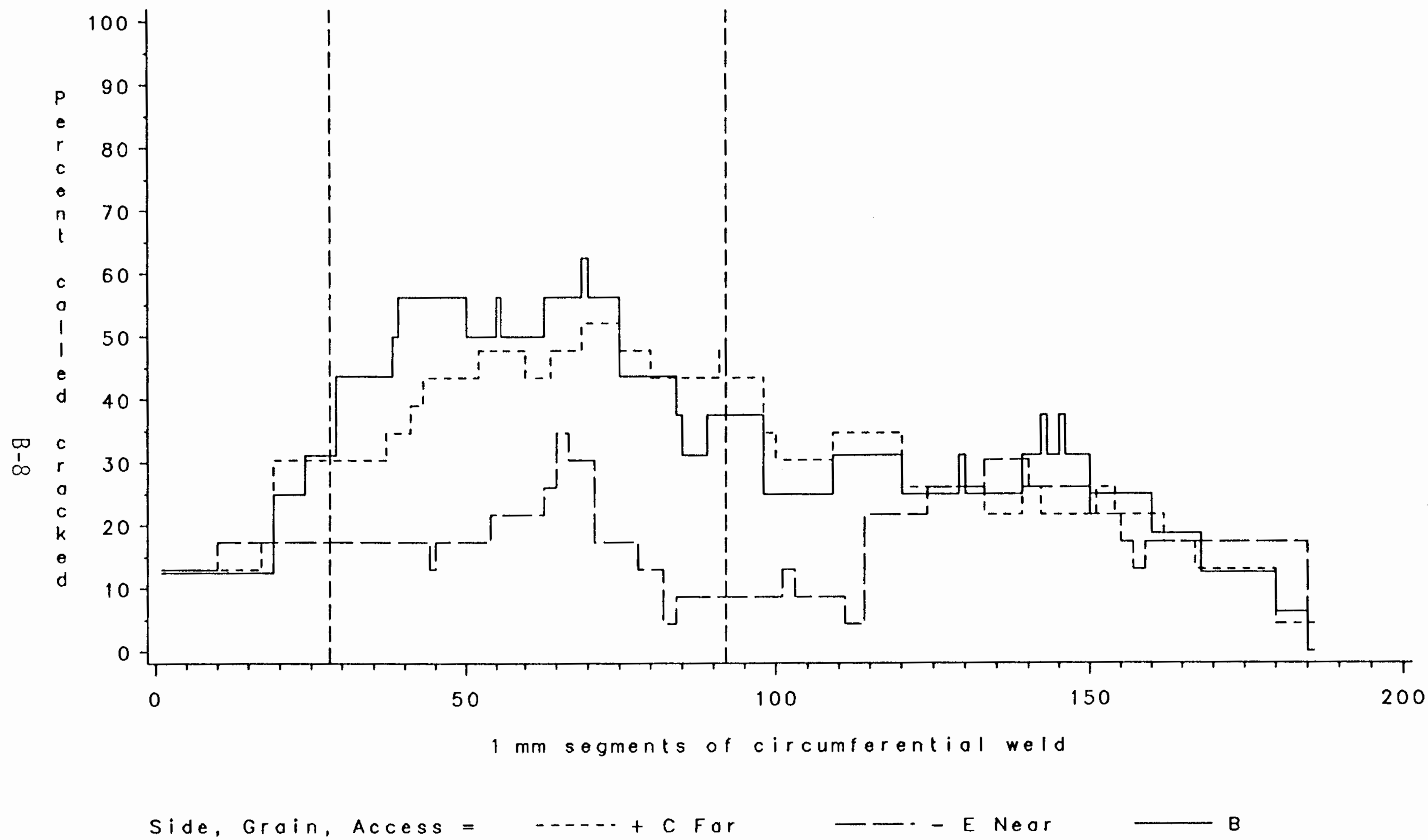
Vertical broken lines are boundaries of crack
23 Single-side inspections, 16 Both-side inspections
FIGURE B.5 Summary of Crack Calls for Specimen 5



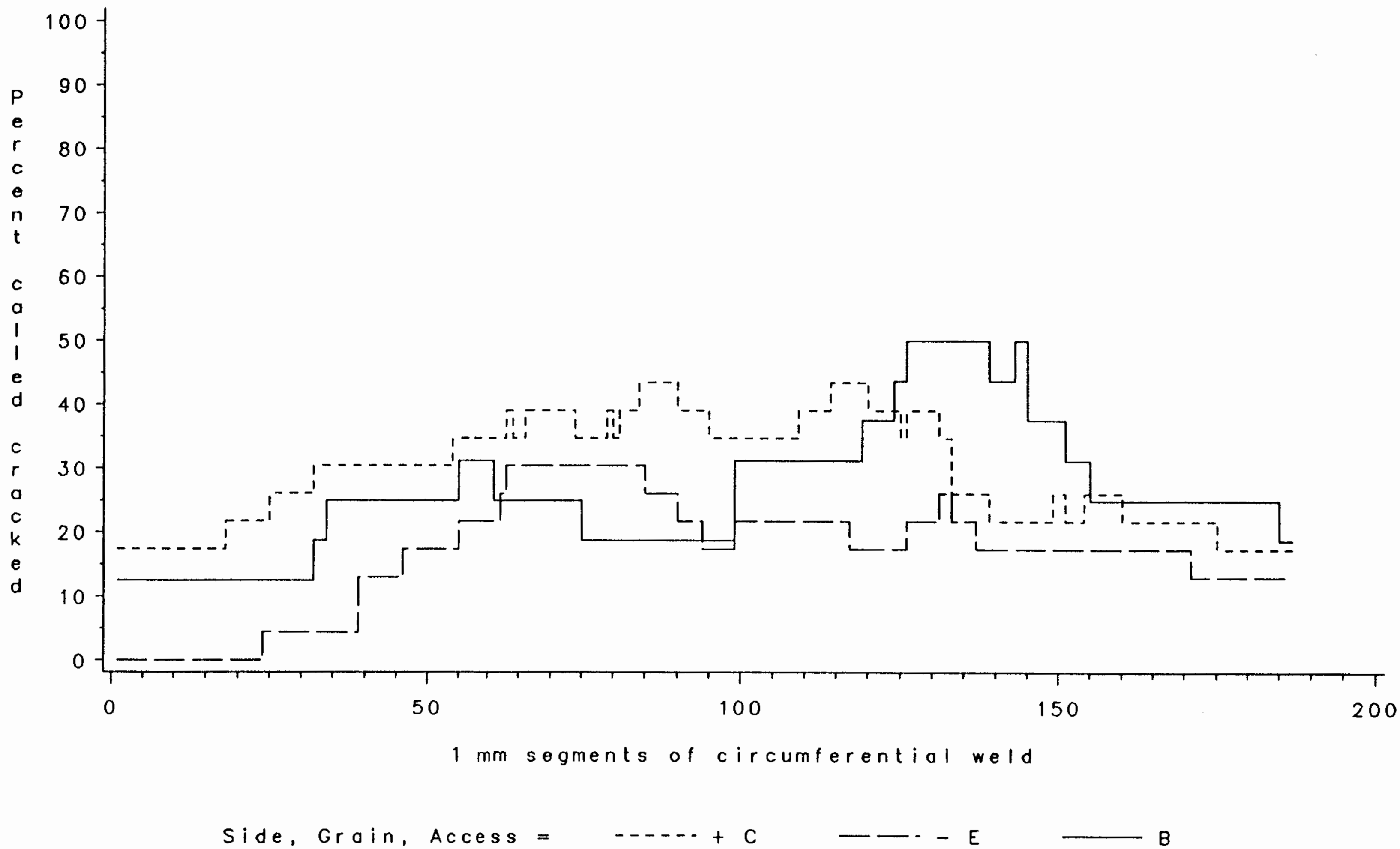
Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.6 Summary of Crack Calls for Specimen 6



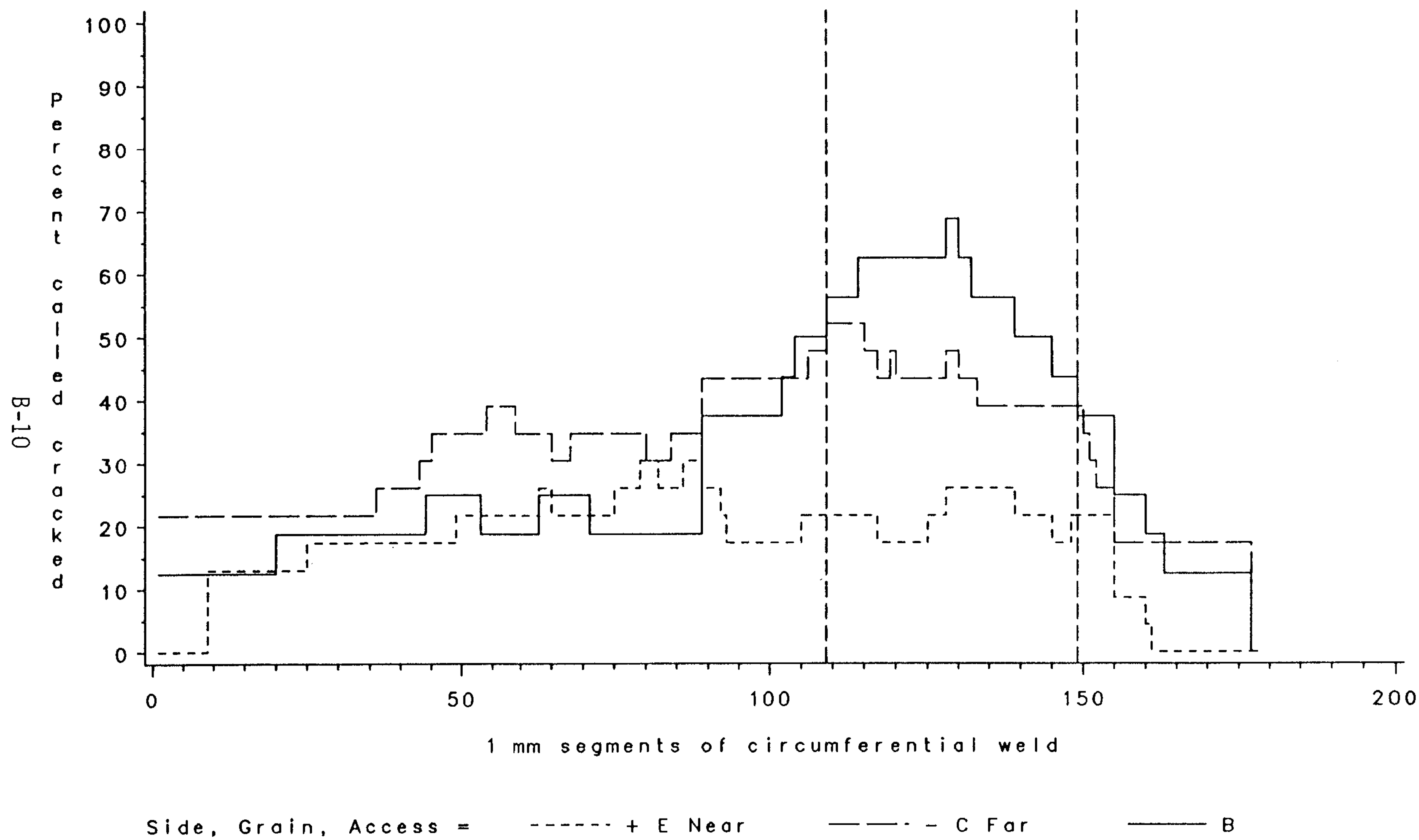
Vertical broken lines are boundaries of crack
23 Single-side inspections, 16 Both-side inspections
FIGURE B.7 Summary of Crack Calls for Specimen 7



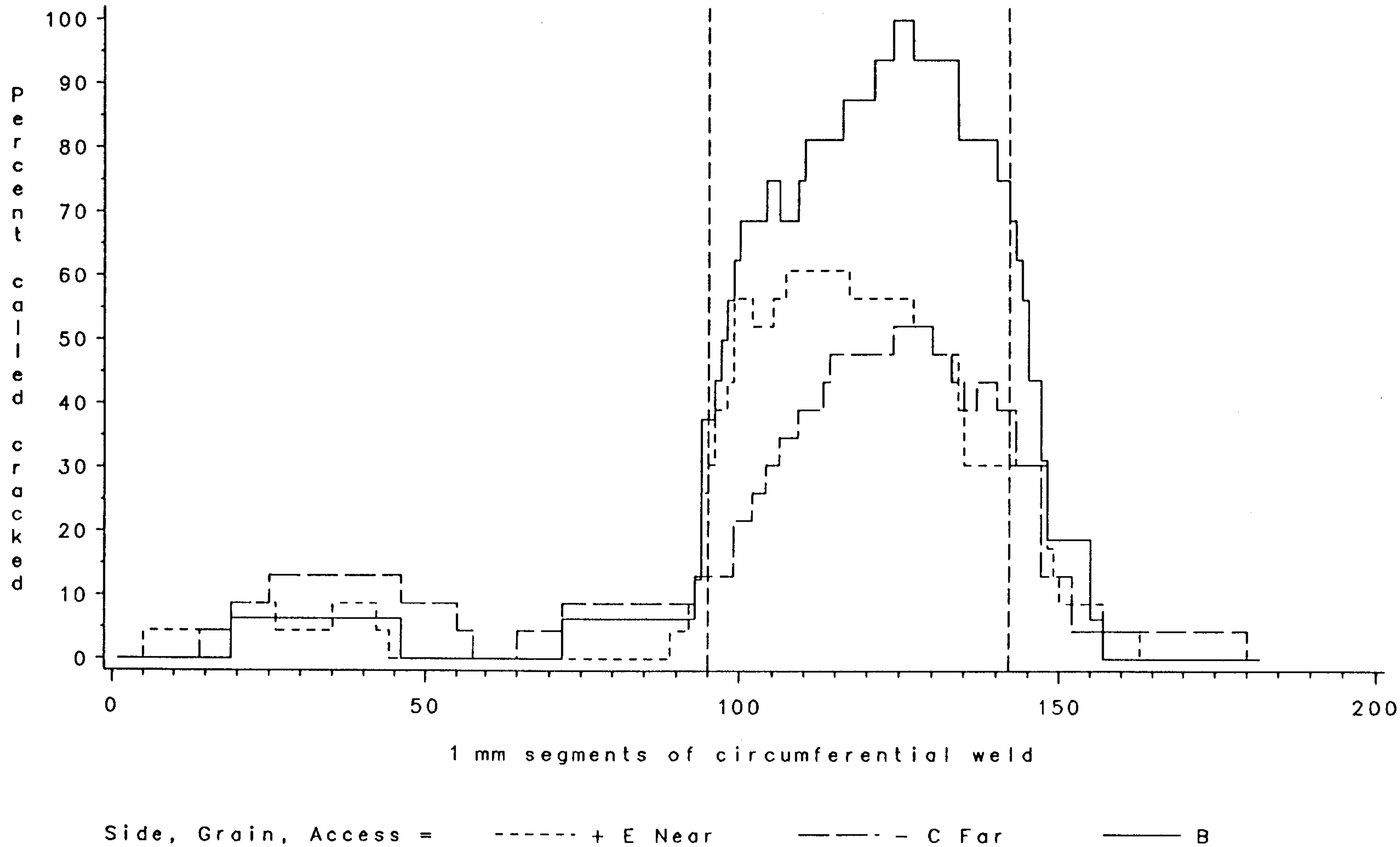
Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.8 Summary of Crack Calls for Specimen 8



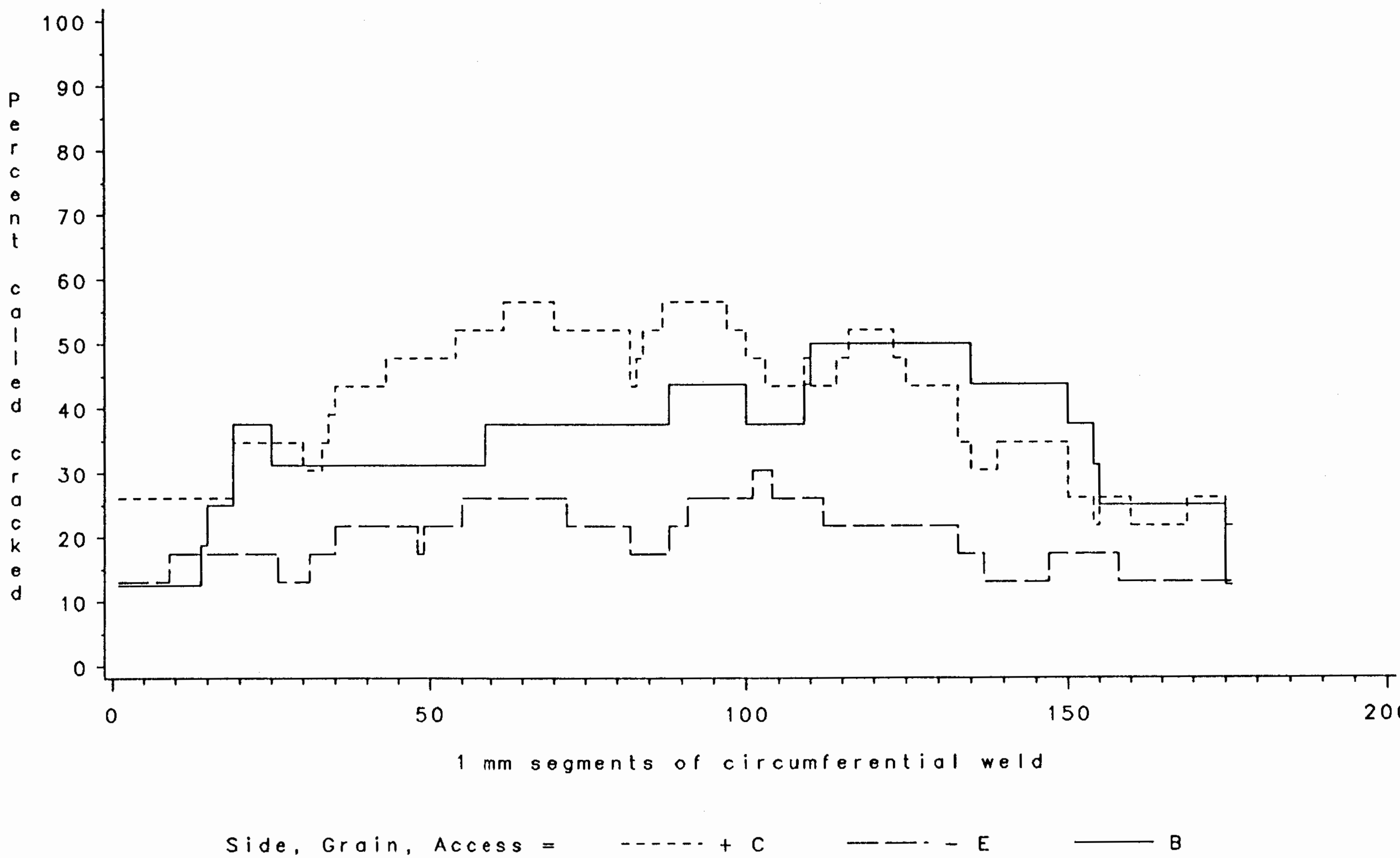
Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.9 Summary of Crack Calls for Specimen 9



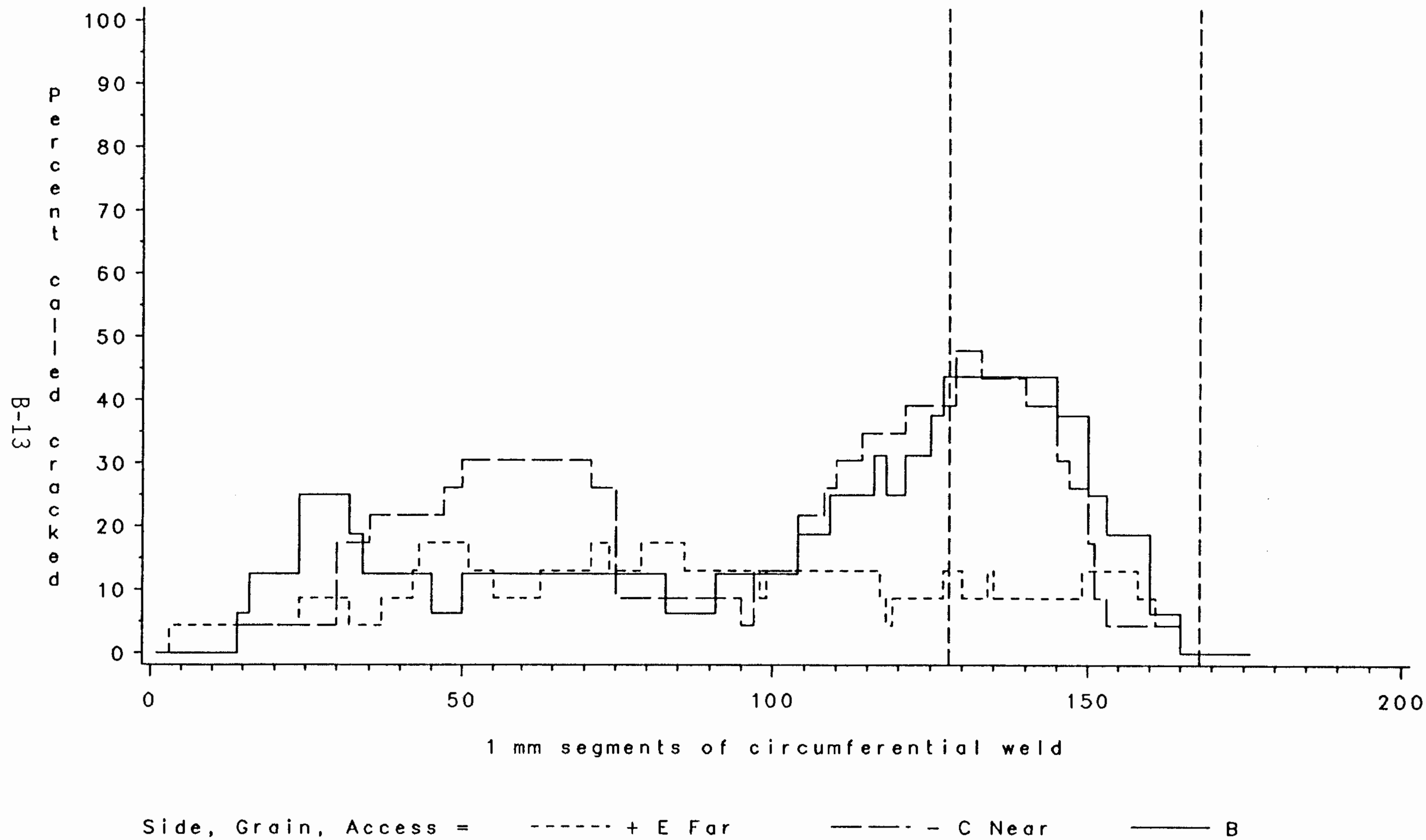
Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.10 Summary of Crack Calls for Specimen 10



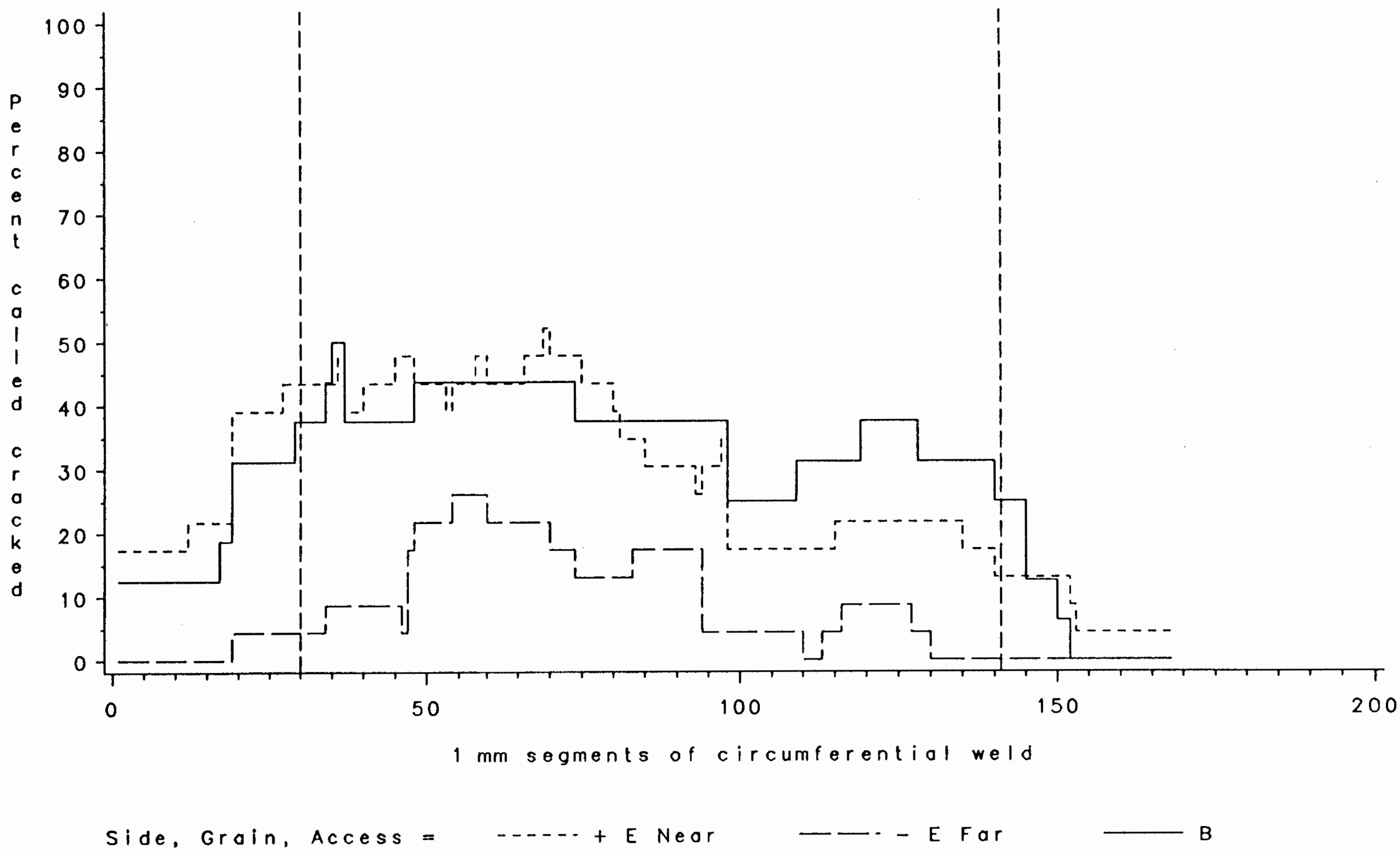
Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.11 Summary of Crack Calls for Specimen 11



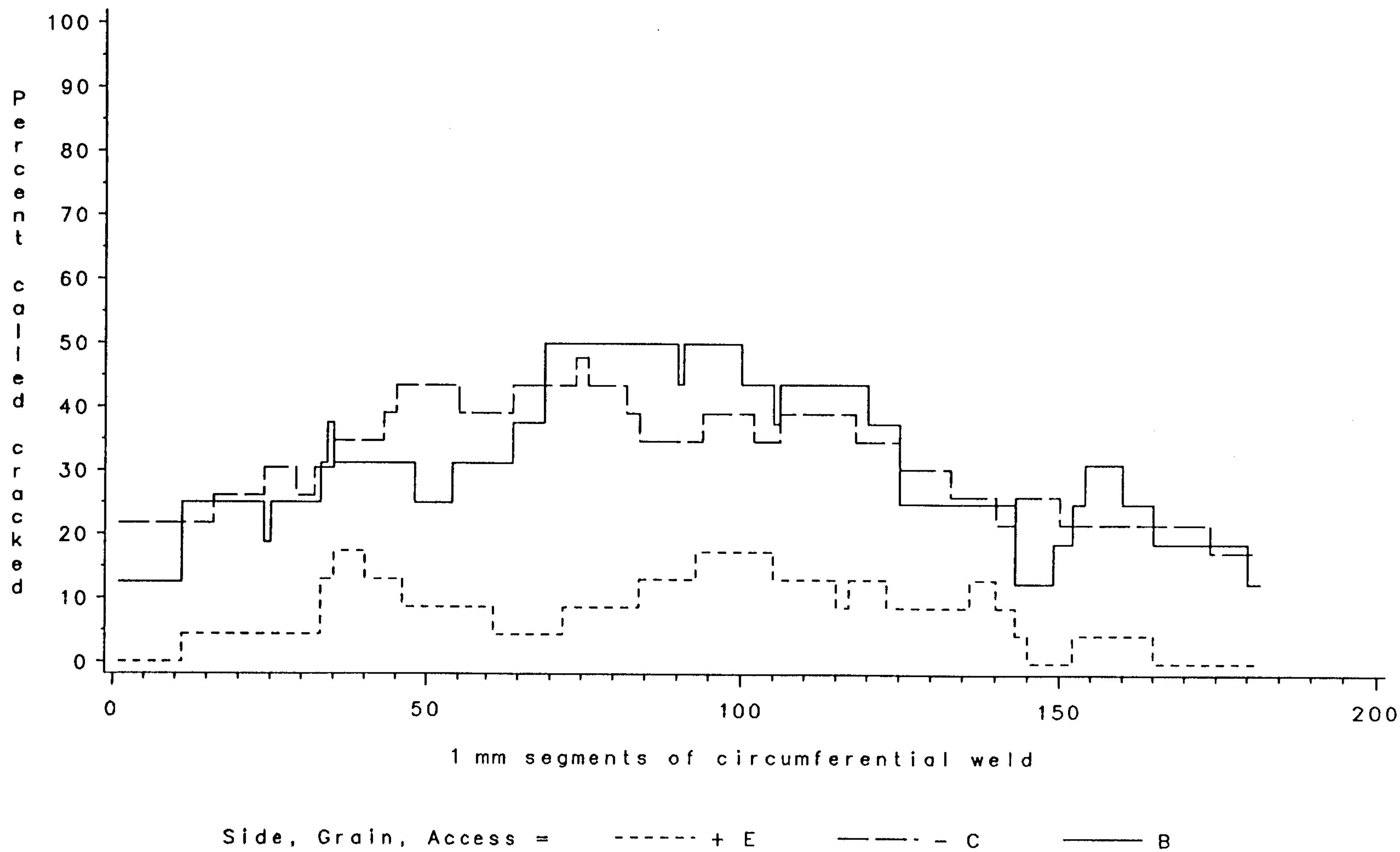
Vertical broken lines are boundaries of crack
23 Single−side inspections, 16 Both−side inspections
FIGURE B.12 Summary of Crack Calls for Specimen 12



Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.13 Summary of Crack Calls for Specimen 13



Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.14 Summary of Crack Calls for Specimen 14



Vertical broken lines are boundaries of crack
23 Single–side inspections, 16 Both–side inspections
FIGURE B.15 Summary of Crack Calls for Specimen 15

APPENDIX C

STAINLESS STEEL ROUND ROBIN TEST PHASE I
POST-TEST EXAMINATION OF SPECIMENS AT THE JRC ISPRA

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Non Destructive Evaluation Laboratories

Originally prepared as
JRC Report SP.I.87.24/I

January 1986

TABLE OF CONTENTS

This technical report concerns the post-test examinations of the Stainless Steel Round Robin Test (SSRRT)-phase 1 specimens.

These post-test examinations are up-to-now :

a. X-ray examination,
b. Red dye penetrants,
c. Macrography.

A. Post-test X-ray examination

1. Introduction

On the first X-ray inspection of the specimens of the SSRRT, the results have been documented in the inspection report (Ref. 1) and presented at the AST group during the PISC meeting in August 1985, at Varese; they put in evidence some discrepancies between the "intended defects" indicated by BNL and the defects detected by the X-ray inspection.
The rough surface of the specimens, the back plates and the difficulty to put in evidence by X-Ray the intended defects, due to their "nature", created many problems for the detection on the X-ray films and also showed other defects.
In order to explain these discrepancies and also to verify the existence and position of some intended defects, the AST asked the JRC Ispra to do a new X-ray inspection with the same inspection procedure as decribed in Ref.1 but with the following mechanical preparation of the specimens :

- suppress the back plates on the inner surface,
- polish the outer and inner surfaces of the specimens, around the HAZ and welding zones.

The specimens arrived at the JRC on October 9, 1985 (Nrs. 1, 6, 8, 9) and on October 21, 1985 (the others).
The preliminary results of this post X-ray inspection have been communicated to BNL by telex No. 6251 on October 17, 1985 and No. 6501 on October 25, 1985 and presented to the participants of the 2nd AST meeting at Las Vegas on November 4, 1985. Table 1 gives these results.

2. Inspection procedure

The post X-ray inspection was performed, with a linear accelerator from the outer surface of the specimens in three directions : -7,5°, +7,5° and perpendicular to the specimen (see Fig. 1).

The radiographic conditions were as follows :

Source type	: Linear accelerator VARIAN 200A
Energy	: 2 MeV
Dose	: 1000 rads
Focal spot	: 2 mm in diameter
Focal distance	: 2000 mm
Incidence	: Through single wall
Penetrameters	: 6 ISO 12, DIN 54109 Fe
Film type	: AGFA GEVAERT Structurix D2
Front screen	: Pb 0,25 mm
Back screen	: Pb 1 mm
Film size	: 240x300 mm
Film density	: 1,8 - 3,5 D

X-ray wire sensitivity : about 0,8%.

3. Final results

The final visual evaluation of radiograms evidenciated two additional defects in the specimens No. 5 and No. 7. The detailed results and remarks of the post X-ray inspections are given as follows for each specimen and summarized in Table 2.

Specimen No. 1

1. The defect described at -9 mm scribe offset by the first x-ray inspection disappeared. This defect was existing on the internal surface of the weld before polishing.

2. Post test X-ray put in evidence only 1 defect : crack offset + 3mm, defect start 30mm, defect end 118 mm (C).

Specimen No. 2

Two defects have been detected :

1. crack offset + 3mm, defect start 102mm, defect end 161mm (C).
2. defect offset + 1, + 6mm, defect start 119mm, defect end 128mm (N).

Specimen No. 3

One defect has been detected :

crack offset +2mm, defect start 106mm, defect end 141mm (C).

Specimen No. 4

One defect has been detected :

crack offset -6mm, defect start 118mm, defect end 146mm (C).
This defect is barely visible.

Specimen No. 5

Two defects have been detected :

1. crack offset + 15mm, defect start 110 mm, defect end 158 mm (C)
2. crack offset + 44mm, defect start 118 mm, defect end 144 mm (C).

Specimen No 6 : Blank.

Specimen No. 7

1. crack offset - 12mm, defect start 28mm, defect end 70mm (C)(natural defect)
2. crack offset - 17mm, defect start 123mm, defect end 147mm (C).

The two defects put in evidence are barely visible.

Specimen No. 8

After polishing (the surfaces were very bad), two defects have been detected, barely visible.

1. crack offset - 9mm, defect start 39mm, defect end 83mm (C)
2. crack offset - 2 mm, defect start 69mm, defect end 84mm (C).

Specimen No 9

Sample arrived with internal surface already polished.
After additional external and internal surface polishing, the defect situated at - 8mm crack offset (1st x-ray inspection) disappeared; this defect was probably a surface defect. The specimen is blank.

Specimen No. 10

The defect situated at -3 mm scribe offset (1st X-ray inspection) disappeared. This defect was probably a surface defect.
The post test X-ray examination put in evidence the following two defects :

1. crack offset - 5mm, defect start 111mm, defect end 149mm (C)
2. defect offset - 1 to - 13mm, defect start 120mm, defect end 131 mm (N).

Specimen No. 11

One defect has been detected :

crack offset + 2 mm, defect start 95 mm, defect end 140 mm (C).

Specimen No. 12

This specimen is blank.

Specimen No. 13

One defect has been detected :

crack offset - 19mm, defect start 128mm, defect end 160mm (C).

Specimen No. 14

1. crack offset + 29 mm, defect start 30 mm, defect end 140mm (C)
2. defect offset - 31mm, defect start 78mm, defect end 80mm (N).

Specimen No. 15

This specimen is blank.

The post-test X-ray results are given in Table 2; in this table, the "non cracks" found in specimens 2, 10 and 14 are not listed; moreover, the values of the weld offsets are not those given by BNL but those measured by JRC on the macrographies.

Reference

1. P.Jehenson and F. Violin
   X-ray examination of welded pieces in the framework of the stainless steel round robin test (JRC Ispra, N.D.E. Laboratories, August 1985).

B. Post-test examination of the SSRRT-Phase 1 specimens with Red dye penetrants

In December 1985, as the back plates were suppressed, the JRC-NDE Laboratories performed an inspection of the inner surface of the welded zone on the SSRRT specimens (phase 1); red dye penetrants were used.
The MET-L-CHEK technique was applied, using the VP-30 penetrant and the D-70 developer; this technique meets the ASME code nuclear.

Results

The results of this inspection on the 15 specimens are shown on Figs. 2-16 and confirmed mainly the existence and position of all intended defects. Many other cracks are visible on the figures but they are only superficial cracks created during the fabrication process of the intended defects.
Moreover, in some cases (for instance : Fig. 2, Fig. 14), two external alignments of cracks are put in evidence; these cracks may be interpreted as corresponding to the existing counterbores.
The results are summarized in Table 2 and so, it is possible to have a direct comparison between :

- intended cracks (BNL),
- cracks put in evidence by the post-test X-ray examination (JRC),
- cracks put in evidence by the red-dye penentrants (JRC).

For this comparison, please note that the crack start and crack end indications in Table 2 given for the red dye penetrant measurements are corrected values, taking into account the decrease of the weld length due to mechanical preparation of the specimens for macrographic inspection and due to the fact that the measurements have been taken on the inner surface of the specimens, while the intended defects (BNL) and the JRC post X-ray values are related to the outer surface.

C. Post-Test macrographic inspection of the SSRRT-Phase 1 specimens

1. Introduction

The results of the ultrasonic inspections on the 15 specimens gave rise to some doubts on wether or not the high rate of so-called "false calls" found in specimens which should be without cracks - was not due to changes of the structure (columnar or equiaxed) through the thickness of the specimens. The JRC-NDE laboratories were asked at Las Vegas, in November 1985, to execute the macrographic inspection on one side of each specimen.

2. Procedure

The following mechanical and chemical procedure was applied for this inspection performed in December 1985 on the 15 specimens and on the reference specimen in January 1986.

- One lateral side of each specimen was milled (up to 3 mm depth) before smoothing this surface with emery paper.

- Etching

A mixture of : 90% HCL (concentration : 37%) at about 80^{o}C
and 10% H_2O_2 at about 20^{o}C, reacted with the polished surface during about 1,5 to 2 minutes; this reaction time was defined by visual inspection.
Directly after this etching, a cleaning of this surface was realised using water alcohol, with consecutive drying.

3. Results

Pictures were taken using a 9x12 Linhof camera with an Agfapan 25 film and printed on Brovira BH paper using Refinal development.
Figs. 17 to 32 represent the macrographies obtained on the 16 specimens.

These macrographies may perhaps give the participants of the SSRRT some complementary information when re-examining the results of their ultrasonic inspection for the different specimens.
Nevertheless, a general impression may be drawn from these macrographies. The columnar macrostructure does not seem to change essentially from one specimen to another while the equiaxed macrostructure seems to be slightly different for the different specimens and shows also alterations through the thickness of the specimen, mainly at the bottom of the weld.
Moreover, specimen No. 11 shows a different welding macrostructure when compared with the other specimens.

D. General considerations made by P. JEHENSON

1. The Post-Test X-ray examinations have given results in good agreement with the "intended results". As we said during the meeting in August 1985 at Varese, polishing the surfaces and suppressing the back plates gave the possibility to obtain better X-ray results.

2. The macrographies only give a general idea on the "texture d'orientation d'ensemble". Instead of asking for macrographies, it should be better, for people trying to understand their own ultrasonic results, to receive informations on :

   a. grain size measurements and variation along the principal ultrasonic paths in the equiaxed base material, in the columnar base material and also for both materials in the bottom of the Heat Affected Zone (HAZ).

   b. The possible anisotropy corresponding to the orientation of the directions of the crystals reticular planes, using the X-ray diffraction method on some specimens well choosen. This may only be realized after the real destructive examination will be decided.

   c. Il will be also important to decide as soon as possible on the destructive examination of some specimens, not only of a blank specimen but also, for instance, of one or two other specimens well choosen. This will also permit to do micrographic examination and X-ray diffraction as defined hereabove.

List of tables and figures

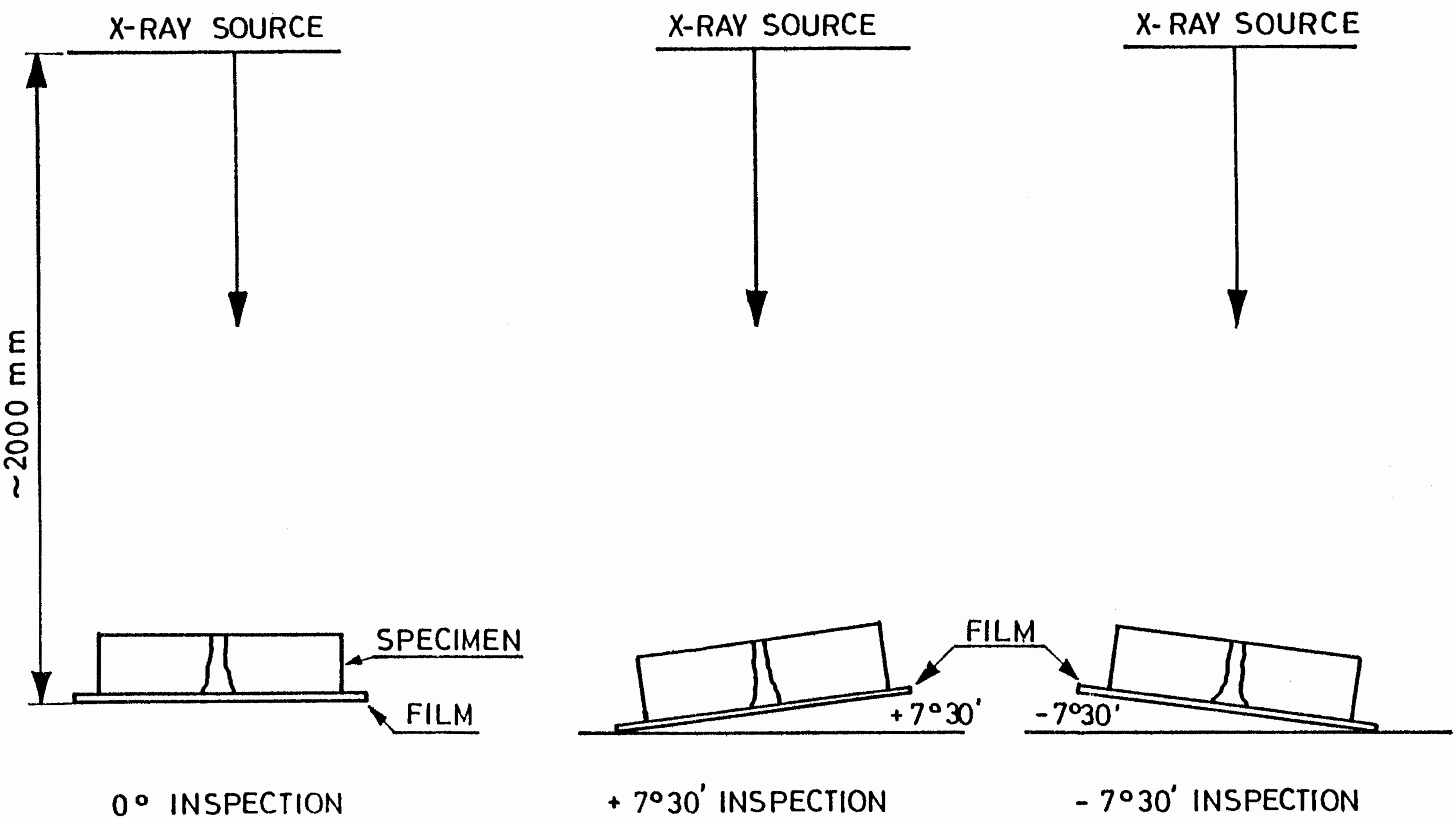

X-RAY SOURCE
X-RAY SOURCE
X-RAY SOURCE
~2000 mm
SPECIMEN
FILM
FILM
+7°30'
-7°30'
0° INSPECTION
+ 7°30' INSPECTION
- 7°30' INSPECTION

FIG. 1

Table 1 - SSRRT - INTENDED DEFECTS (BNL - JRC 2nd) Oct. 1985

Specimen			Weld Length mm	Weld offset mm BNL	Crack offset mm		Crack start mm		Crack end mm		Crack depth % BNL
No	-	+			BNL	JRC	BNL	JRC	BNL		
1	E	E	168	0	3	3	40	30	121	118	-
2	E	C	188	- 1	1	3	112	102	167	161	35
3	C	E	191	1	4	2	110	106	147	141	23
4	C	E	177	- 10	- 12	- 6	126	118	152	146	21
5	E	C	191	15	16	15	104	110	172	158	28
6	E	C	178	- 1	-	-	-	-	-	-	-
7	C	E	177	- 14	- 16	- 12	22	28	57	70	23
8	E	C	186	1	- 2	- 2	28	69	92	84	28
8	E	C	186	1	-	- 9	-	39	-	83	
9	E	C	187	- 1	-	-	-	-	-	-	-
10	C	E	178	- 8	- 5	- 5	111	111	140	149	23
11	C	E	182	0	1	2	108	95	142	140	28
12	E	C	- 6	-	-	-	-	-	-	-	-
13	C	E	176	- 16	- 19	- 19	137	128	168	160	-
14	E	E	169	25	28	29	34	30	141	140	-
15	C	E	182	5	-	-	-	-	-	-	-

Table 2 : Comparison of the crack dimensions and positions obtained by different inspection techniques

Specimen No	Specimen -	Specimen +	Original Weld Length mm	Weld offset mm (JRC)	Crack offset BNL	Crack offset JRC XRay Post	Crack offset JRC Red dye pen.	Crack start BNL	Crack start JRC XRay Post	Crack start JRC Red dye pen.	Crack end BNL	Crack end JRC XRay Post	Crack end JRC Red dye pen.	REMARKS
1	E	E	168	- 4	+ 3	+ 3	- 1	40	30	43	121	118	118	
2	E	C	188	- 2	+ 1	+ 3	+ 1	112	102	98	167	161	158	
3	C	E	191	+ 2	+ 4	+ 2	+ 2	110	106	111	147	141	145	
4	C	E	177	- 10	- 12	- 6	- 9	126	118	119	152	146	139	very poor visibility
5	E	C	191	+ 21	+ 16	+ 15	+ 17	104	110	99	172	158	155	
5	E	C	191	+ 21	-	+ 44	-	-	118	-	-	144	-	external defect
6	E	C	178	- 3	-	-	-	-	-	-	-	-	-	
7	C	E	176	- 14	- 16	- 17	- 16	22 ** (119)	123	115	57** (154)	147	143	very poor visibility
7	C	E	176	- 14	-	- 12	-	-	28	-	-	70	-	natural defect
8	E	C	186	- 2	- 2	- 2	- 2	28	69	72	92	84	84	very poor visibility
8	E	C	186	- 2	-	- 9	- 5	-	39	32	-	83	83	very poor visibility
9	E	C	187	- 2	-	-	-	-	-	-	-		-	
10	C	E	178	- 6	- 5	- 5	- 4	111	111	109	140	149	145	
11	C	E	182	+ 3	+ 1	+ 2	+ 6	108	95	100	142	140	132	
12	E	C	176	- 7	-	-	-	-	-	-	-	-	-	
13	C	E	176	- 18	- 19	- 19	- 19	137	128	132	168	160	158	
14	E	E	168	+ 27	+ 28	+ 29	+ 28	34	30	38	141	140	133	
15	C	E	182	- 6	-	-	-	-	-	-	-	-	-	

* The crack start and crack end indications for the liquid penetrant measurements are corrected values taking into account, the decrease of the weld length due to mechanical preparation for macrographic inspection and due to the fact that they have been taken on the inner surface of the specimens, while the BNL and JRC X-Ray post values are related to the outer surface.

** These BNL values have been measured from the opposite side to the 0 point. The corrected values in brackets are obtained by calculating weld length minus crack start (crack end).

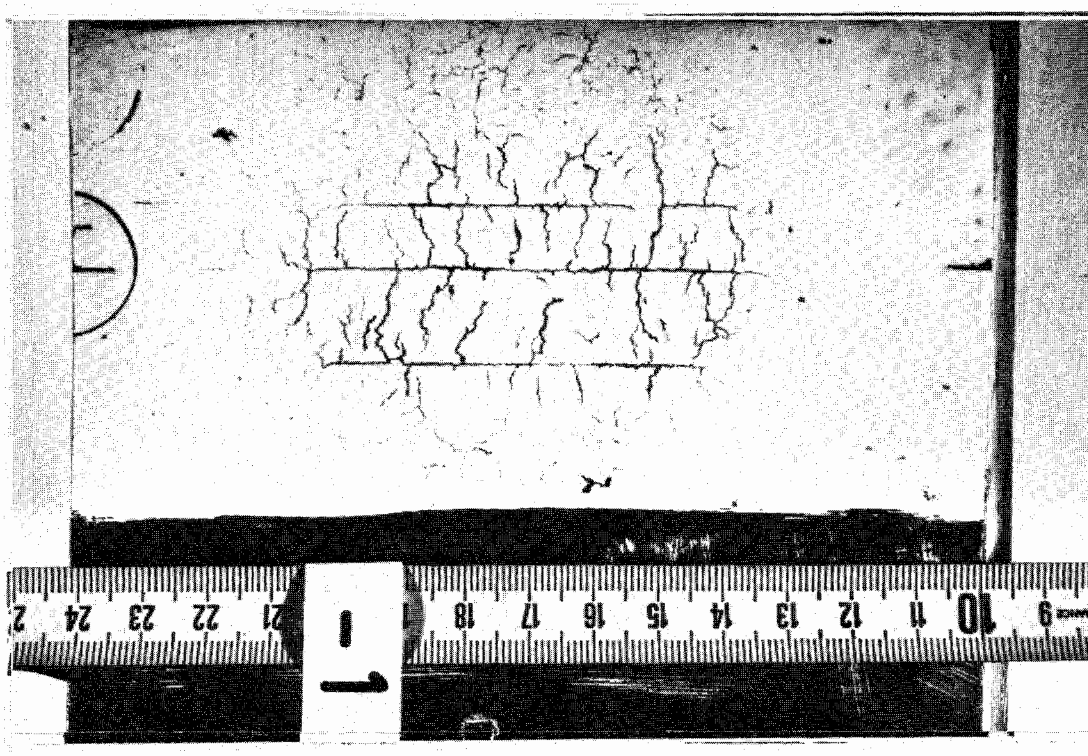


Fig. 2 : Specimen No. 1 : crack offset : - 1 mm
crack start : 43 mm corrected values
crack end : 118 mm

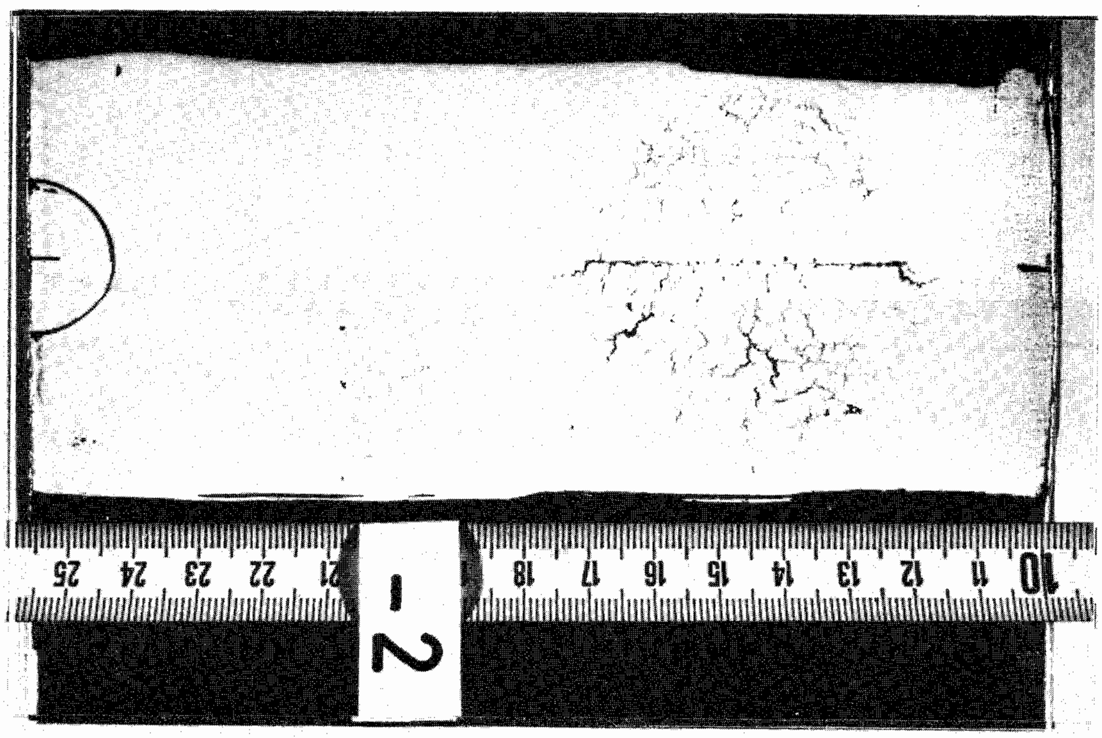


Fig. 3 : Specimen No. 2 : crack offset : + 1 mm
crack start : + 98 mm corrected values
crack end : + 158 mm

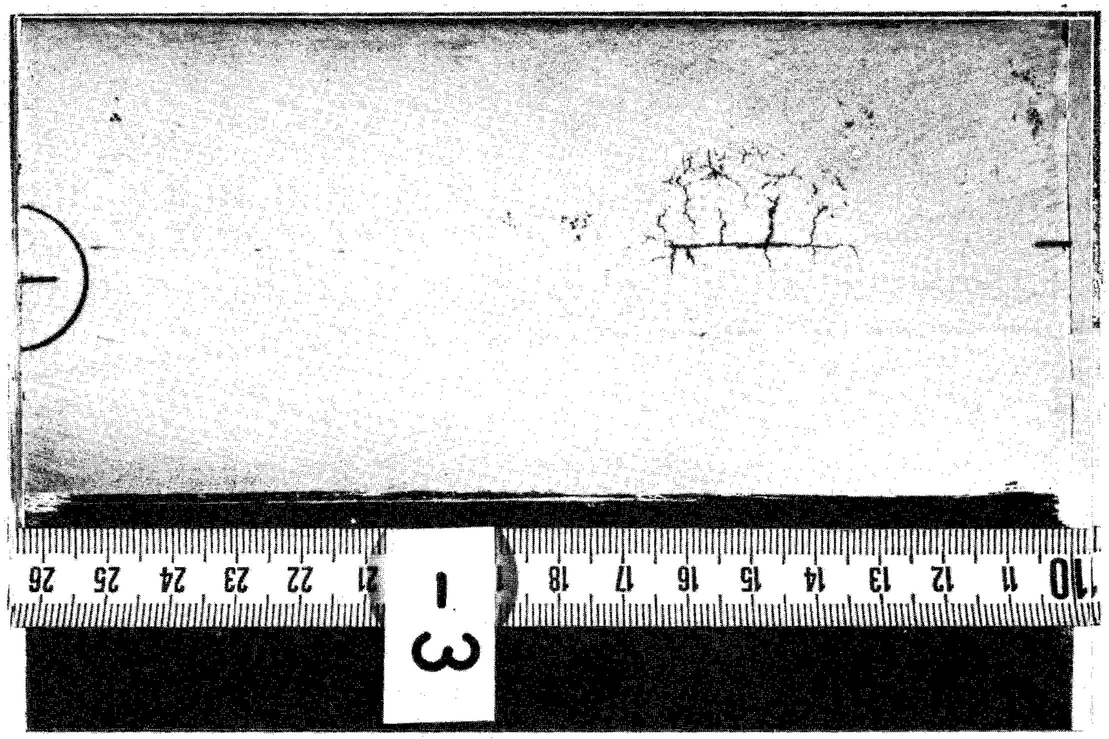


Fig. 4 : Specimen No. 3 : crack offset : + 2 mm
crack start : 111 mm corrected values
crack end : 145 mm

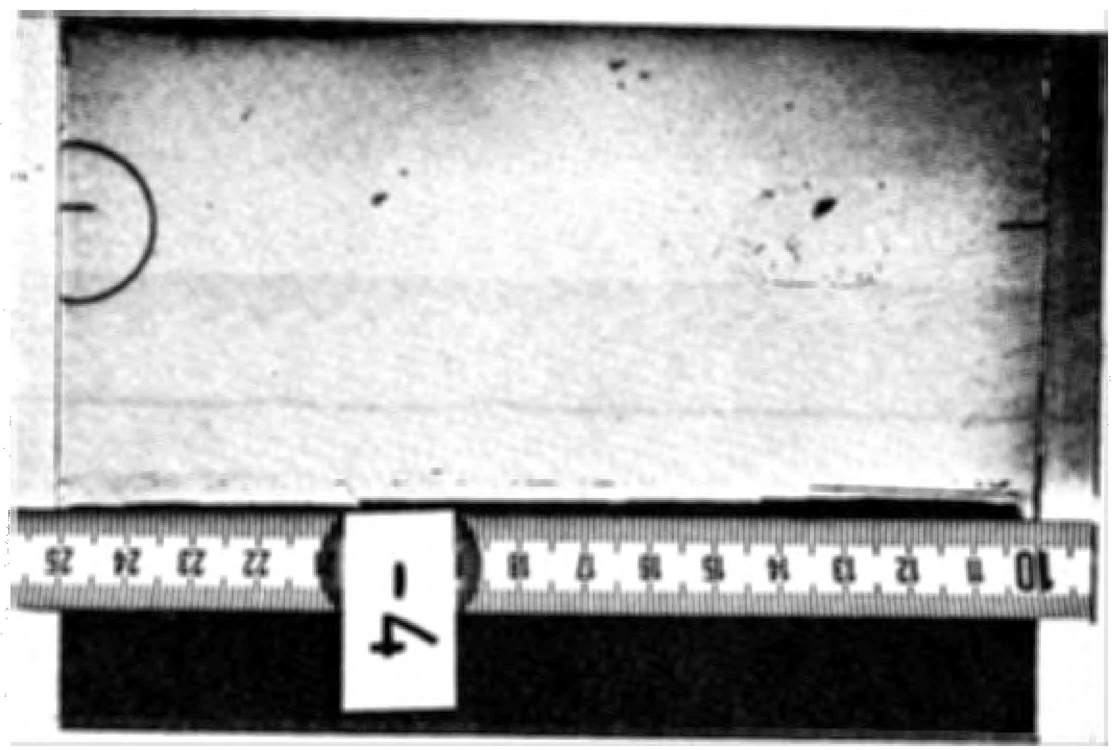


Fig. 5 : Specimen No. 4 : crack offset :-9 mm
crack start : 119 mm corrected values
crack end : 139 mm

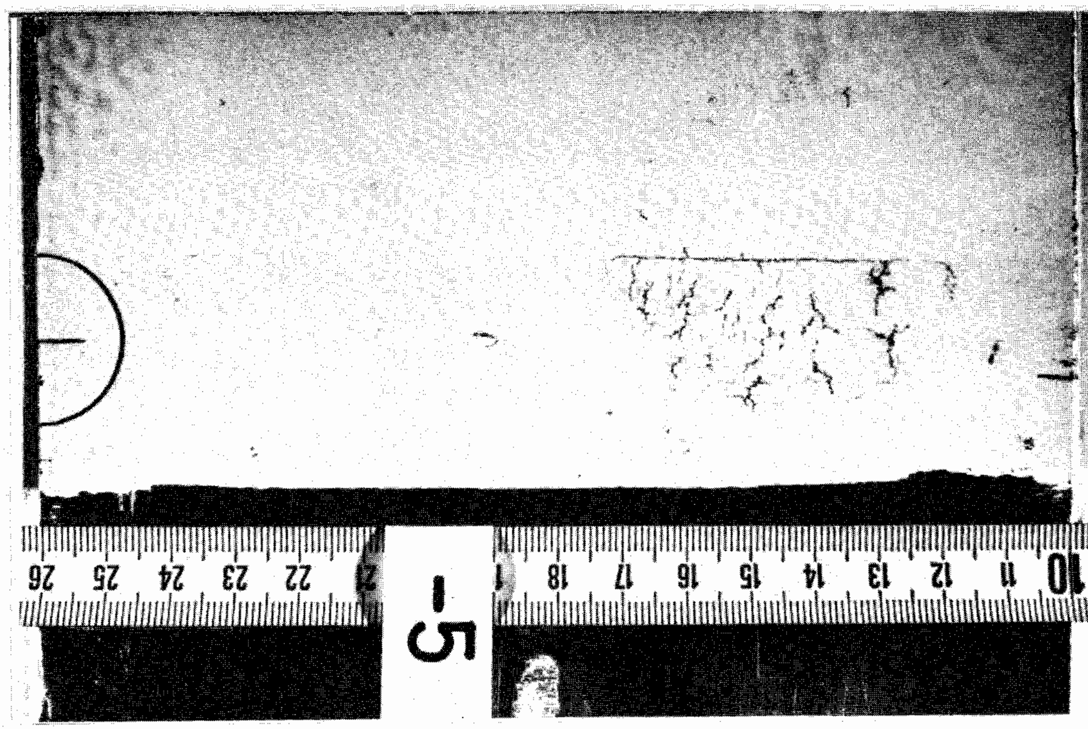


Fig. 6 : Specimen No. 5 : crack offset : + 17 mm
crack start : 99 mm corrected values
crack end : 155 mm

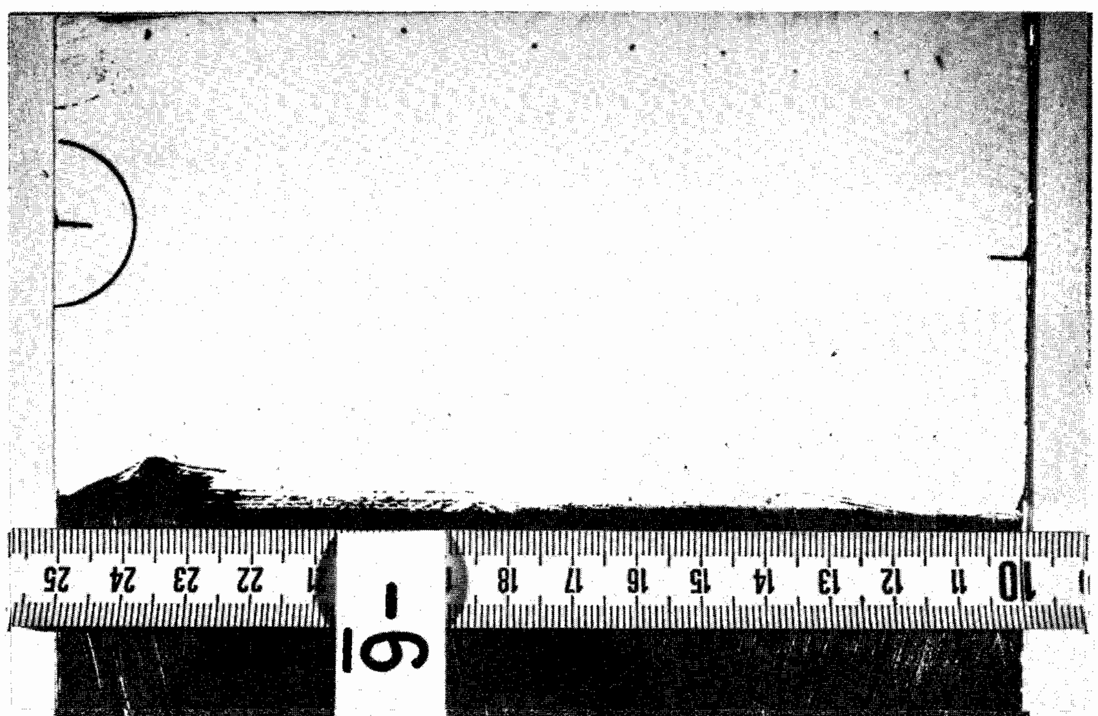


Fig. 7 : Specimen No. 6 : blank

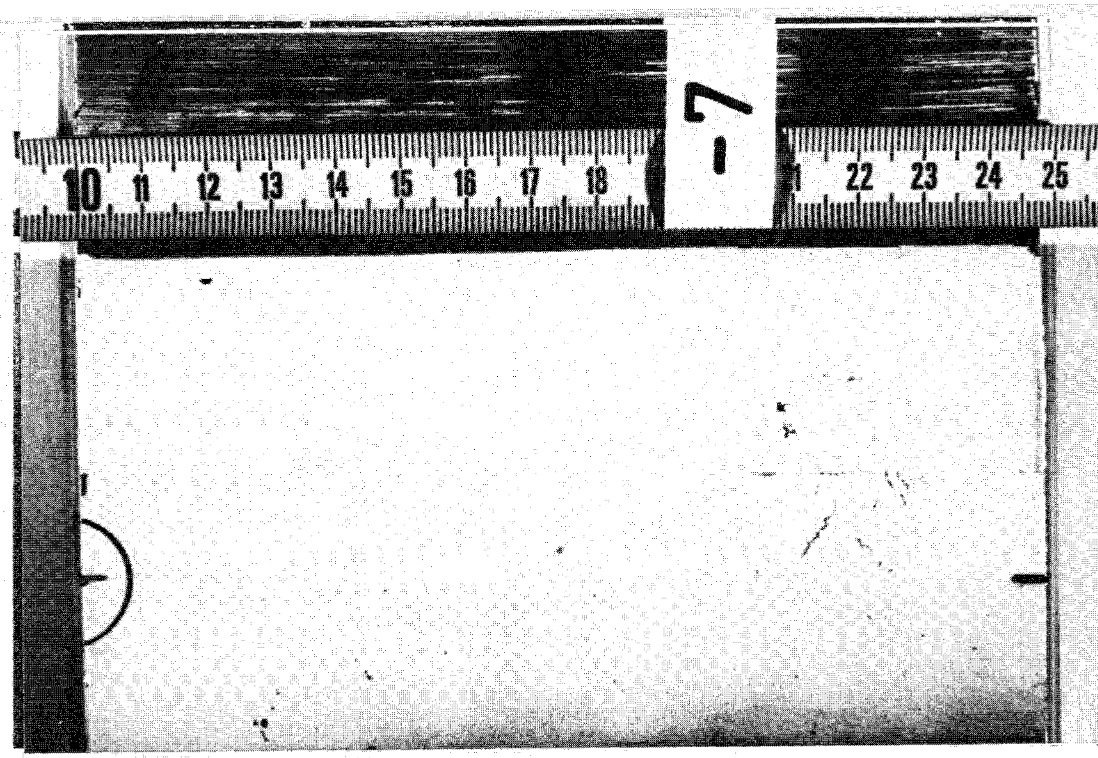


Fig. 8 : Specimen No. 7 : crack offset : - 16 mm
crack start : 115 mm corrected values
crack end : 143 mm

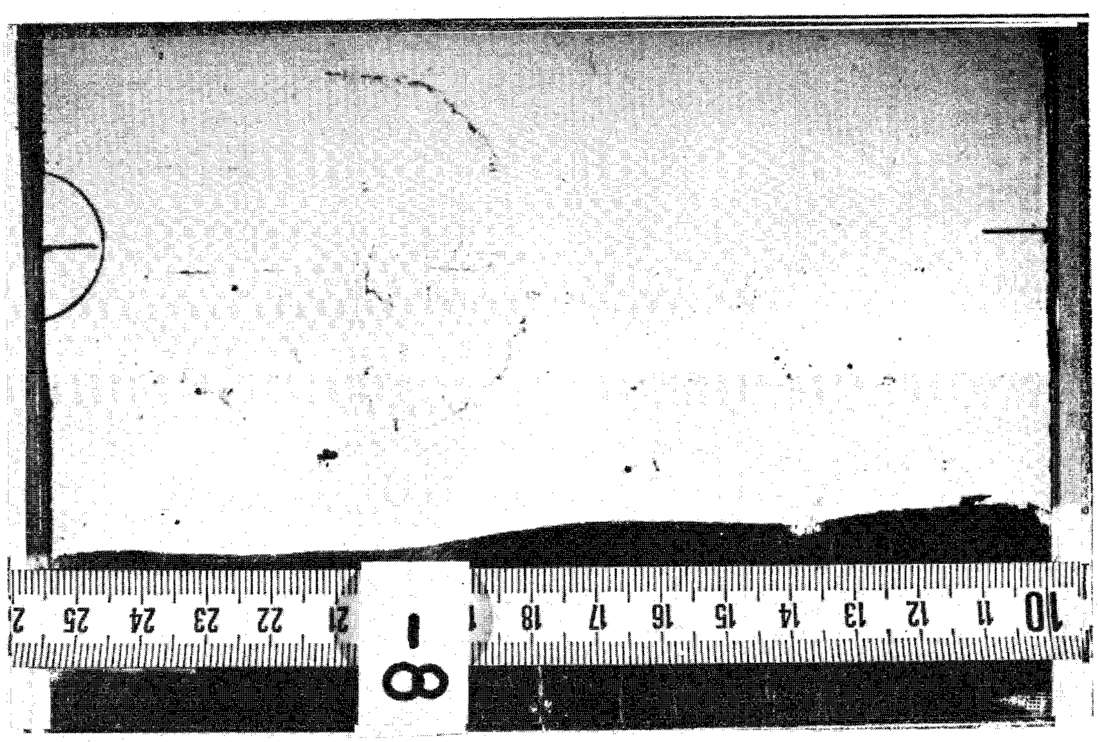


Fig. 9 : Specimen No. 8 : crack offset : - 5 mm
crack start : 32 mm corrected values
crack end : 83 mm
crack offset : - 2 mm
crack start : 72 mm
crack end : 84 mm

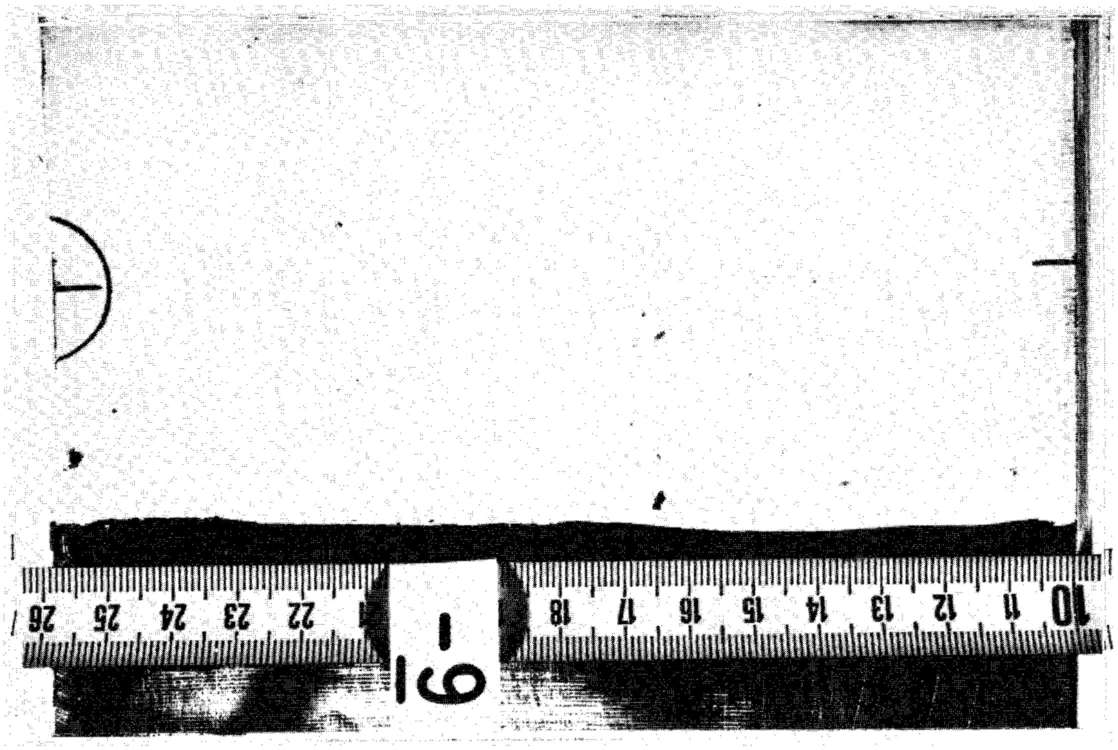


Fig. 10 : Specimen No. 9 : blank

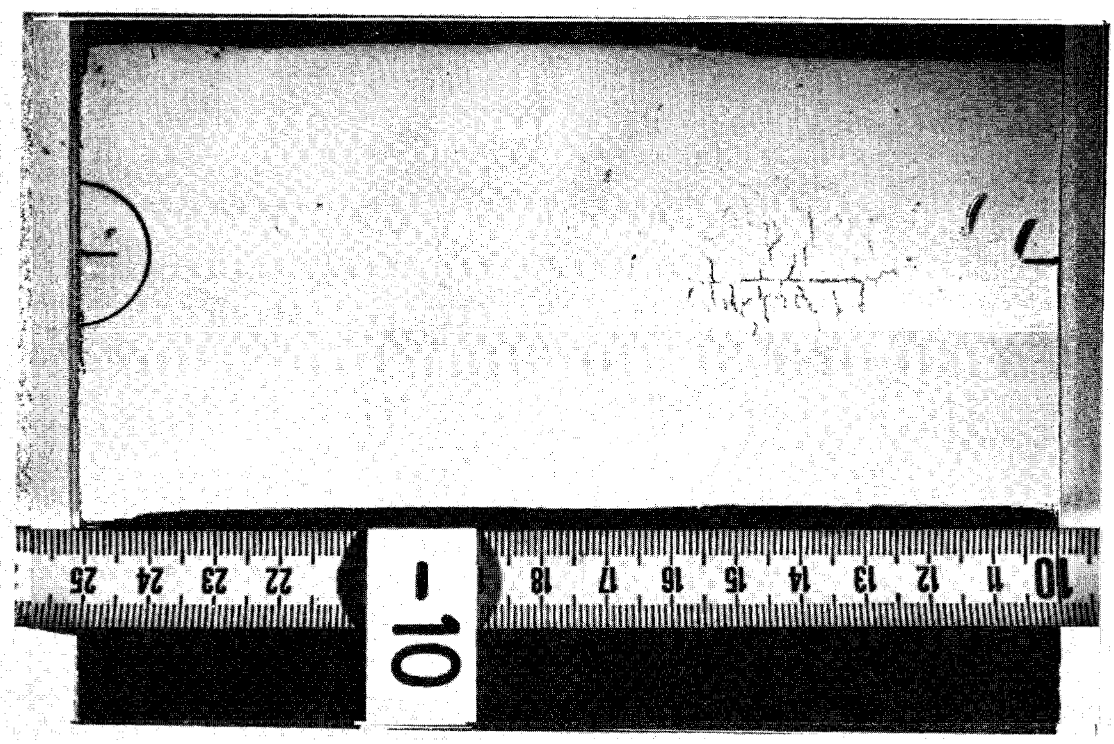


Fig. 11 : Specimen No. 10 : crack offset : - 4 mm
crack start : 109 mm corrected values
crack end : 145 mm

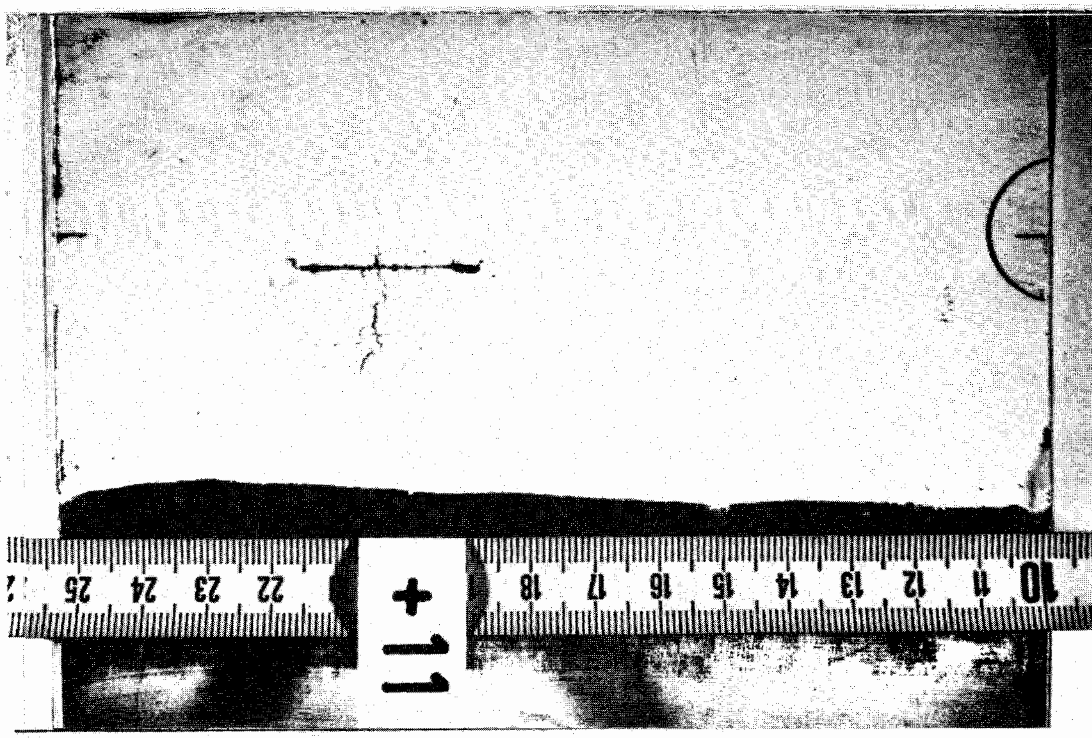


Fig. 12 : Specimen No. 11 : crack offset : + 6 mm
crack start : 100 mm corrected values
crack end : 132 mm

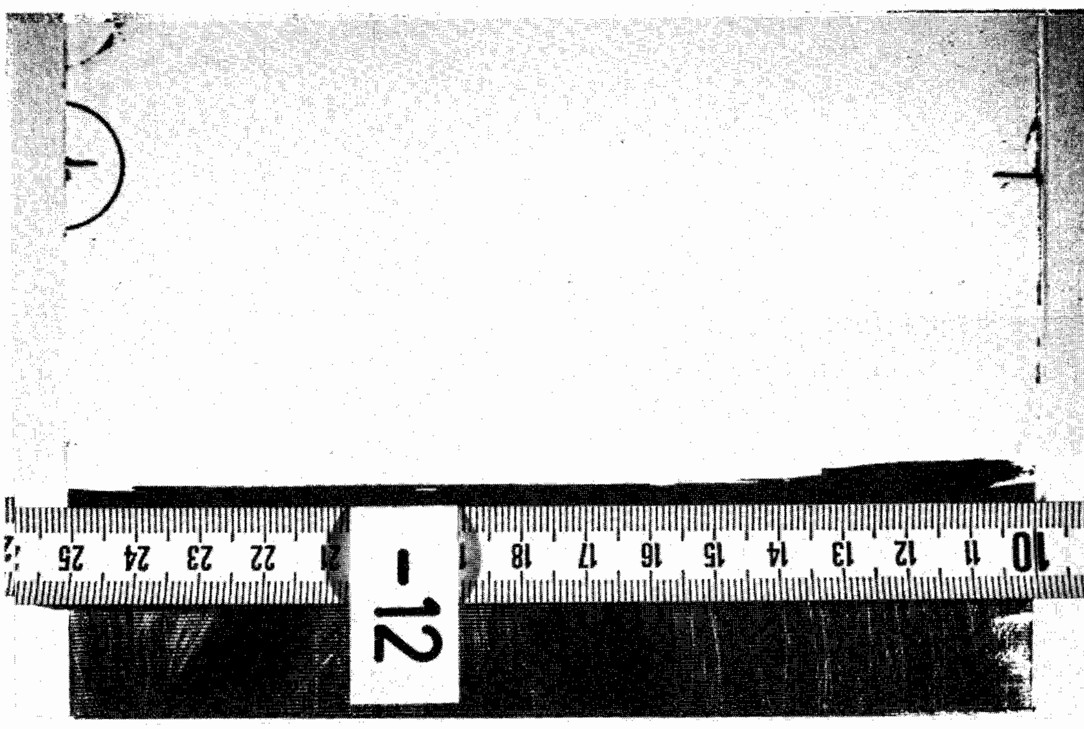


Fig. 13 : Specimen No. 12 : blank

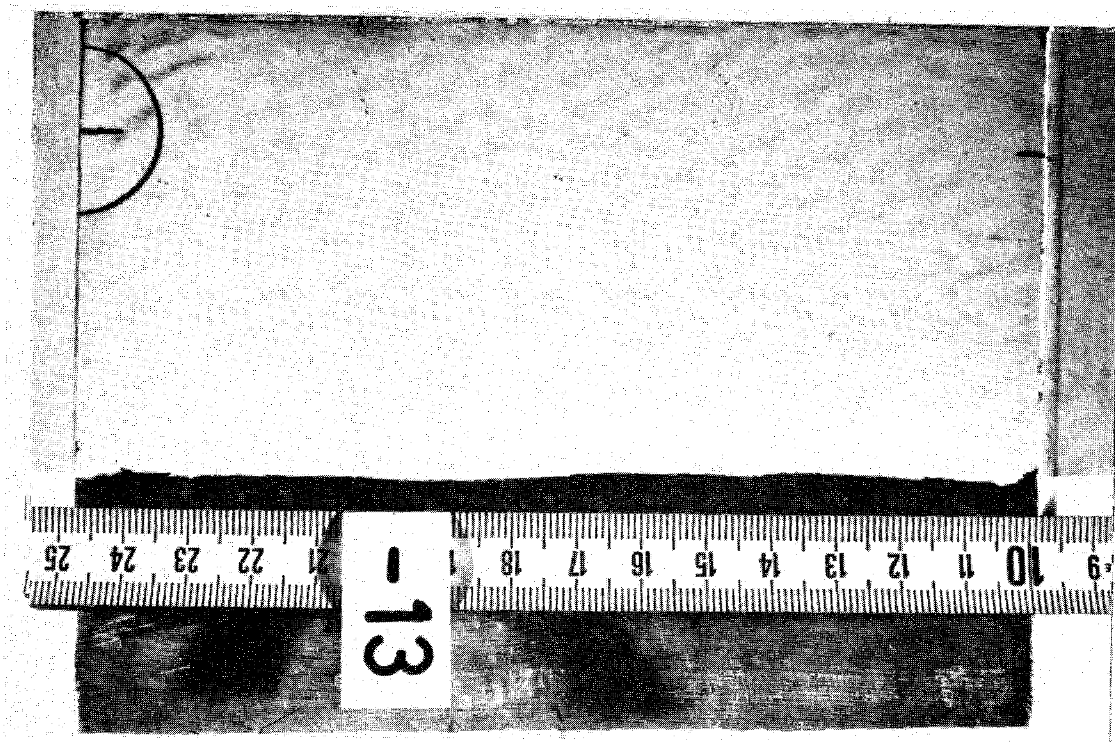


Fig. 14 : Specimen No. 13 : crack offset : - 19 mm
crack start : 132 mm corrected values
crack end : 158 mm

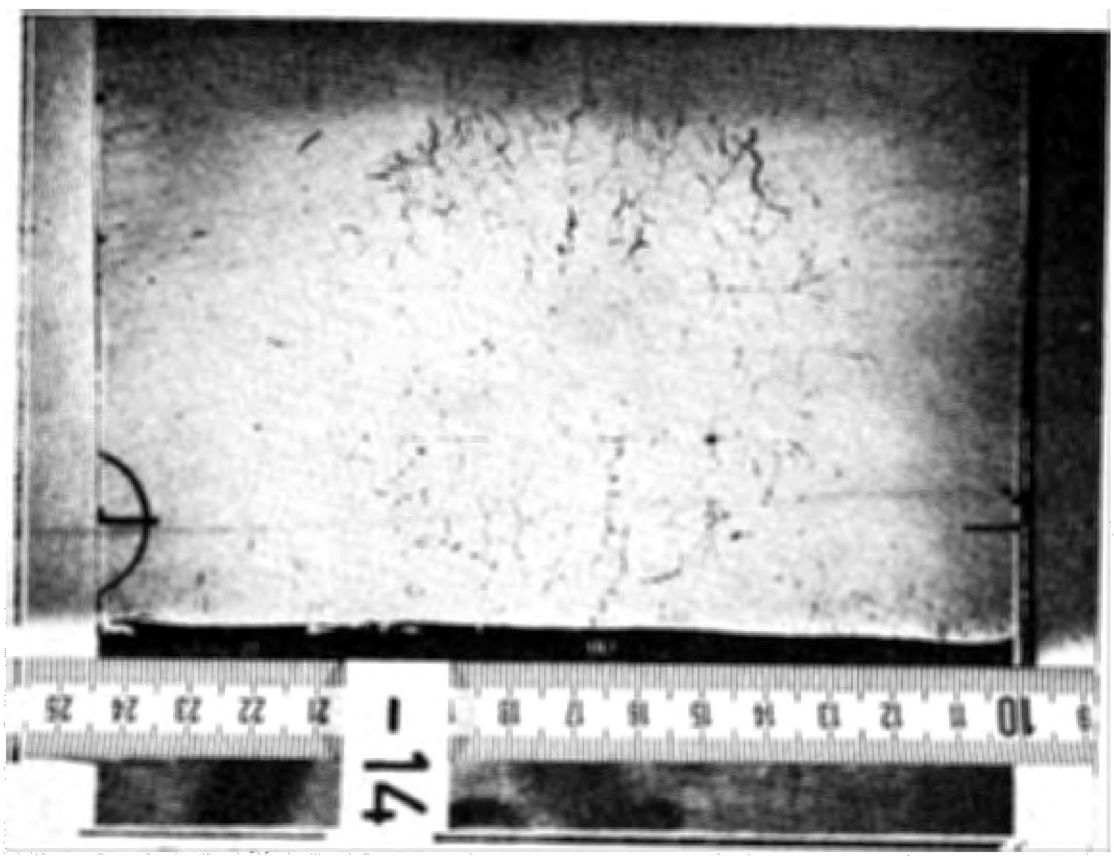


Fig. 15 : Specimen No. 14 : crack offset : + 28 mm
crack start : 38 mm corrected values
crack end : 133 mm

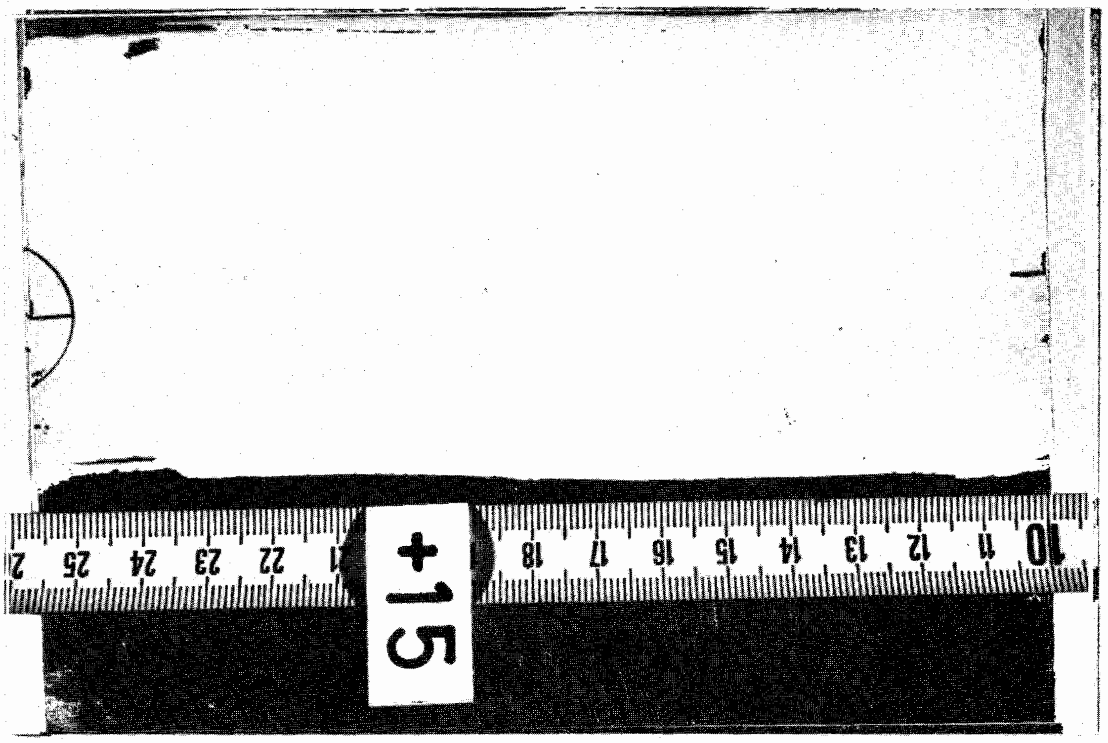
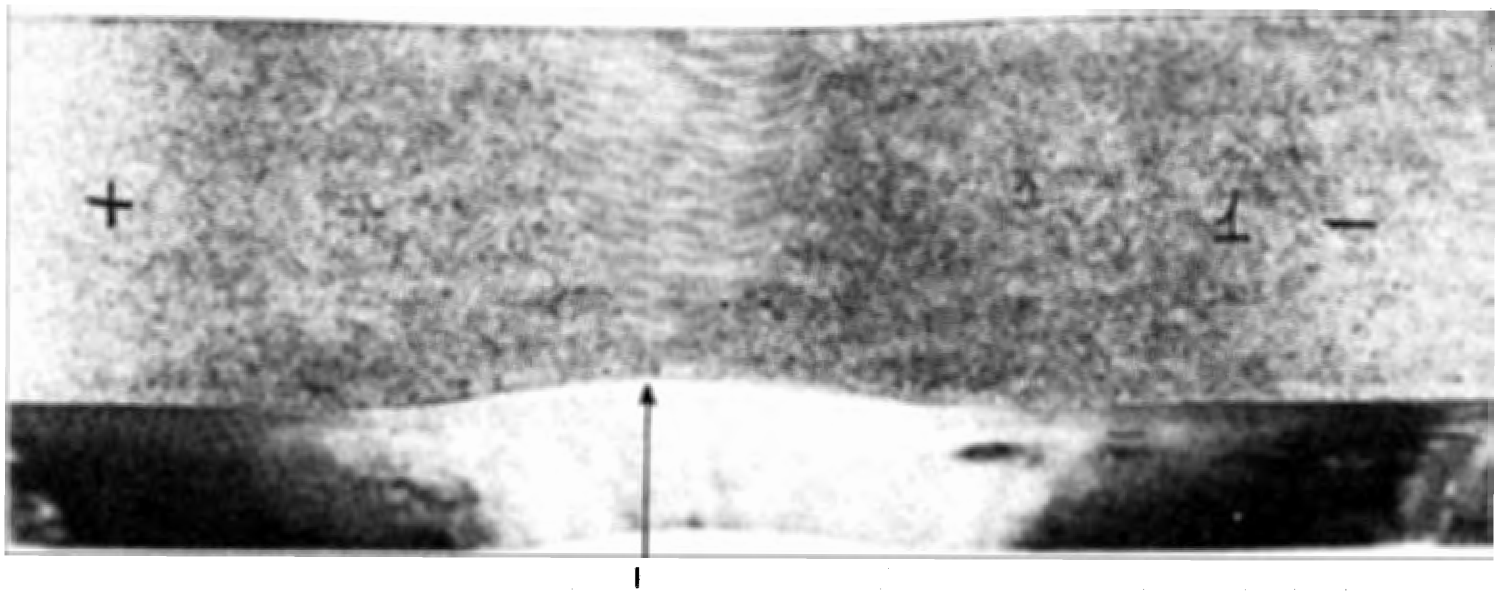
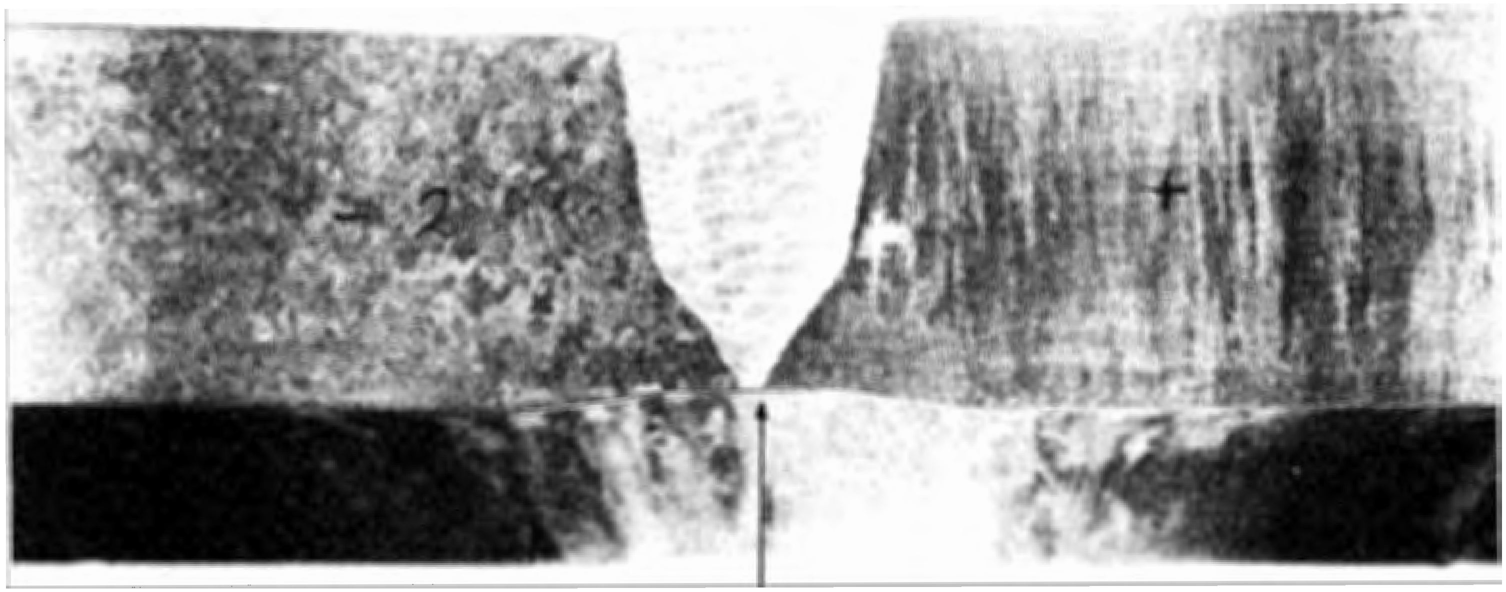


Fig. 16 : Specimen No. 15 : blank



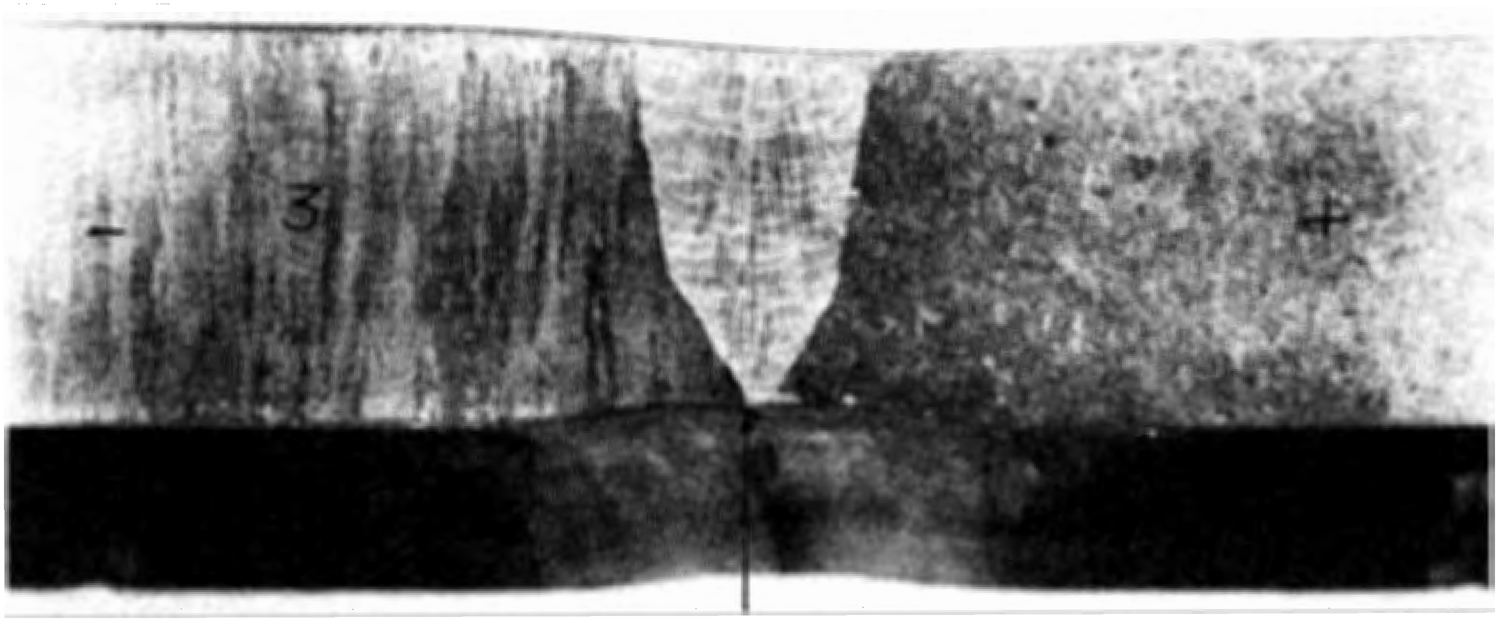
SPECIMEN: 1　　SCRIBE LINE　　SCALE: 1:1

FIG: 17



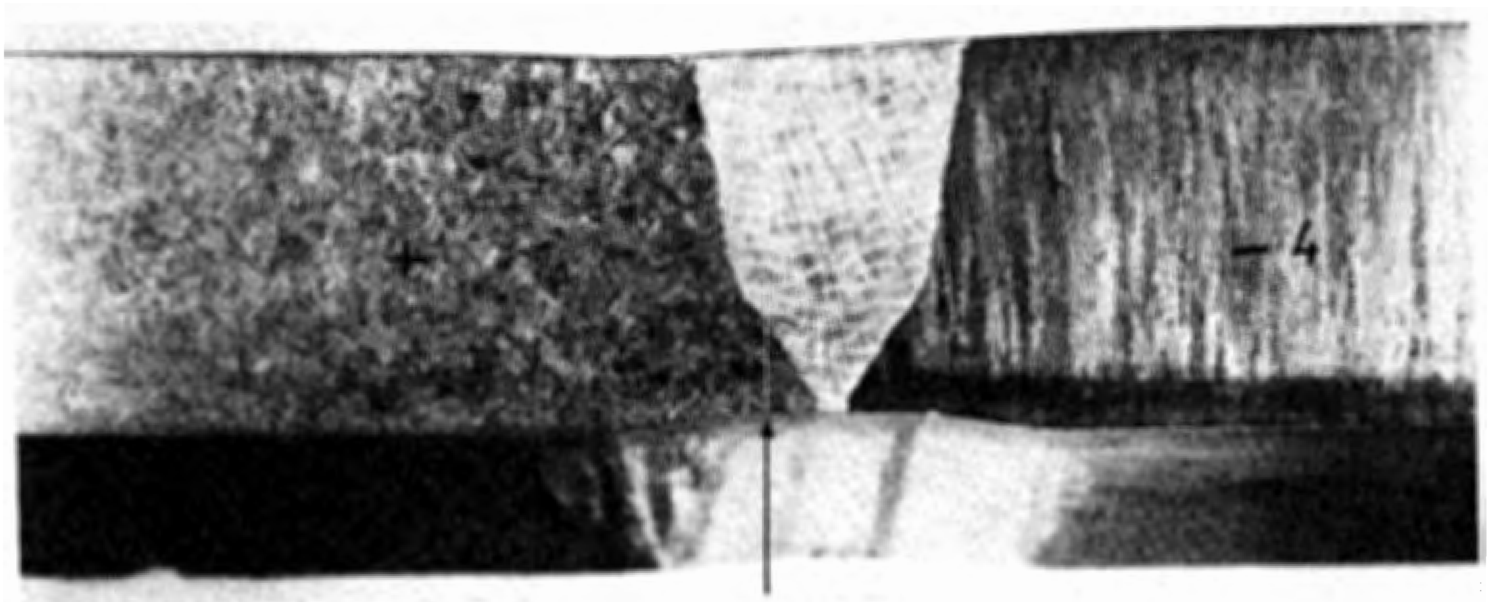
SPECIMEN: 2 SCRIBE LINE SCALE: 1:1

FIG: 18



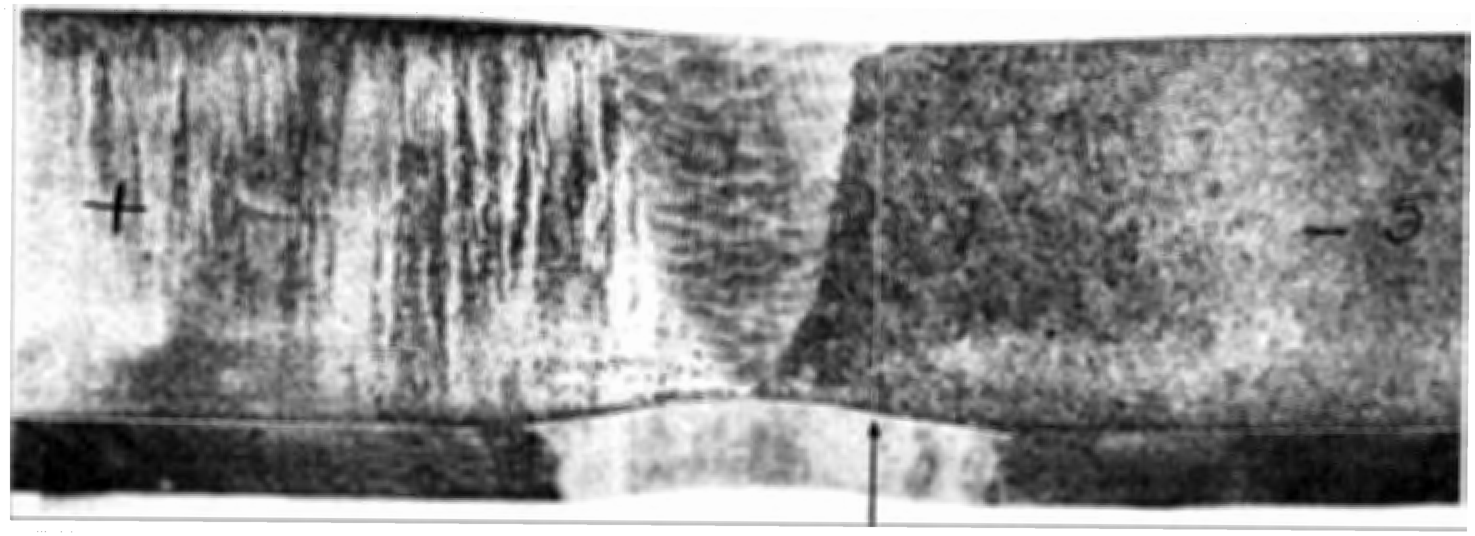
SPECIMEN: 3 SCRIBE LINE SCALE: 1:1

FIG: 19



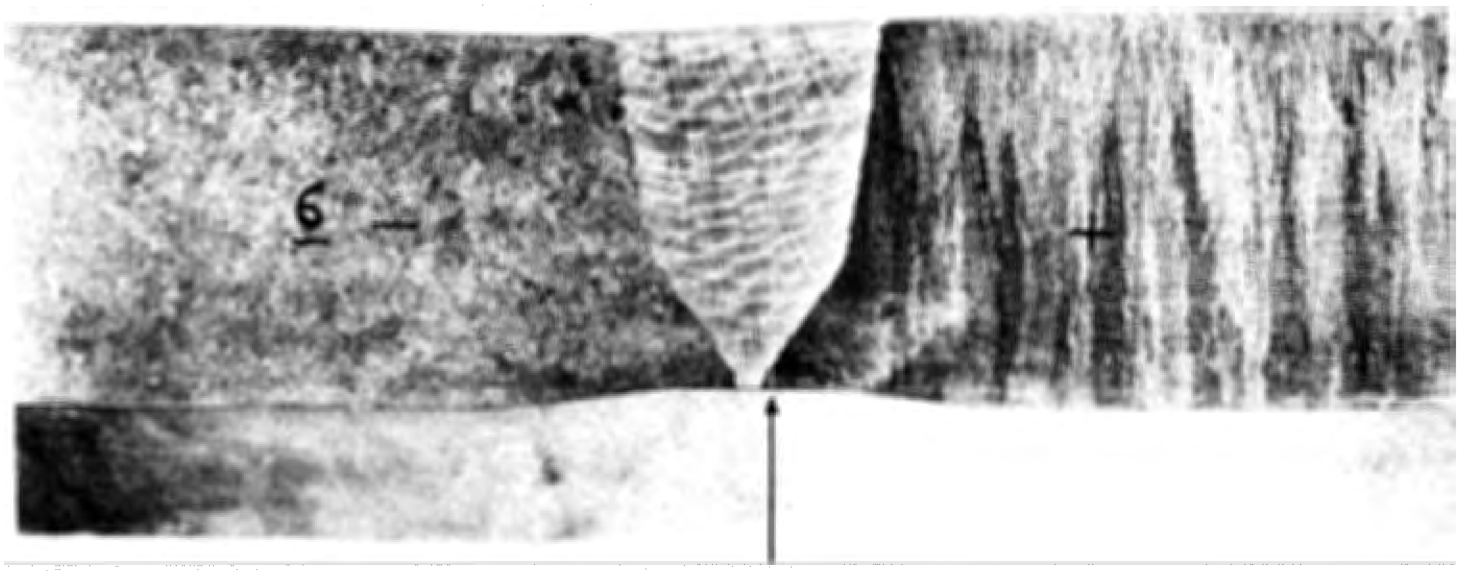
SPECIMEN: 4 SCRIBE LINE SCALE: 1:1

FIG: 20



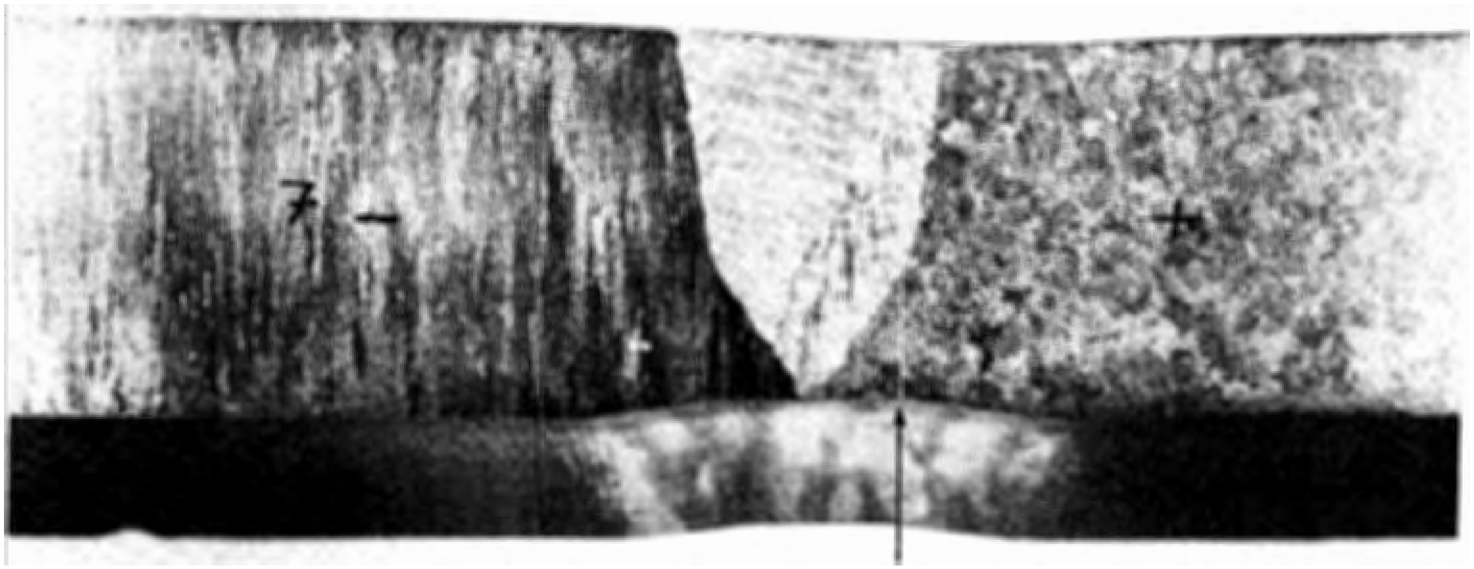
SPECIMEN: 5 SCRIBE LINE SCALE: 1:1

FIG: 21



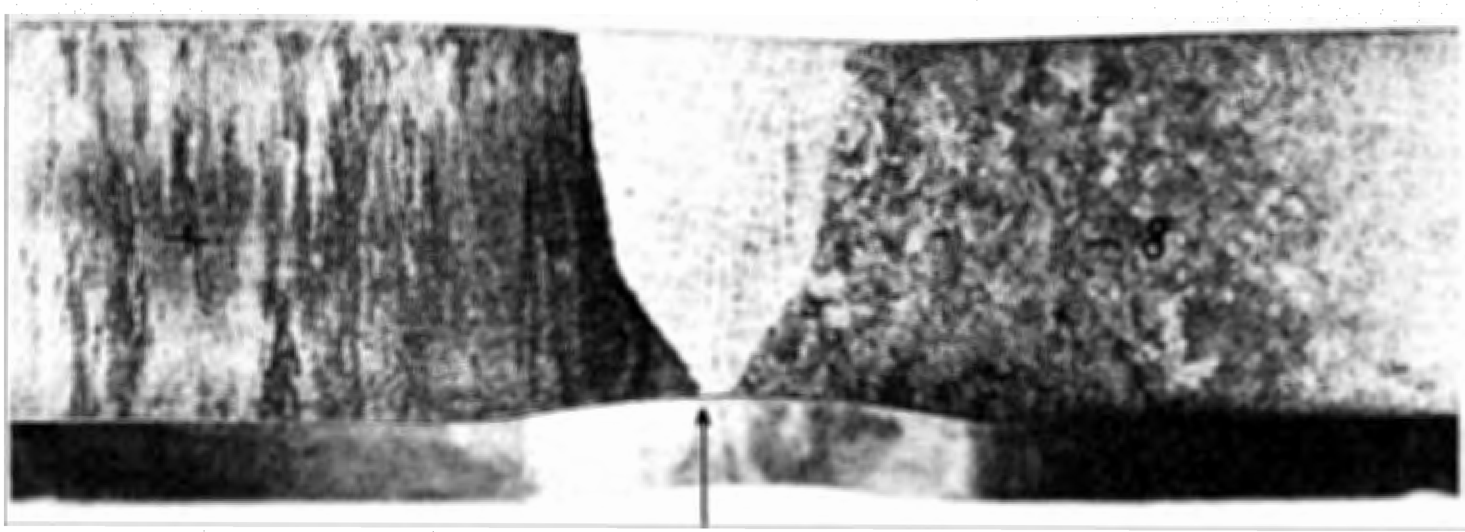
SPECIMEN:6 SCALE: 1:1

FIG: 22



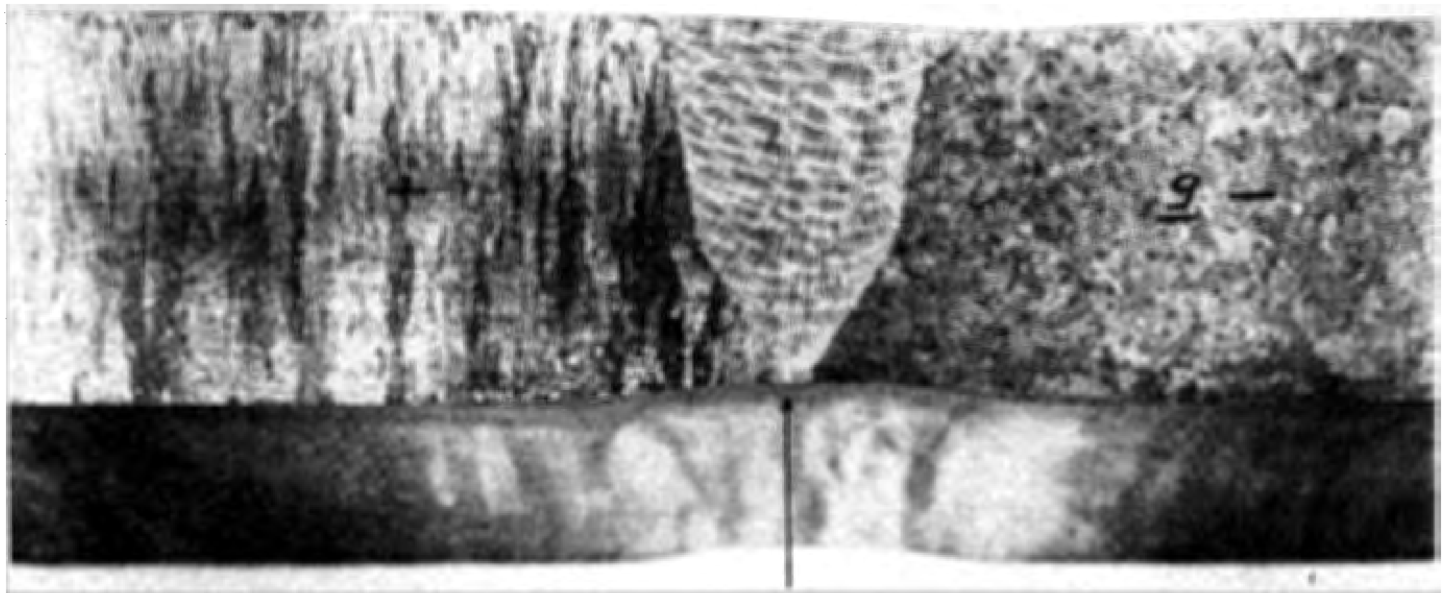
SPECIMEN: 7 SCRIBE LINE SCALE: 1:1

FIG: 23



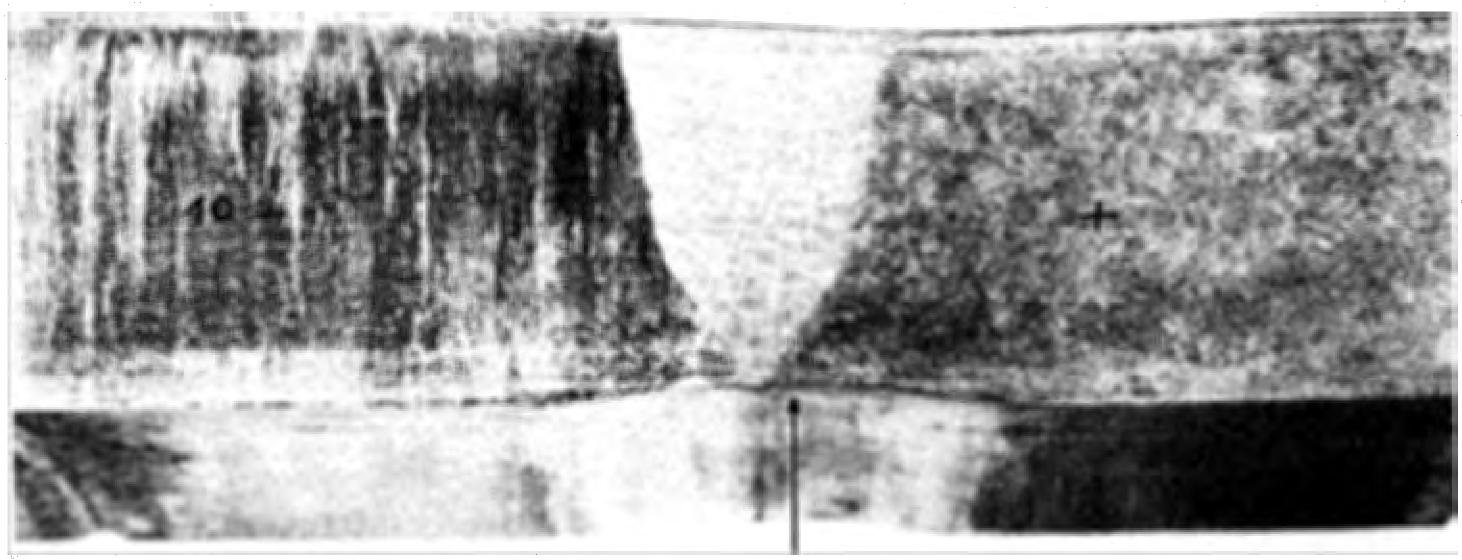
SPECIMEN: 8 SCRIBE LINE SCALE: 1:1

FIG: 24



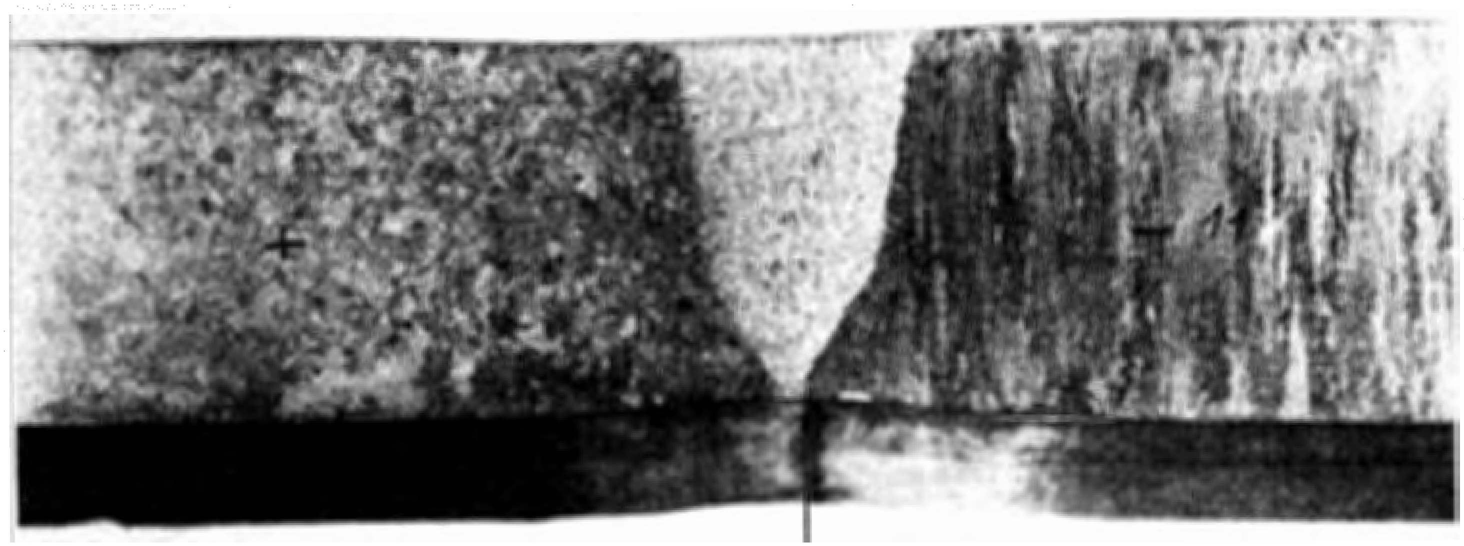
SPCIMEN: 9   SCRIBE LINE   SCALE: 1:1

FIG: 25



SPECIMEN: 10 SCRIBE LINE SCALE: 1:1

FIG: 26



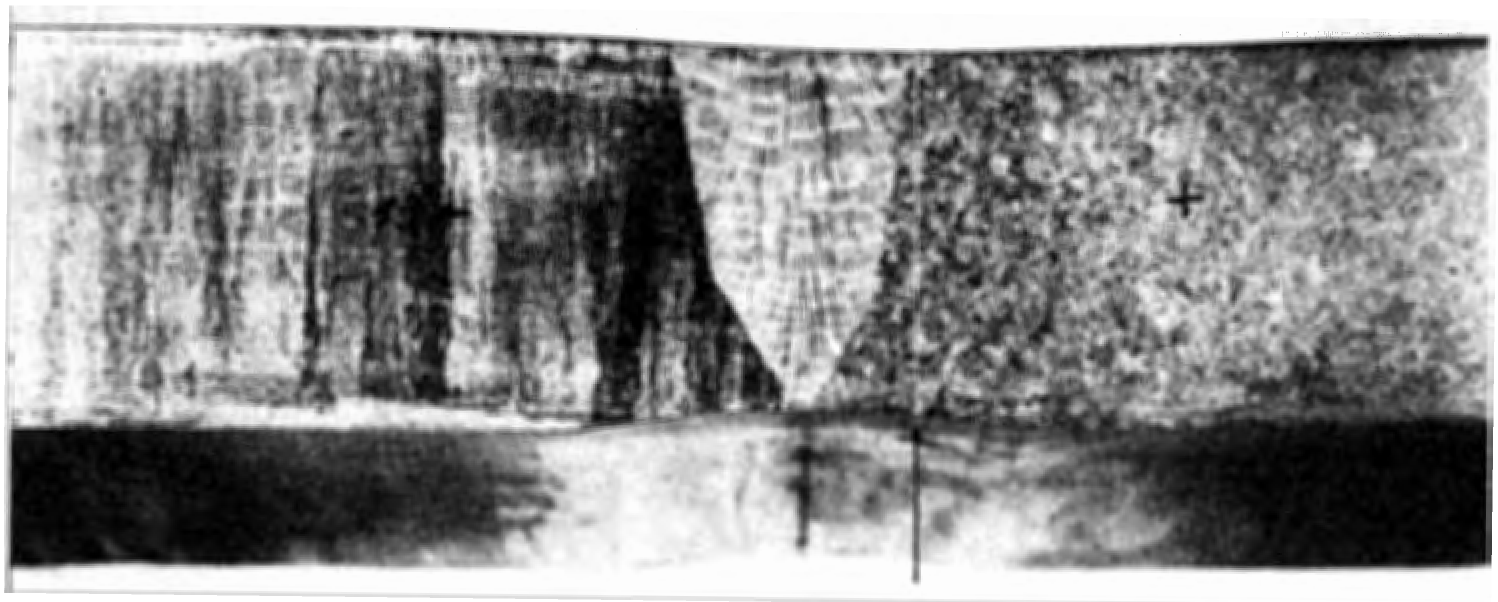
SPECIMEN: 11

SCALE: 1:1

FIG: 27

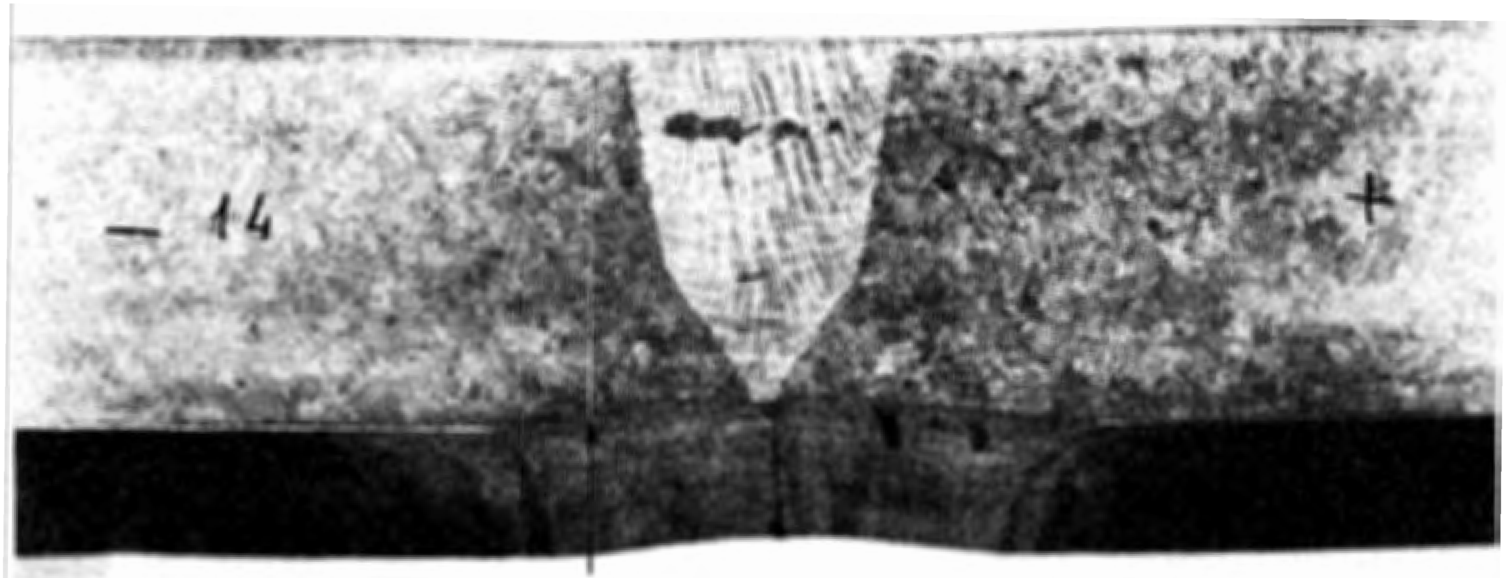
SPECIMEN: 12 SCRIBE LINE SCALE: 1:1

FIG: 28



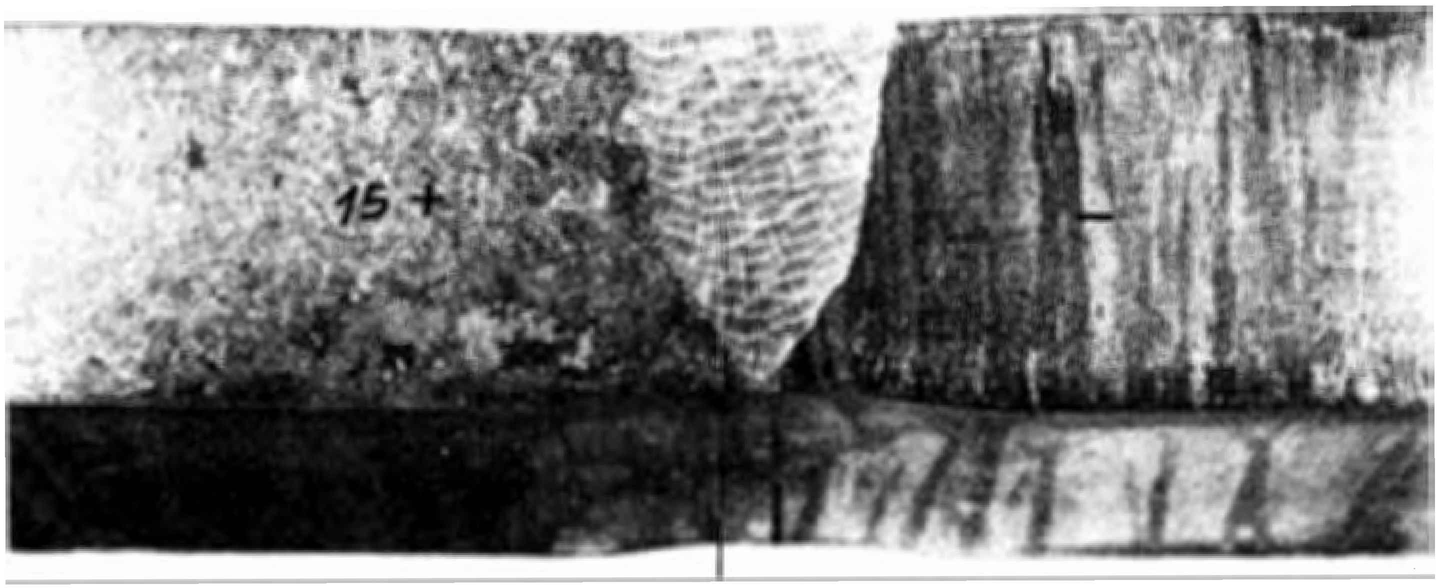
SPECIMEN: 13 SCRIBE LINE SCALE: 1:1

FIG: 29



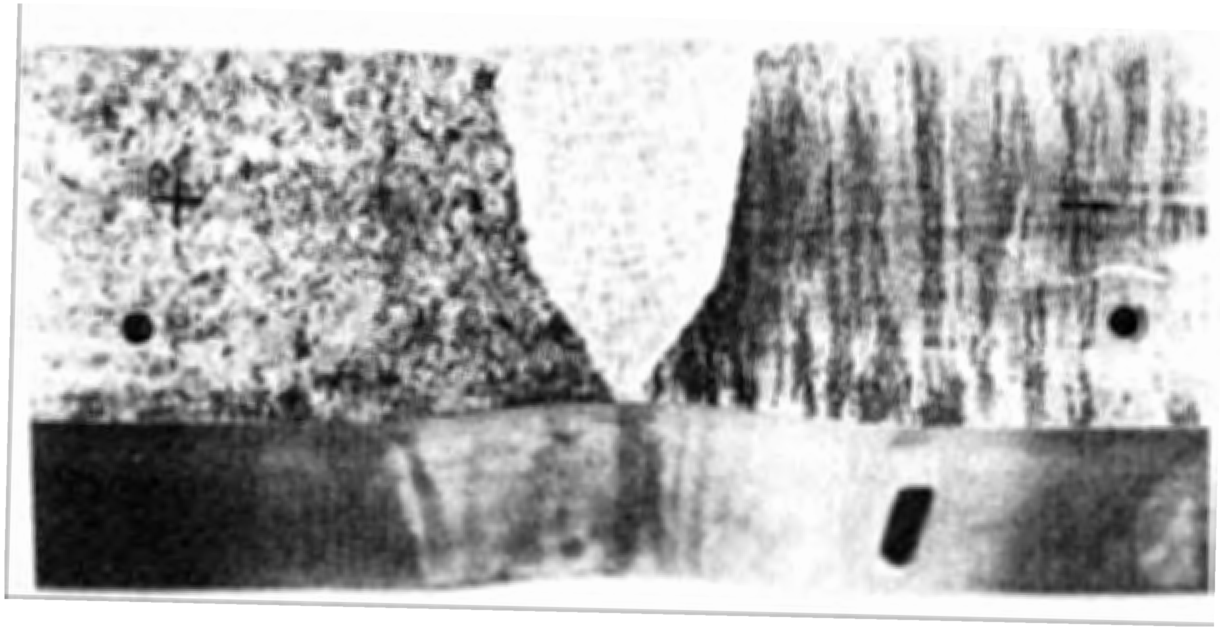
SPECIMEN: 14 SCRIBE LINE SCALE 1:1

FIG: 30



SPECIMEN: 15 SCRIBE LINE SCALE 1:1

FIG: 31



CALIBRATION BLOCK SCALE: 1:1

FIG: 32

APPENDIX D

STAINLESS STEEL ROUND ROBIN TEST PHASE I
Destructive Examination of Specimens Nos. 1-5 and 12

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Materials Science Division
Non Destructive Evaluation Laboratories

Originally prepared as
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August 1986

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1. INTRODUCTION

The results of the Phase I (Screening phase) of the SSRRT have been presented to the PISC II Managing Group in August 1985 (1). Concerns related to the presence of unintended defects were the reasons to encharge the JRC Ispra, NDE Labs. to verify the presence of the intended thermal fatigue cracks or other nonintended flaws by means of dye penetrant examinations and optimized radiographic examinations. The results of these examinations (post-test examinations) have been presented to the AST group of the PISC III Managing Board in March 1986 (2). Taking into account the results of these post-test examinations, a status report has been prepared by PNL Battelle and presented to the PISC III Managing Board in June 1986 (3).
During this meeting, it has been decided to proceed with a destructive examination of the specimens 1, 5 and 12. The reasons for the choice of these three specimens were the following.

- Specimen No. 12 was declared to be blank; this has been confirmed by the post X-ray tests but the U.S. inspections of the SSRRT gave a high rate of crack calls all over the welded length.

- Specimen No. 5 had an intended defect and a so called blank zone. Post X-ray examination confirmed the intended defect but put in evidence also a non intended defect. U.S. inspections of the SSRRT gave nearly the same rate of crack calls for both regions, the cracked and the blank one.

- Specimen No. 1 has been chosen by PNL Battelle because the defect was known not to be a single defect but could be more approximatively considered as a crack zone, which was confirmed also by the JRC dye penetrant results.

The AST Group and the PISC III Managing Board have not given any indications on how to execute the destructive examination. Based on the experience of the JRC in the PISC II exercise, the main aim of the destructive examination should be to verify if there are any nonintended fabrication defects and to provide documentation on all the existing typical fatigue cracks (i.e. position, width, depth and shape) in these three specimens.
Preliminary results of these examinations were presented orally to the PISC III Managing Board in June 1986.

The following procedure has been applied for the execution of the destructive examination.

- Cutting of the specimens in the Y-direction in slices all over the welded length, respecting individual needs for each specimen (inclusion of most US indications).
- Radiographic examination of these slices in the X-direction.
- Ultrasonic inspection on the Y-Z faces of these slices.

- Second cutting of the slices in the X-direction, respecting individual needs (zones of numerous US indications).
- Radiographic examination of the resulting pieces in the Y-direction.
- Macrographic inspection of some surfaces of different slices or pieces.

The cutting scheme and inspection procedure are given individually together with the results for each specimen.

2. DESCRIPTION OF THE INSPECTION PROCEDURES AND RESULTS

Specimen No. 5

Table 1 gives an overview and the comparison of crack dimension and position in specimen No. 5.

Fig. 1	shows the results of the dye penetrant examination.
Fig. 2	shows the position of the intended defects and the post X-ray results as given in Table 1.
Fig. 3	shows graphically the summary of the US inspection results.
Fig. 4	shows the macrograph of the welding zone.
Fig. 5	shows the two cutting schemes of specimen 5, as also indicated in Fig. 2.

After the first cutting phase into two slices at the X positions - 5/25 and 135/150, the two slices have been inspected by X-ray in X-direction.

Slice - 5/+25mm : 2MEV, 425 Rads, 2m, D2,Pb - no defect detected.

Slice +35/+50mm : 2MEV, 260 Rads, 2m, D2,Pb - no defect detected.

The US inspection has been performed on both sides of the two slices with the following equipment :

US SONIC MK1, Panametrix transducer, 2,25 MHz and 0,25 inch diameter, longitudinal waves, in immersion; this inspection put in evidence the intended defect in the slice -5/+25mm as shown in Fig. 6.
During the second cutting phase, the slice -5/+25 has been cut in X direction at the Y positions 80/90, 126/136, 138/150mm.
The cuttings in X directions at Y positions 126/136mm and 138/150mm were chosen to fall in the defect zone, while the cutting at Y position 80/90mm was done in a blank zone with high rate of US crack calls.

The slices 80/90, 126/136 and 138/150mm have then been inspected by X-ray under the following conditions :

Slice 80/90mm : 400 KV, 10mA, 1', 1 mt, D2,Pb - no defect detected.

Slice 126/136mm : 400KV, 10 mA, 30'', 1 mt, D2,Pb - defect detected and shown in Fig. 7.

Slice 138/150mm : 400 KV, 10 mA, 15'', 1 mt, D4,Pb - defect detected but with very poor visibility as shown in Fig. 8.

The main slice + 35/+50mm has been cut in the second phase in the X direction at the Y position 110/130 and inspected by X-ray under the following conditions :

Slice 110/130mm : 400 KV, 10 mA, 25'', 1 mt, D4,Pb - no defect has been detected, see Fig. 9. Please note on this figure the columnar structure put in evidence by X-ray examination.

The macrographic inspection of the two sides of the slice -5/+ 25 mm (see Fig. 10), evidenced only the different macrostructures of the specimen materials and a part of the welding (weld centre line at + 21mm).

The macrograph of slice -5mm/+25mm at Y position Y = 136mm put in evidence the intended defect in specimen No. 5 (see Fig. 11).

Specimen No. 1

Table 2 gives an overview and the comparison of crack dimension and position in specimen No. 1.

Fig. 12 shows the results of the dye penetrant examination.

Fig. 13. shows the position of the intended defects and the post X-ray results as given in Table 2.

Fig. 14 shows graphically the summary of the US inspection results.

Fig. 15 shows the macrograph of the welding zone.

Fig. 16 shows the cutting scheme of specimen No. 1 as also indicated in Fig. 13.

After having cut one slice at the X positions -25/+15mm, the slice has been inspected by X-ray in X direction at the following conditions :

Slice -25/+15mm : 2MEV, 600 rads, 2m, D2-Pb - no defect detected.

The US inspection has been performed on both sides of the slice -25/+15mm with the following conditions :
US-SONIK MK 1, Panametrix transducer, 2,25 MHz and 0,25 inch diameter, longitudinal waves in immersion; this inspection put in evidence the intended defect as shown in Fig. 17.

Macrographic inspection of both YZ surfaces of the slice -25/+15mm have been made and are shown in Fig. 18 for the X position -25mm and in Fig. 19 for the X position + 15mm.

At the X position -25mm, a crack G has been detected as indicated in Fig. 18 which is better shown in scale X 20 in Fig. 20.

At the X position +15mm, a crack zone with different cracks (A,B,C,D,-E,F) as seen in Fig. 19, has been detected and these cracks are shown in scale x40 in Figs. 21, - A,B,C,D,E,F.
During the second cutting phase, the slice -25/+15mm has been cut in X direction at the Y positions 69/79mm which is the zone of the intended defect and of a maximum of US indications (see also Figs. 13 and 14) and inspected by x-ray under the following conditions :

Slice 69/79mm : 400 KV, 10 mA, 40'', lmt, D2,Pb - the defect has been put in evidence as shown in Fig. 22.

Macrographic inspection has been done on the Y = 79mm face of slice 69/79mm which evidentiated 3 defects (A,B,C) as shown in Fig. 23. Details of this macrograph are shown in Fig. 24 and Fig. 25.

Specimen No. 12

Table 3 gives an overview of the non destructive results in specimen No. 12.

Fig. 26 shows the results of the dye penetrant examination,

Fig. 27 shows graphically the summary of all US inspection results and the cutting scheme,

Fig. 28 shows the macrograph of the welding zone,

Fig. 29 shows the cutting scheme of specimen No. 12 as also indicated in Fig. 27.

After having cut one slice at the X positions -17/+15mm, the slice has been inspected by X-ray in X direction at the following conditions :

Slice -17/15mm : 2 MEV, 450 Rads, 2m, D2,Pb - no defect detected.

The US inspection of both sides of the slice -17/15mm with the following equipment :

US-SONIC MK1, Panametrix transducer, 2,25 MHz and 0,25 inch diameter, longitudinal waves in immersion - did not show any defect (see Fig. 30).

The main slice of specimen No. 12 (-17/+15mm) has then been cut in the second phase in X direction at the following Y positions 20/60/ 120/130mm.
The X-ray inspection of the slice 120/130mm under the following conditions :

Slice 120/130mm : 400 KV, 10 mA, 30'', 1mt, D2-Pb, did not show any defect but evidentiated the different textures of the materials (see Fig. 31).

Metallographic inspection of the two YZ surfaces and one XZ surface of the slice (130B/end) in the specimen No. 12 are shown in :

Fig. 32 and 32a	Metallographic inspection of face X = - 17mm
Fig. 33	Metallographic inspection of face X = + 15mm
Fig. 34 and 34a+b	Metallographic inspection of face Y = 130B mm.

3. CONCLUSIONS

1. Due to the results obtained by US inspections in the screening phase of the SSRRT (very high rate of false calls), several participants expressed some doubts on the declared "intended defects". Moreover, the first X-ray inspection on the specimens in original state put in evidence some discrepancies between the "intended defects" indicated by PNL-Battelle and the defects detected by the x-ray inspection. The unmachined surfaces, the counterbore of the specimens as well as the back plates together with the structure of the base materials created some problems for the detection and definition of the X-ray indications.

2. Therefore, a second post test examination was decided in August 1985 under the following conditions :

- the back plates were lifted,
- the outer and inner surface of the specimens around the welding and the heat affected zone were polished.

2.1. The results of the post X-ray examination confirmed the existence of all the intended defects as well as their position and dimensions (length).
Only one additional defect was detected in specimen No. 5 (2).

2.2. In addition to the post X-ray tests, the specimens were also inspected with red dye penetrants which confirmed also the existence of all the intended defects in dimensions and position but put in evidence also the presence of many superficial cracks created during the fabrication process of these intended defects (2).

2.3. The post-test macrographs of the transverse surfaces of all the specimens confirmed the structures of the base materials (2).

3. Taking into consideration the results of the post X-ray examination and the results of the dye penetrant examination and having in mind the high rate of false calls by US techniques, the AST group decided in March 1986 to encharge the JRC NDE Labs. with the destructive examination of the specimens No. 1, 5 and 12.
The reasons for the choice of these three specimens were the following.

- Specimen No. 12 was declared to be blank, this has been confirmed by the post-test examination, but the US inspections have given a high rate of crack calls all over the welded length.

- Specimen No. 5 had an intended defect and a so called blank zone. Post-test examination confirmed the intended defect but put in evidence also a non intended defect.
US inspections gave nearly the same rate of crack calls for both regions, the cracked and the blank one.

- Specimen No. 1 has been chosen by PNL Battelle because the defect was known not to be a single defect but could be more approximatively considered as a crack zone, a part of which was confirmed also by the JRC dye penetrant results.

4. The destructive examination led to the final conclusions :

4.1. The intended defects in specimens 1 and 5 were confirmed in position and length.

4.2. The depth of the intended defect in specimen No. 1 was defined by X-ray and macrographic inspection (≃ 38%).
The depth of the intended defect in specimen No. 5 (PNL Battelle indication = 28%) was confirmed by X-ray and micrographic inspection.

4.3. The non intended defect in specimen No. 5, found by the post X-ray inspection was not confirmed by the micrographic examination.
This false X-ray call was due to the columnar structure of the base material.

4.4. The destructive examination of specimen No. 1 has shown that the nonintended cracks put in evidence also by the red dye penetrants may be even very deep (up to 12,5 mm) while they are only a few mm deep in specimen No. 5.

4.5. These conclusions were also confirmed by some US inspection on the cut pieces of the specimens.

5. Having in mind the scope of the post-test examination and also the destructive examinations of some specimens, that means mainly the explanation of the high rate of false calls by US inspections, it seems that these are partly due to :

- unadequate surface preparation of the specimens,
- structure of the base materials (large equiaxed grains f.i.),
- texture of orientation of these materials (large columnar grains f.i.),
- interface between base materials and the weld.

6. It is evident that the ultrasonic results of the screening phase of this SSRRT together with the results of the post-test examination and the destructive examination of some specimens have to be taken in mind for the preparation and the choice of the specimens and the defects for the second phase of the austenitic steel piping round robin test in PISC III.

REFERENCES

(1) Stainless Steel Round Robin Test Cast
Stainless Steel Screening Phase
Working Draft prepared by PNL Battelle, August 1985.

(2) Post-Test Examination of the SSRRT Phase I
Specimens at the JRC Ispra
Technical note prepared by JRC Ispra, NDE Labs., Jan. 1986.

(3) Stainless Steel Round Robin Test Cast
Stainless Steel Screening Phase
Status Report prepared by PNL Battelle, June 1986.

List of Tables

List of Figures

Table 1 : Comparison of the crack dimension and position obtained by different inspection techniques Specimen No. 5

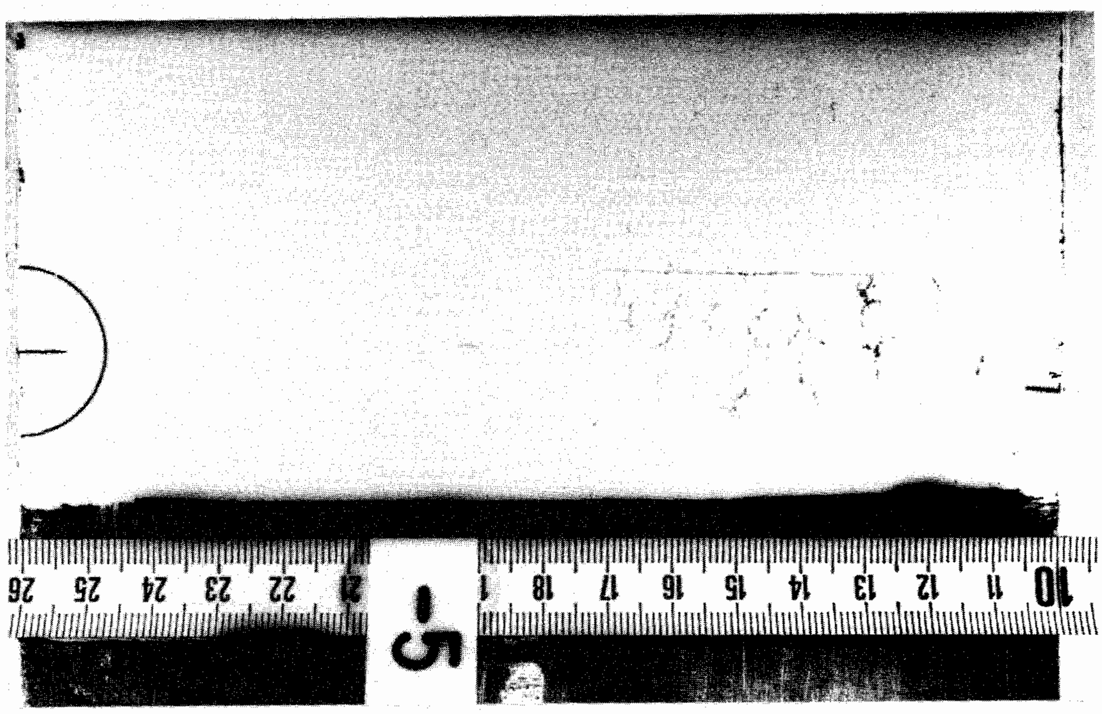
Specimen			Original Weld Length (mm)	Weld offset mm (JRC)	Crack offset			Crack start			Crack end			REMARKS
No	-	+			BNL	JRC XRay Post	JRC Red dye pen.	BNL	JRC XRay Post	JRC Red dye pen.	BNL	JRC XRay Post	JRC Red dye pen.	
5	E	C	191	+ 21	+ 16	+ 15	+ 17	104	110	99	172	158	155	
5	E	C	191	+ 21	-	+ 44	-	-	118	-	-	144	-	

Table 2 - Comparison of the crack dimension and position obtained by different inspection techniques Specimen No. 1

Specimen			Original Weld Length (mm)	Weld offset mm (JRC)	Crack offset			Crack start			Crack end			REMARKS
No	-	+			BNL	JRC XRay Post	JRC Red dye pen.	BNL	JRC XRay Post	JRC Red dye pen.	BNL	JRC XRay Post	JRC Red dye pen.	
1	E	E	168	- 4	+ 3	+ 3	- 1	40	30	43	121	118	118	

Table 3 - Comparison of the crack dimension and position obtained by different inspection techniques Specimen No. 12

Specimen			Original Weld Length (mm)	Weld offset mm (JRC)	Crack offset			Crack start			Crack end			REMARKS
No	-	+			BNL	JRC XRay Post	JRC Red dye pen.	BNL	JRC XRay Post	JRC Red dye pen.	BNL	JRC XRay Post	JRC Red dye pen.	
12	E	C	176	- 7	-	-	-	-	-	-	-	-	-	



Specimen No. 5 : crack offset : + 17 mm
crack start : 99 mm corrected values
crack end : 155 mm

FIG.1- DYE PENETRANT RESULTS FOR SPECIMEN N° 5

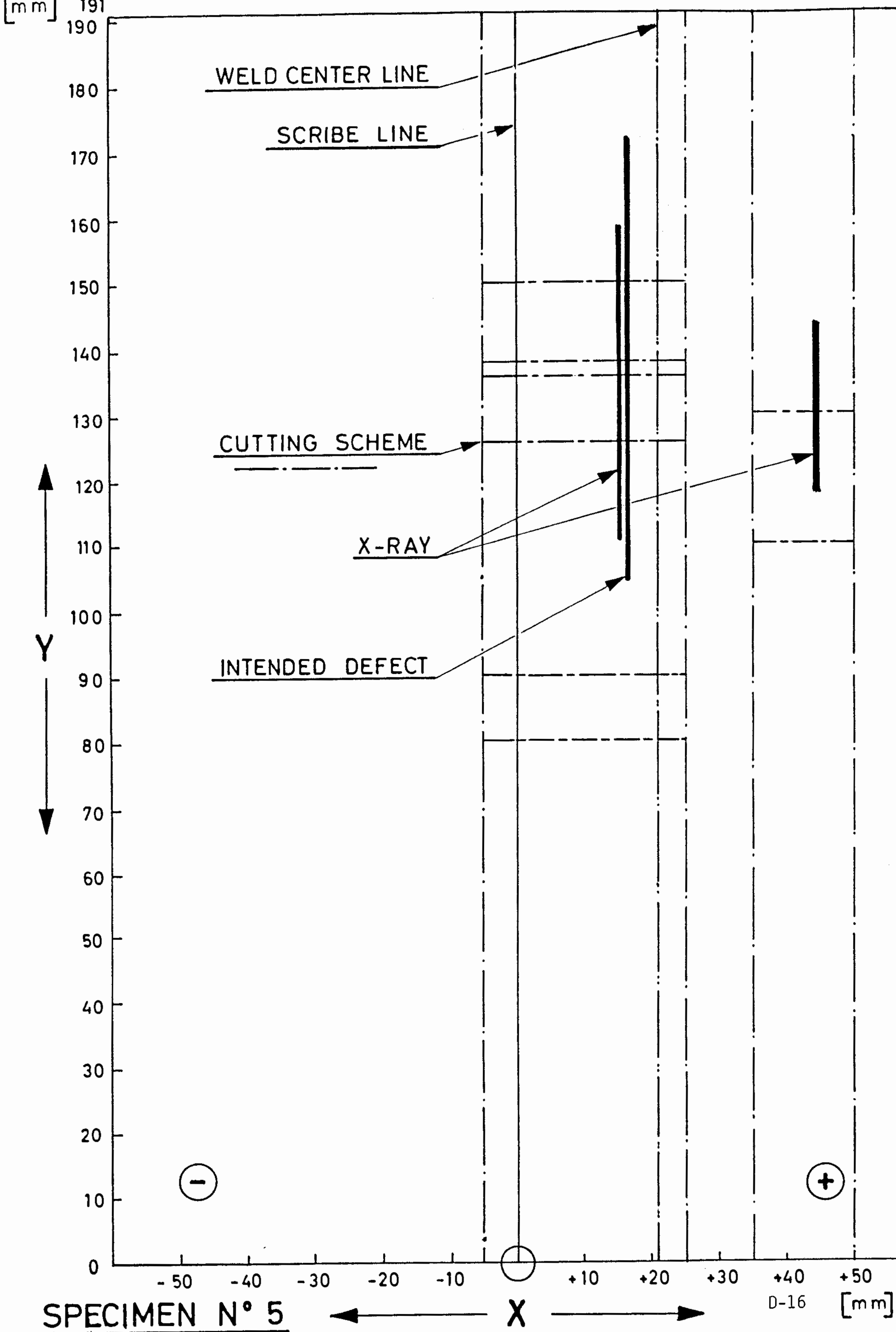


FIG. 2- INTENDED DEFECT POST X-RAY RESULT AND CUTTING SCHEME OF SPECIMEN N° 5

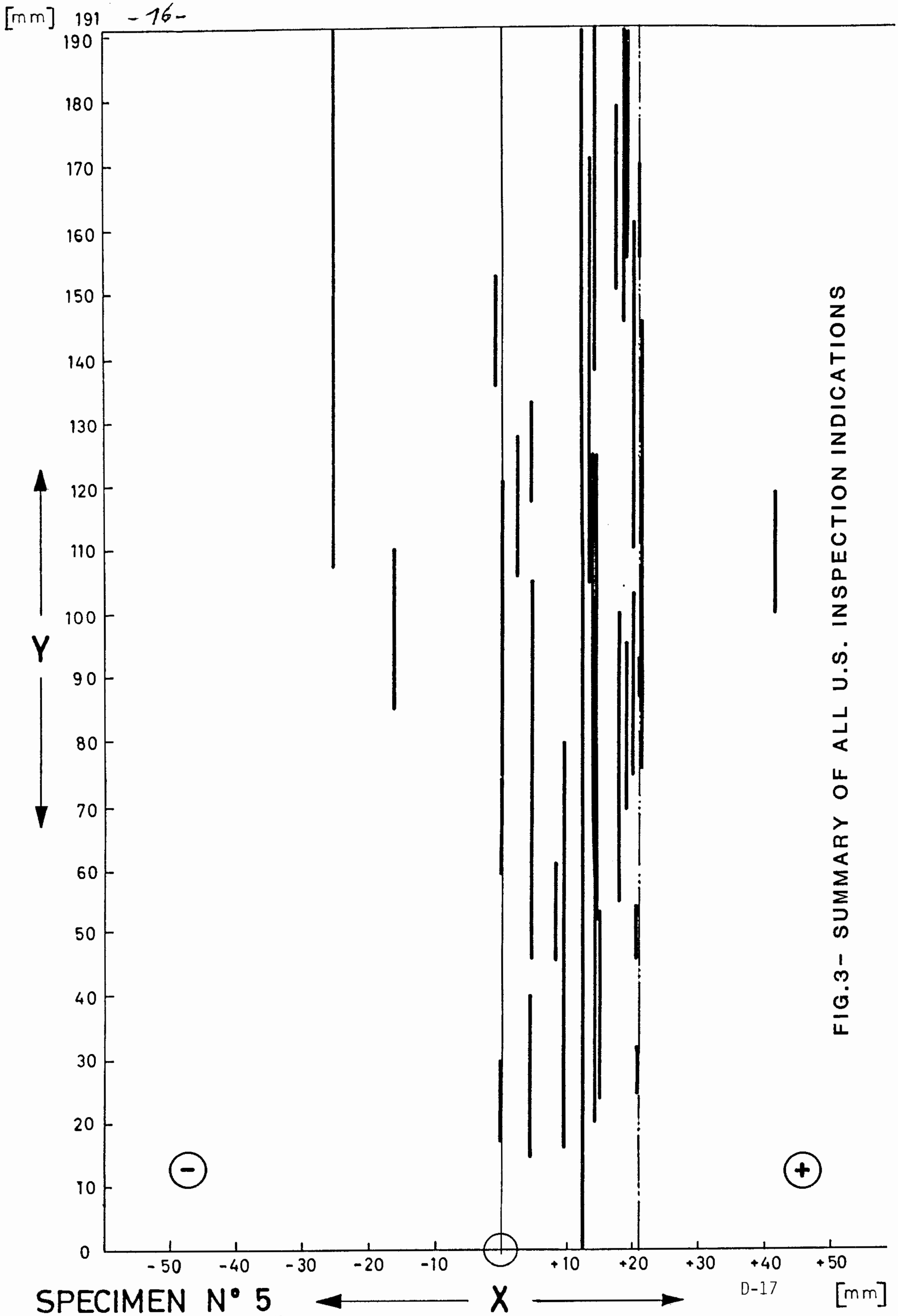


FIG.3- SUMMARY OF ALL U.S. INSPECTION INDICATIONS

SPECIMEN N° 5

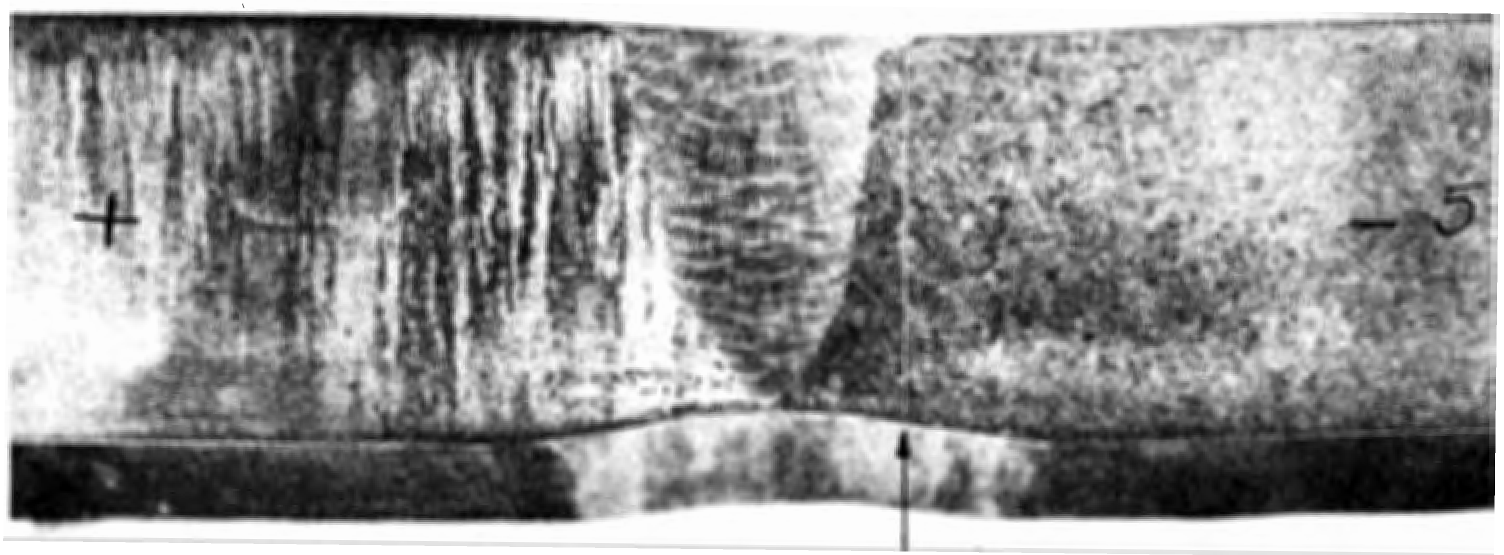


FIG. 4-MACROGRAPH OF THE WELDING ZONE OF SPECIMEN N°5

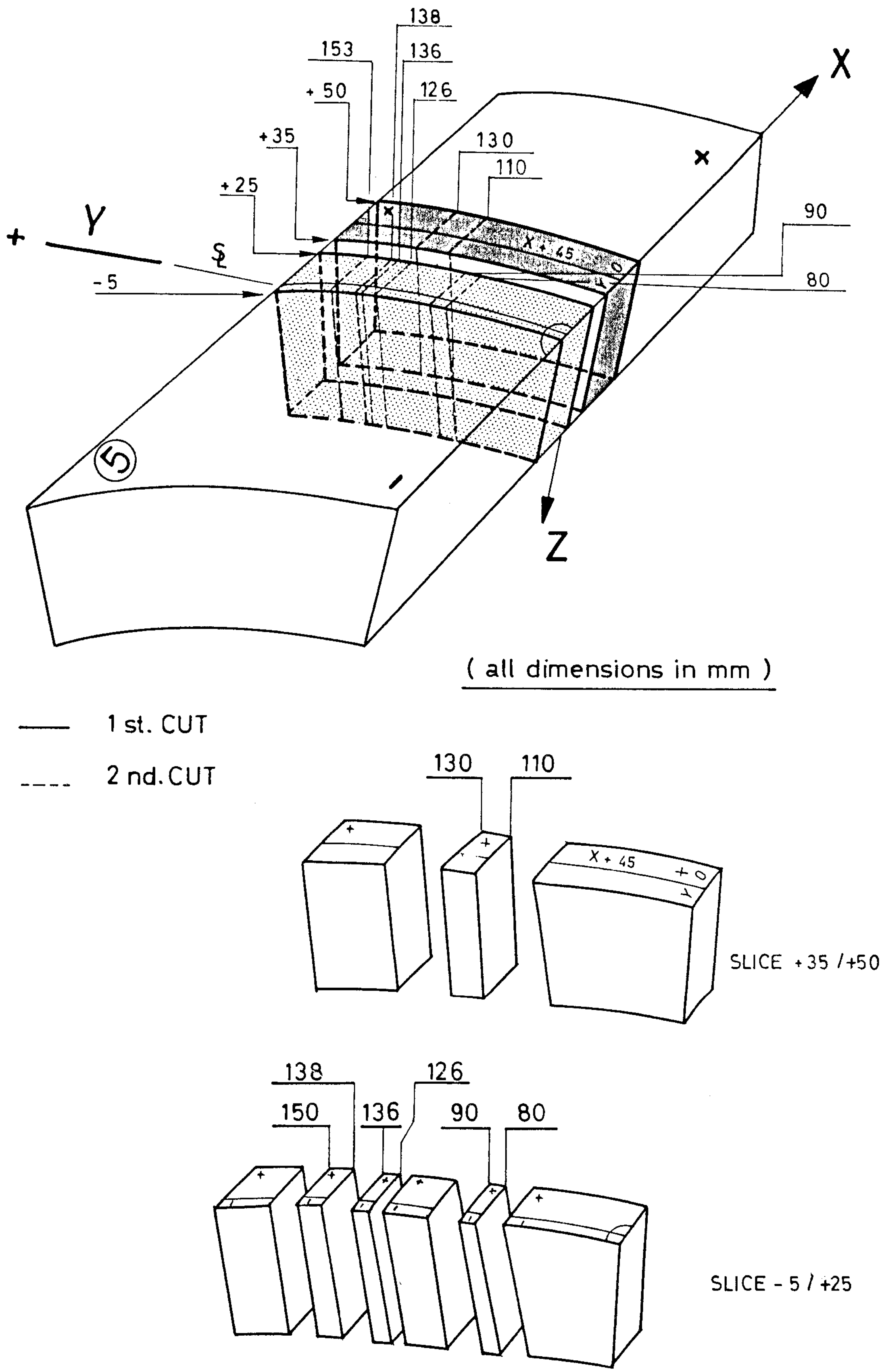


FIG.5 - CUTTING SCHEME OF SPECIMEN N° 5

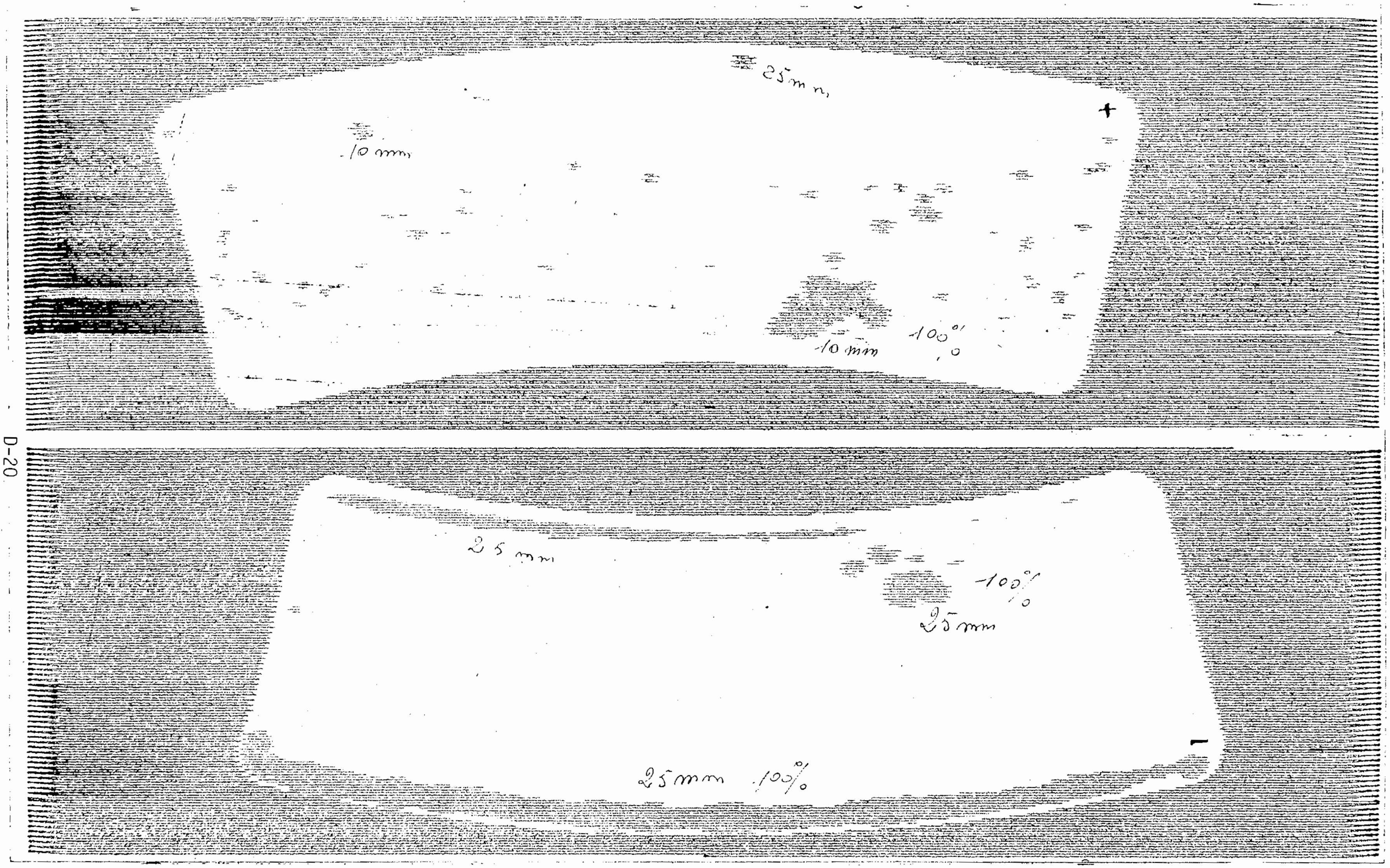


FIG.6- U.S. INSPECTION OF SLICE -5/+25 OF SPECIMEN N°5

SPECIMEN :5

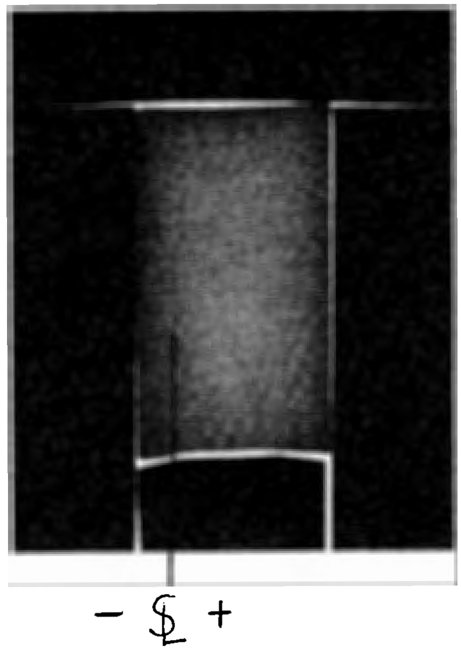


FIG. 7- RADIOGRAPH THROUGH PLAN X Z

AT Y-126 IN DIRECTION Y+

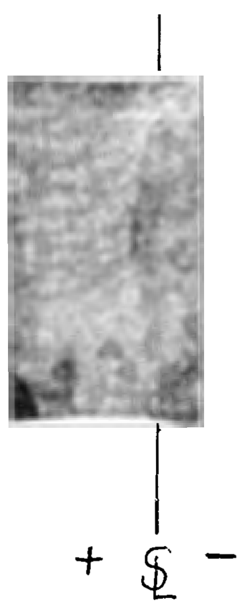


FIG. 11- MACROGRAPH AT Y -136

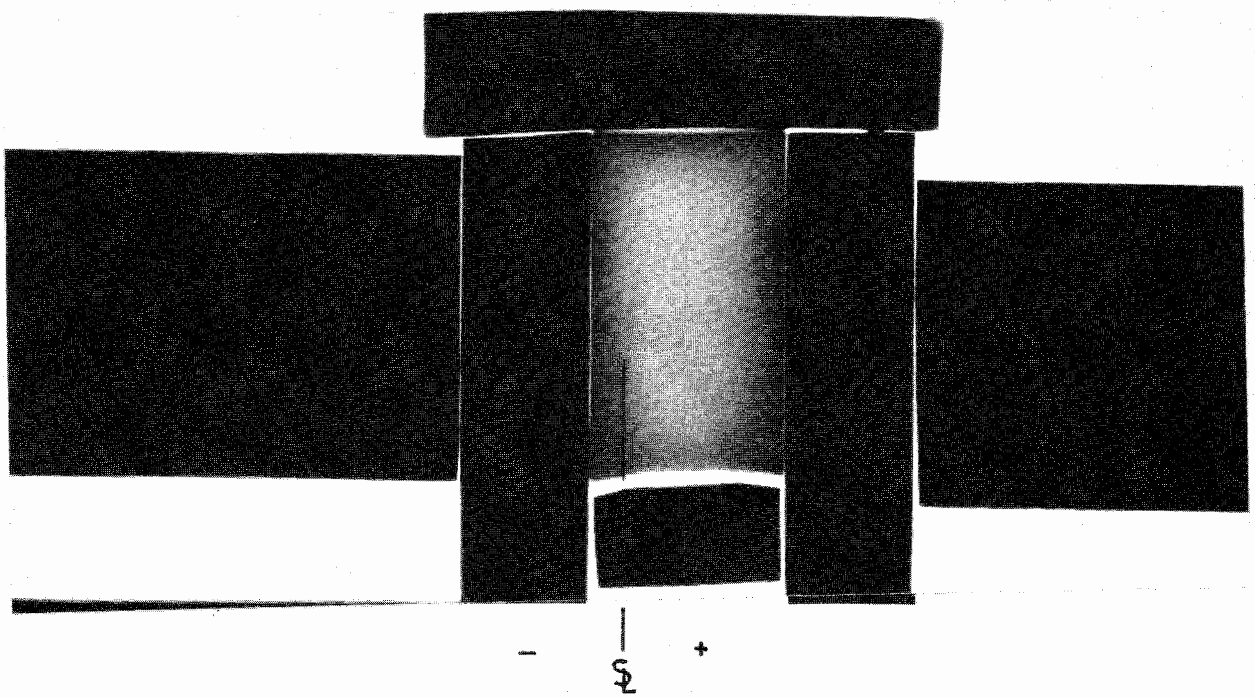


FIG. 8- RADIOGRAPH OF SLICE 138/150 OF SPECIMEN N° 5

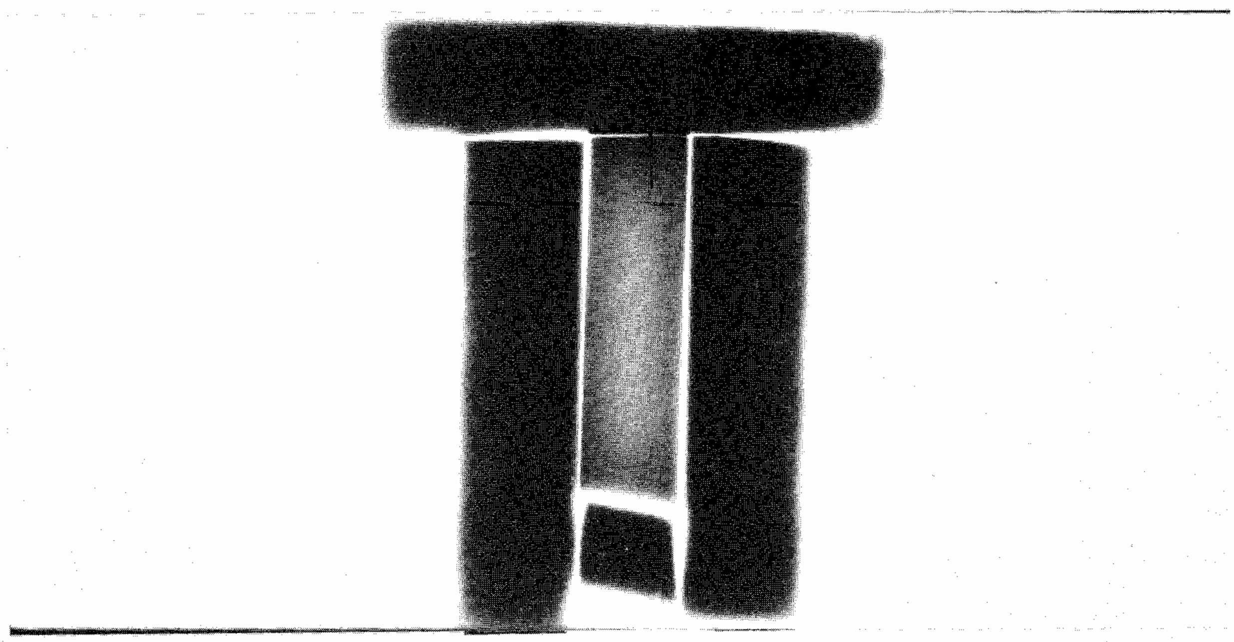
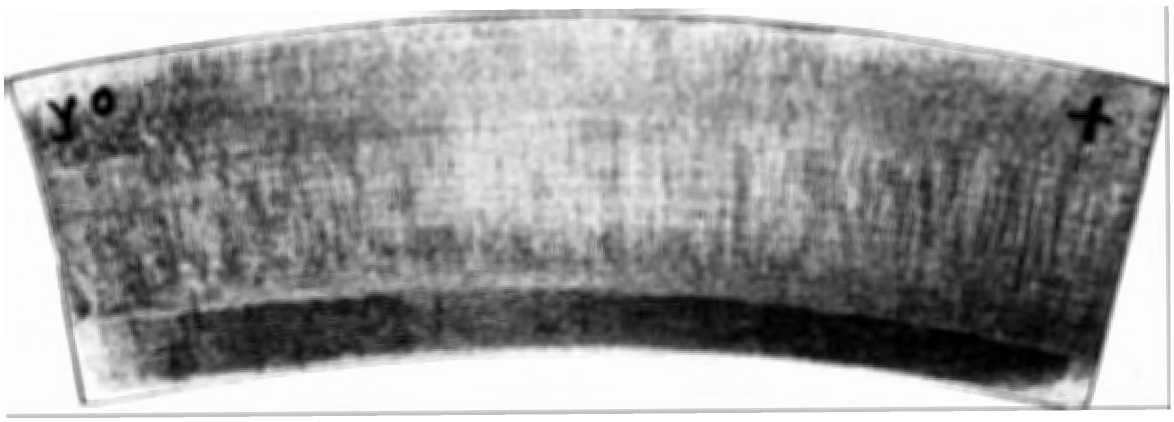


FIG. 9- RADIOGRAPH OF SLICE 110/130 OF SPECIMEN N° 5

SPECIMEN :5



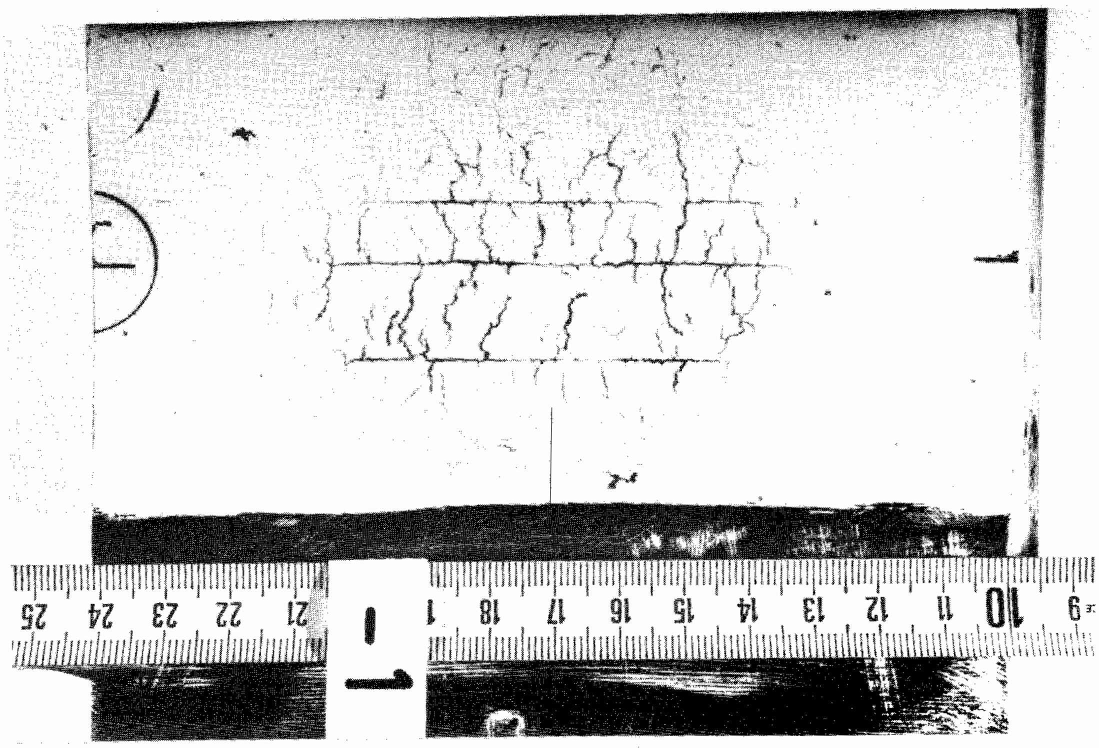
MACROGRAPHY SCALE 1:1

SCRIBELINE + 25MM

MACROGRAPHY SCALE 1:1

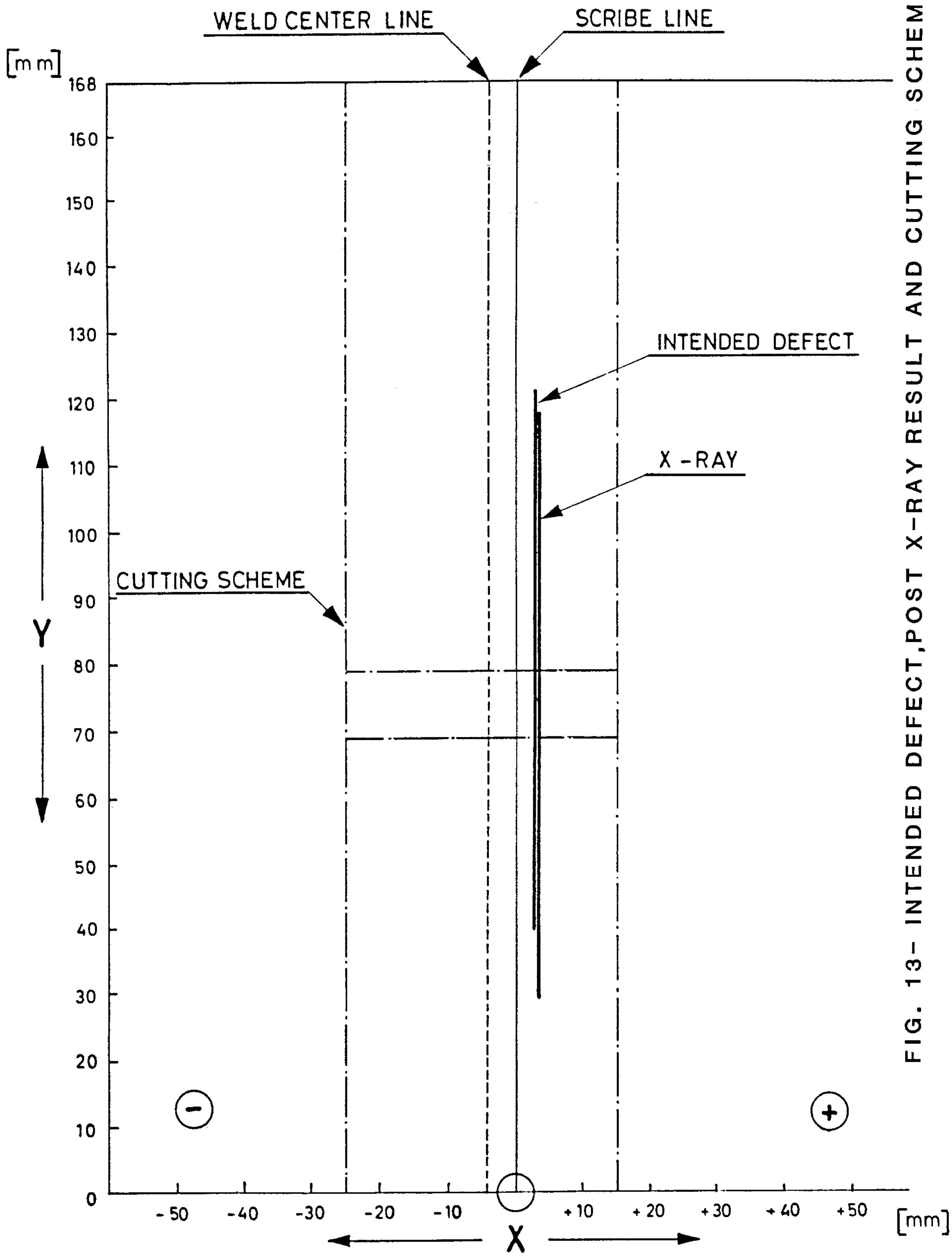
SCRIBELINE - 5MM

FIG.10-MACROGRAPH OF SPECIMEN N°5,SLICE-5/+25



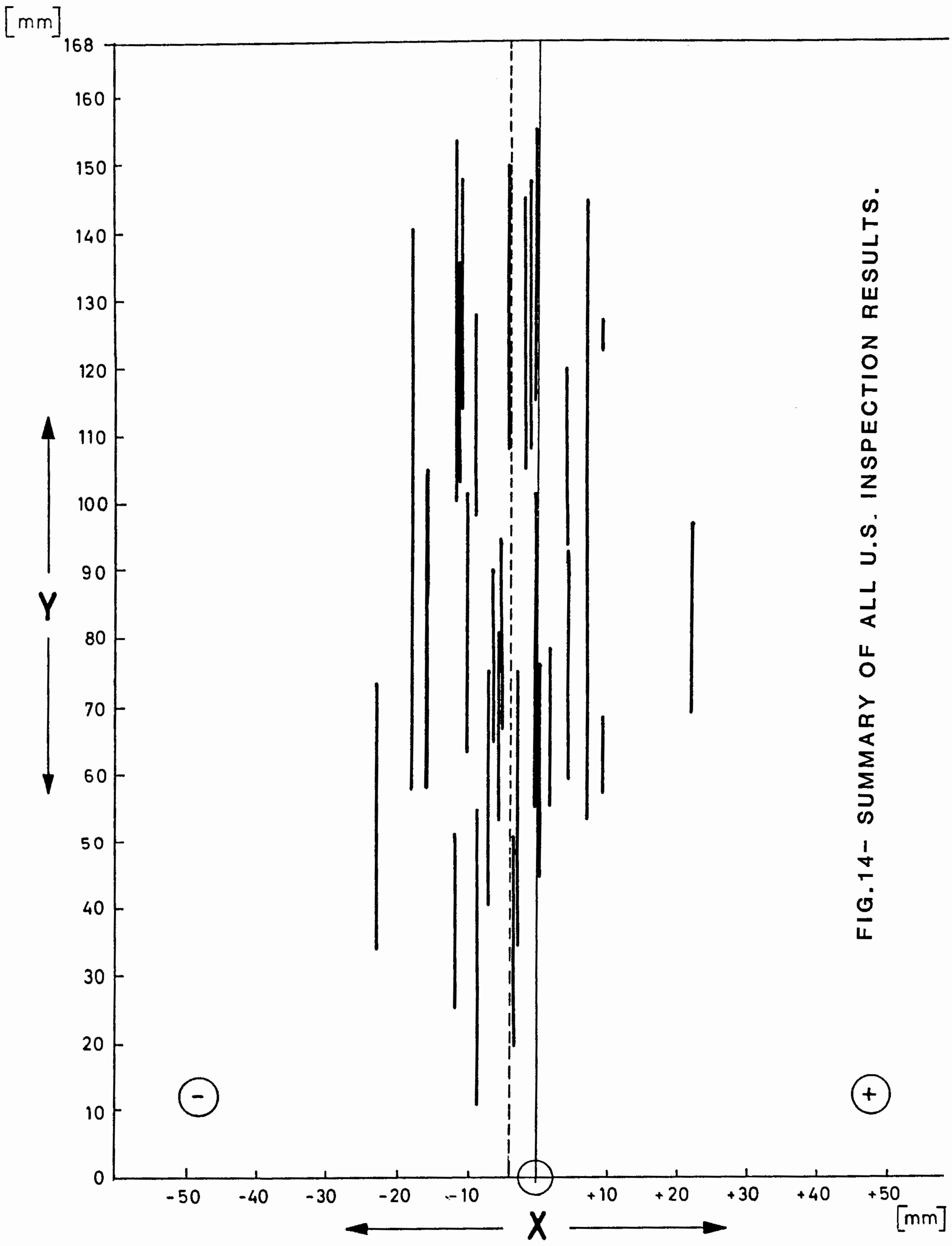
Specimen No. 1 : crack offset : - 1 mm
crack start : 43 mm corrected values
crack end : 118 mm

FIG.12- DYE PENETRANT RESULTS FOR SPECIMEN N° 1



SPECIMEN N° 1

FIG. 13- INTENDED DEFECT,POST X-RAY RESULT AND CUTTING SCHEME OF SPECIMEN N° 1



SPECIMEN N° 1

D-26

FIG.14- SUMMARY OF ALL U.S. INSPECTION RESULTS.

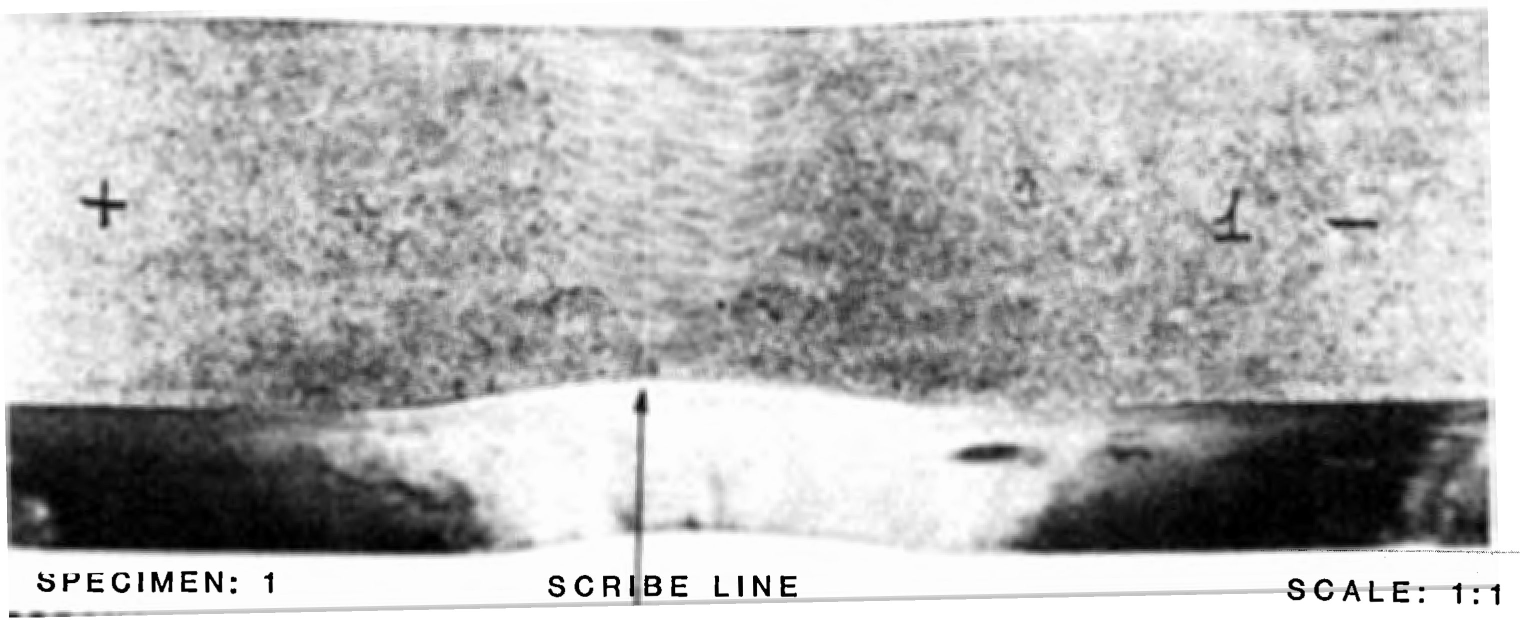
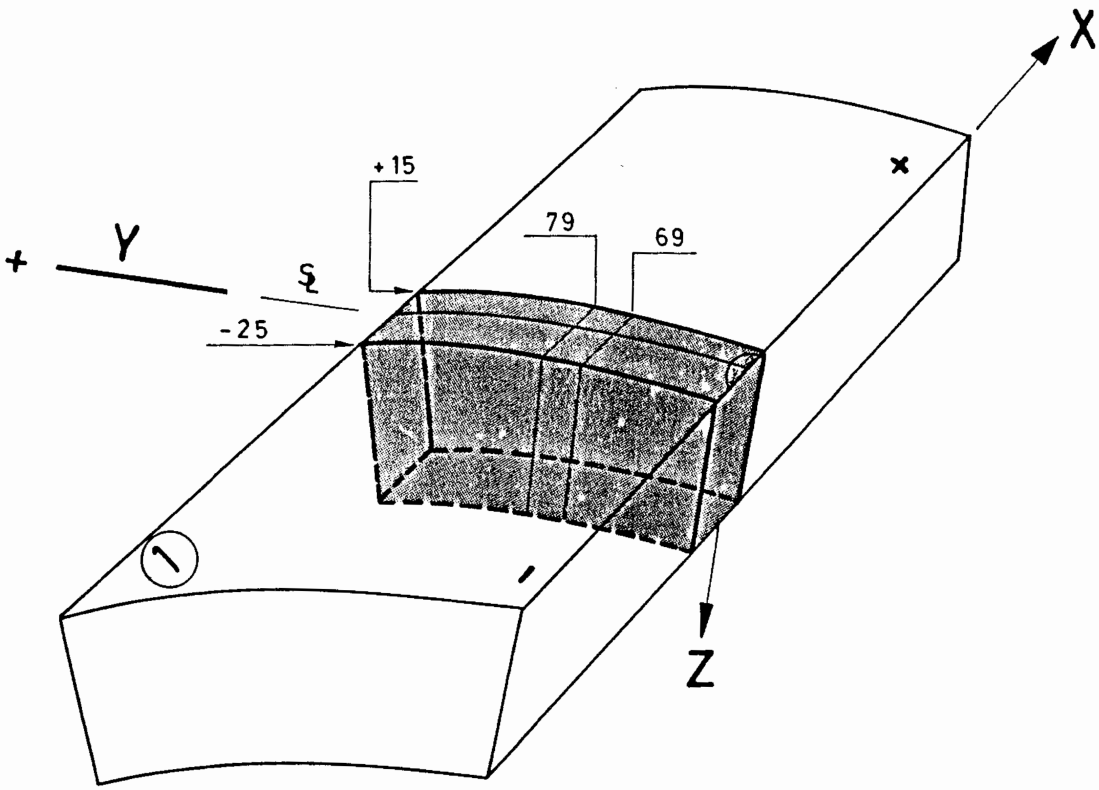


FIG. 15-MACROGRAPH OF THE WELDING ZONE OF SPECIMEN N°1



(all dimensions in mm)

—— 1st. CUT

----- 2st. CUT

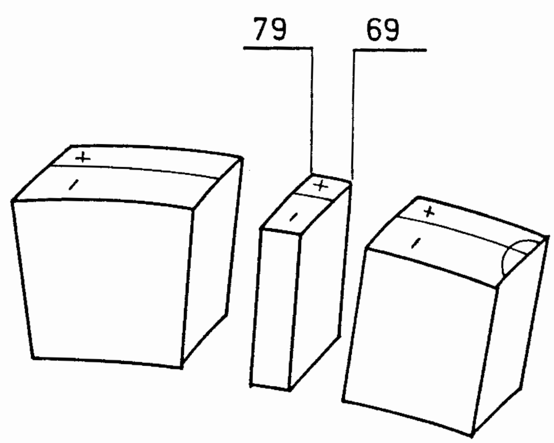


FIG. 16 - CUTTING SCHEME OF SPECIMEN N° 1

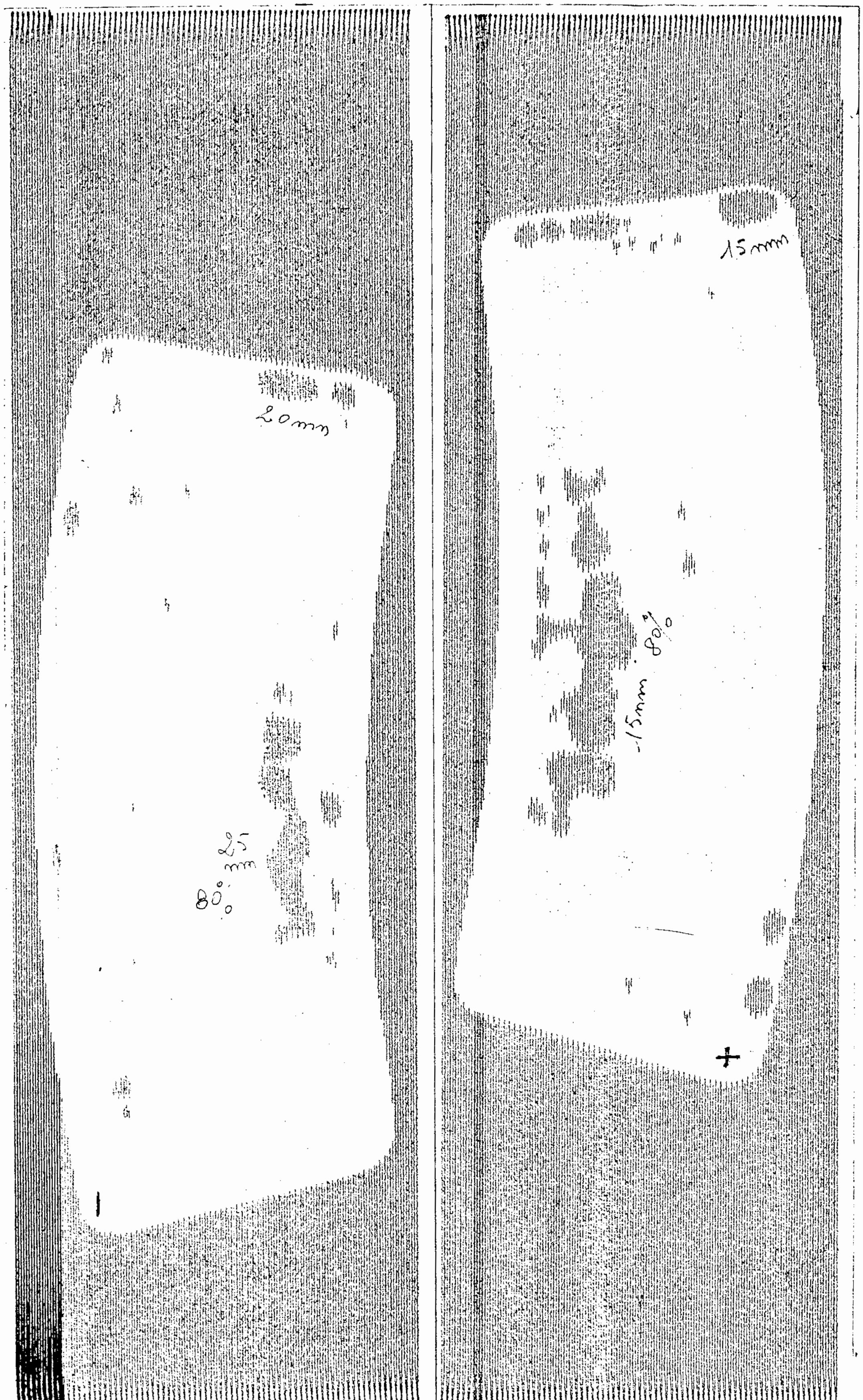


FIG.17- U.S. INSPECTION OF SLICE -25/+15 OF SPECIMEN N°1

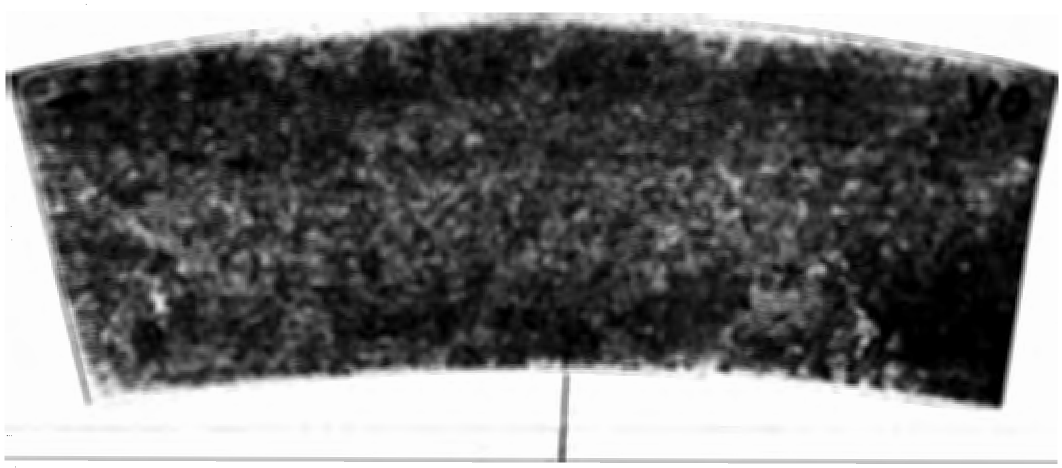


FIG.18- MACROGRAPHY(SCALE 1:1)OF SPECIMEN N°1

AT X POSITION - 25

SPECIMEN : 1

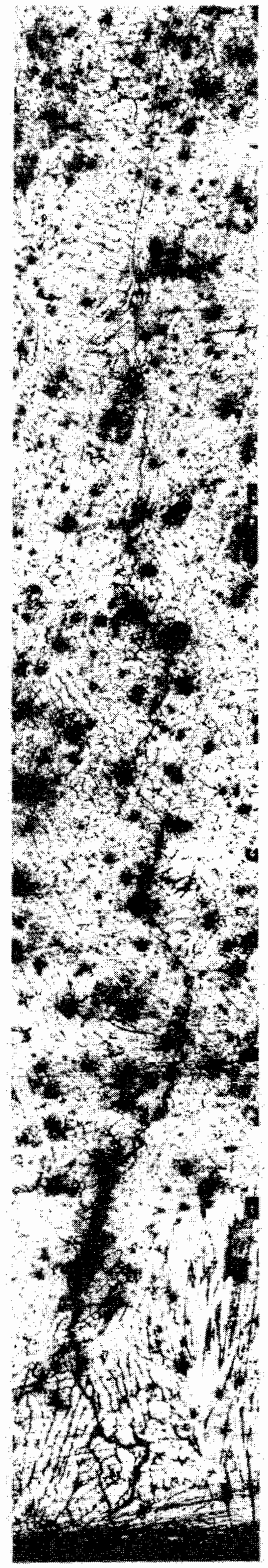
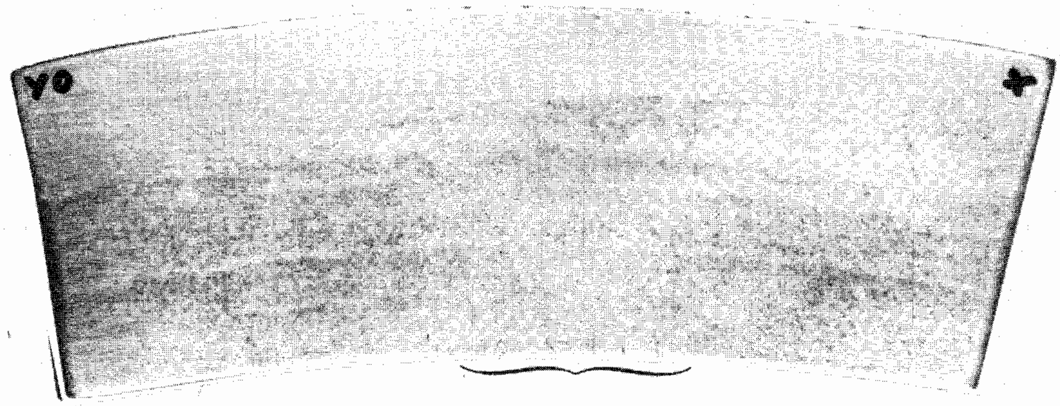


FIG.20.-DETAIL G OF FIG.18 ℄ -25 MM

(SCALE X20)



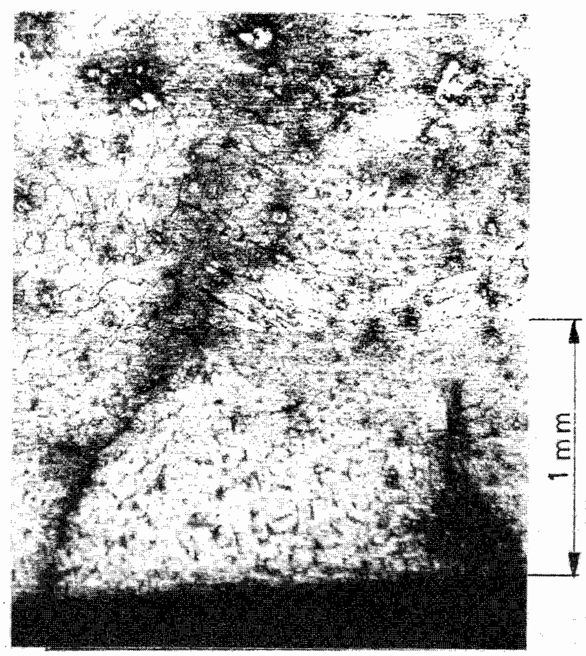
CRACK ZONE WITH CRACKS A B C D E F

FIG.19- MACROGRAPHY(SCALE 1:1)OF SPECIMEN N°1

AT X POSITION + 15

SCRIBELINE +15MM

CRACK A X40

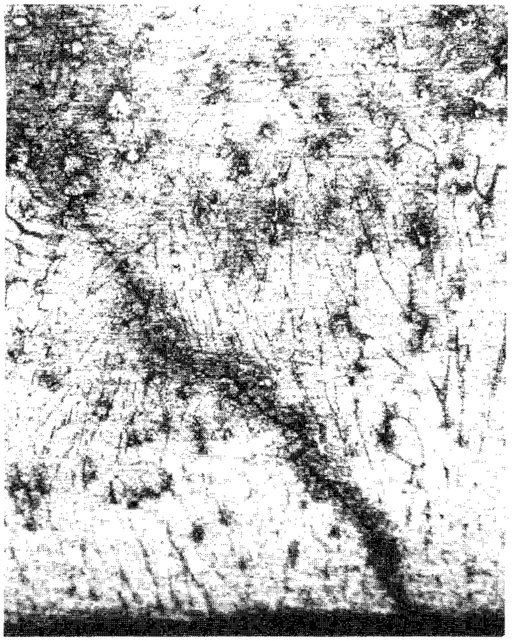


CRACK B X40

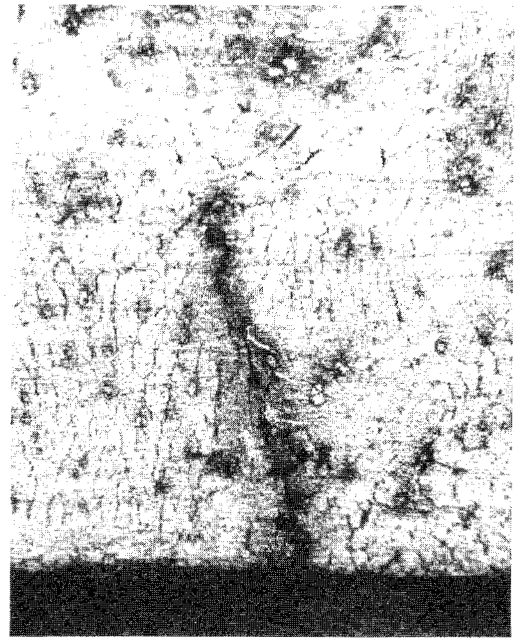
FIG. 21- DETAILS A B C D E F OF CRACK ZONE OF FIG.19

(SCALE x 40)

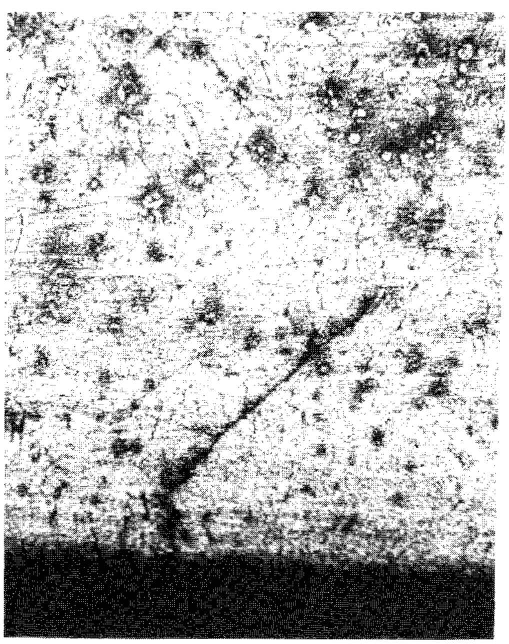
SPECIMEN : 1



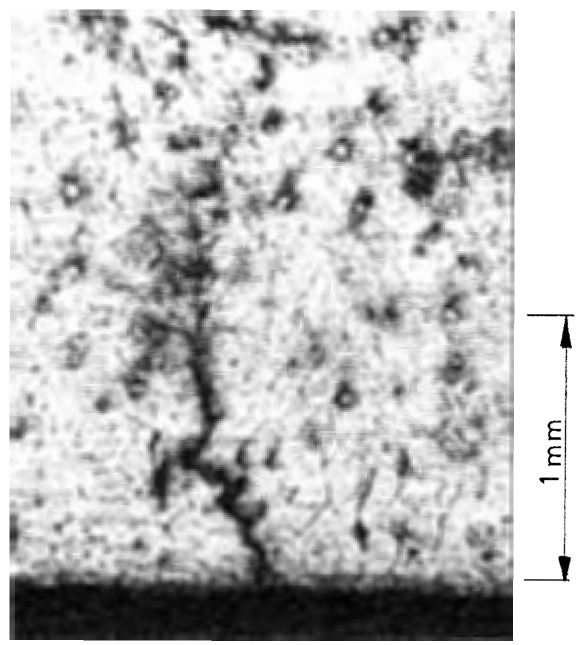
CRACK C(X 40)



CRACK D(X 40)



CRACK E(X 40)



CRACK F(X 40)

FIG. 21a

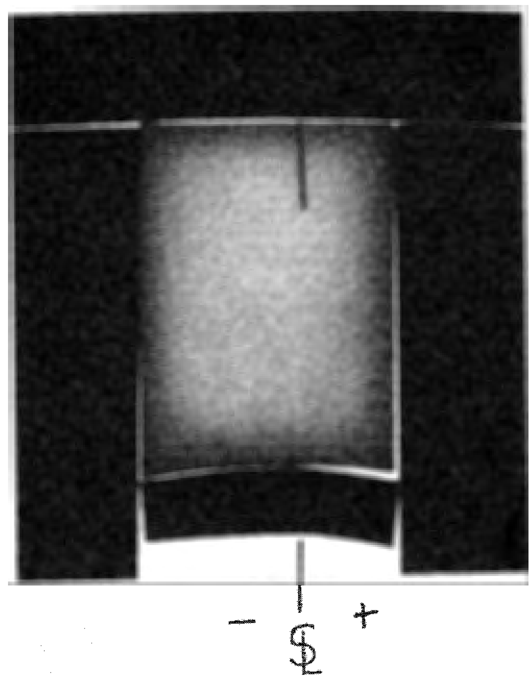


FIG. 22- RADIOGRAPH OF THE SPECIMEN N°1 THROUGH PLAN XZ (Y= 69) IN DIRECTION Y+ (SCALE 1:1)

SPECIMEN :1

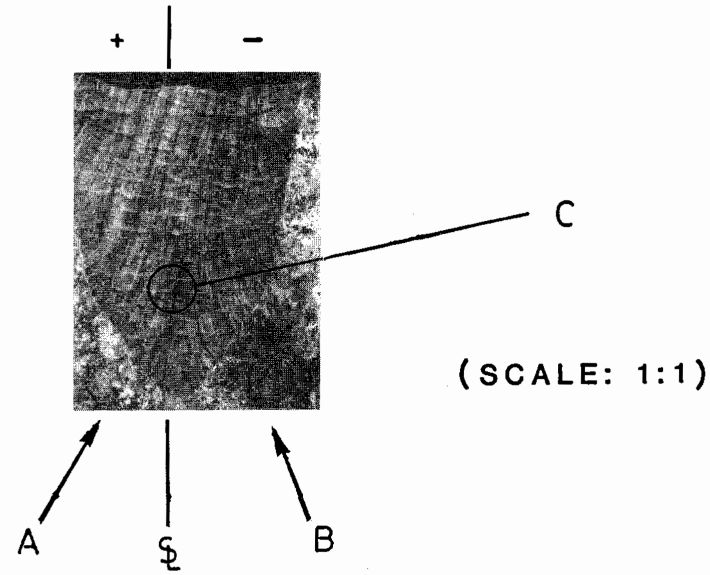


FIG. 23- MACROGRAPH OF SPECIMEN 1 (SLICE 69/79) AT Y-79

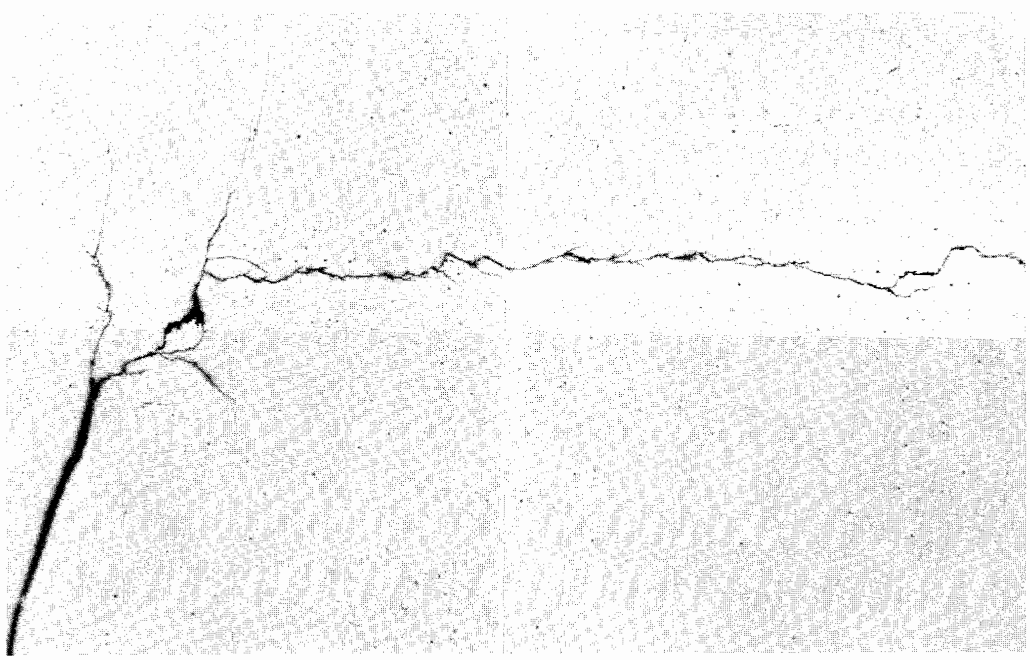
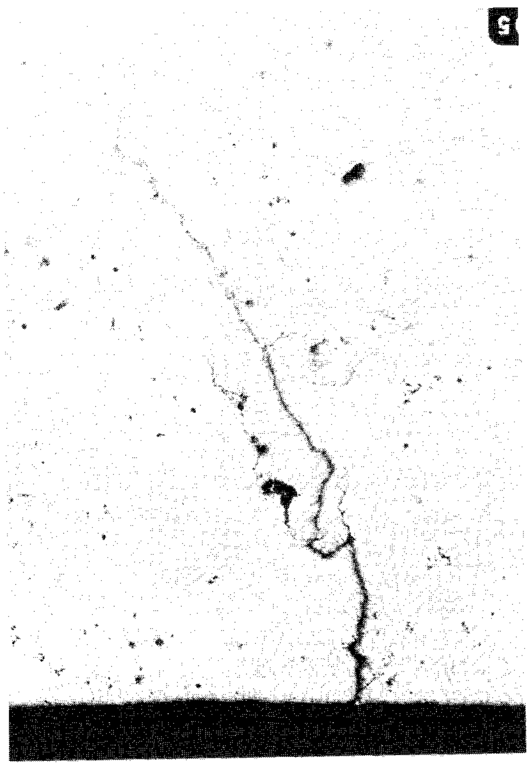
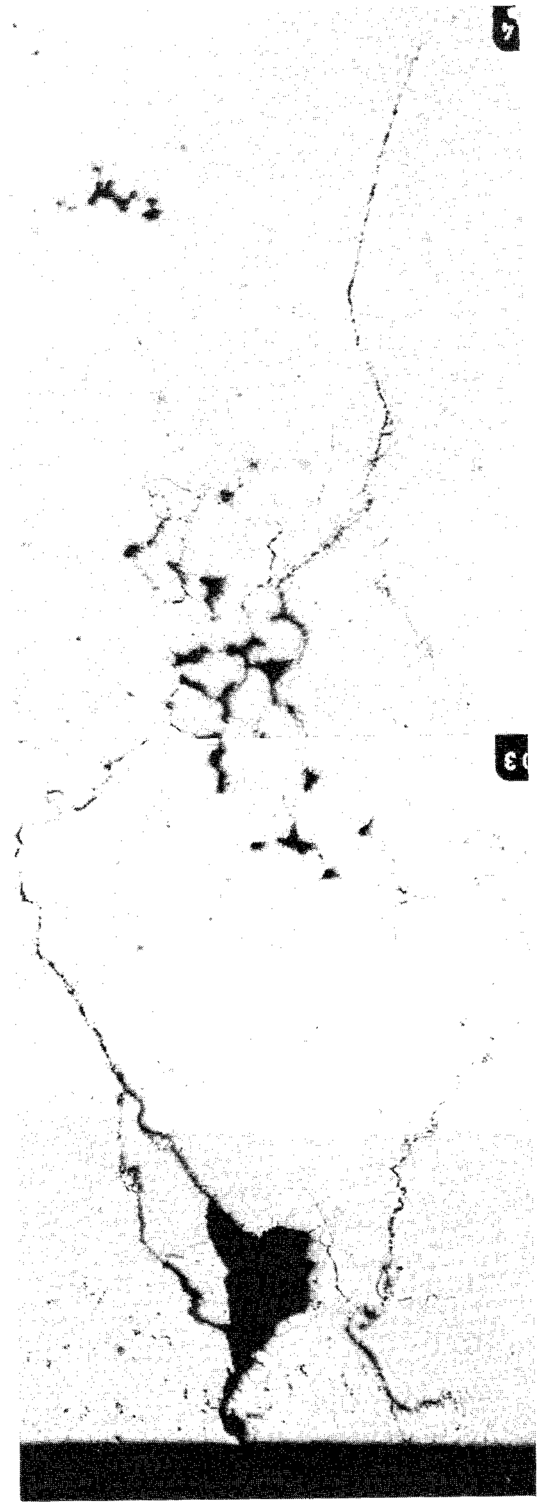


FIG. 24- DETAIL C OF FIG.23 AT Y-79. THE TOP OF THE INTENDED DEFECT C (SCALE x 40)

SPECIMEN :1

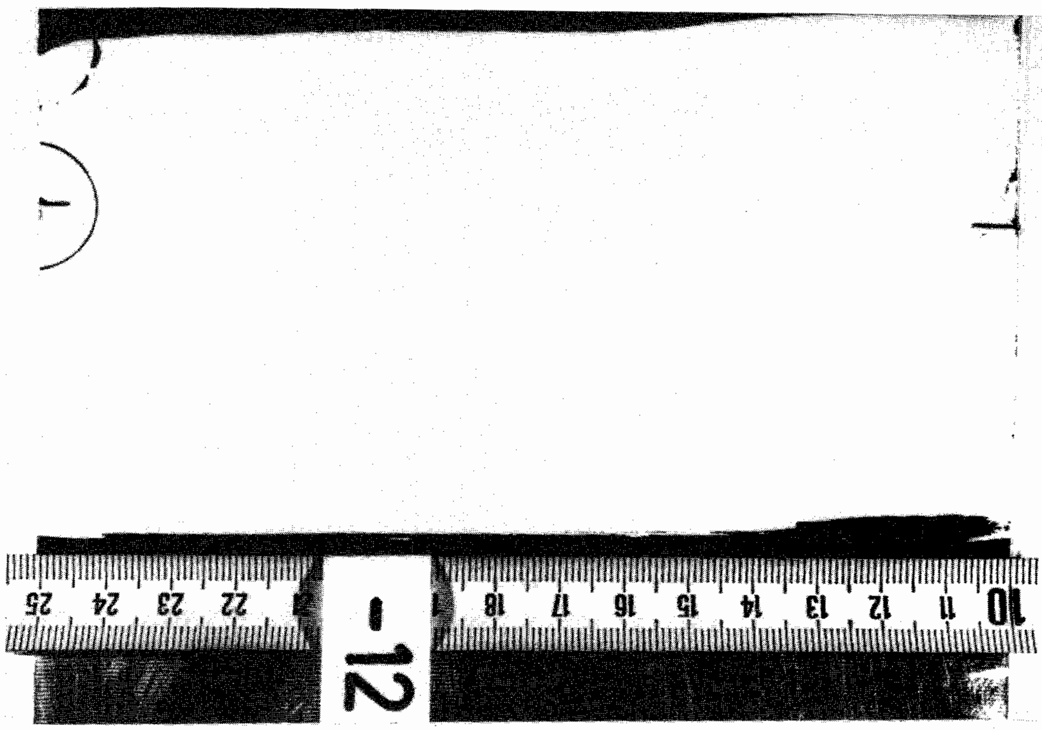


DETAIL A (X 20)



DETAIL B (X 20)

FIG. 25- DETAILS A AND B OF FIG. 23 AT Y=79



Specimen No. 12 : blank

FIG.26- DYE PENETRANT RESULTS FOR SPECIMEN N° 12

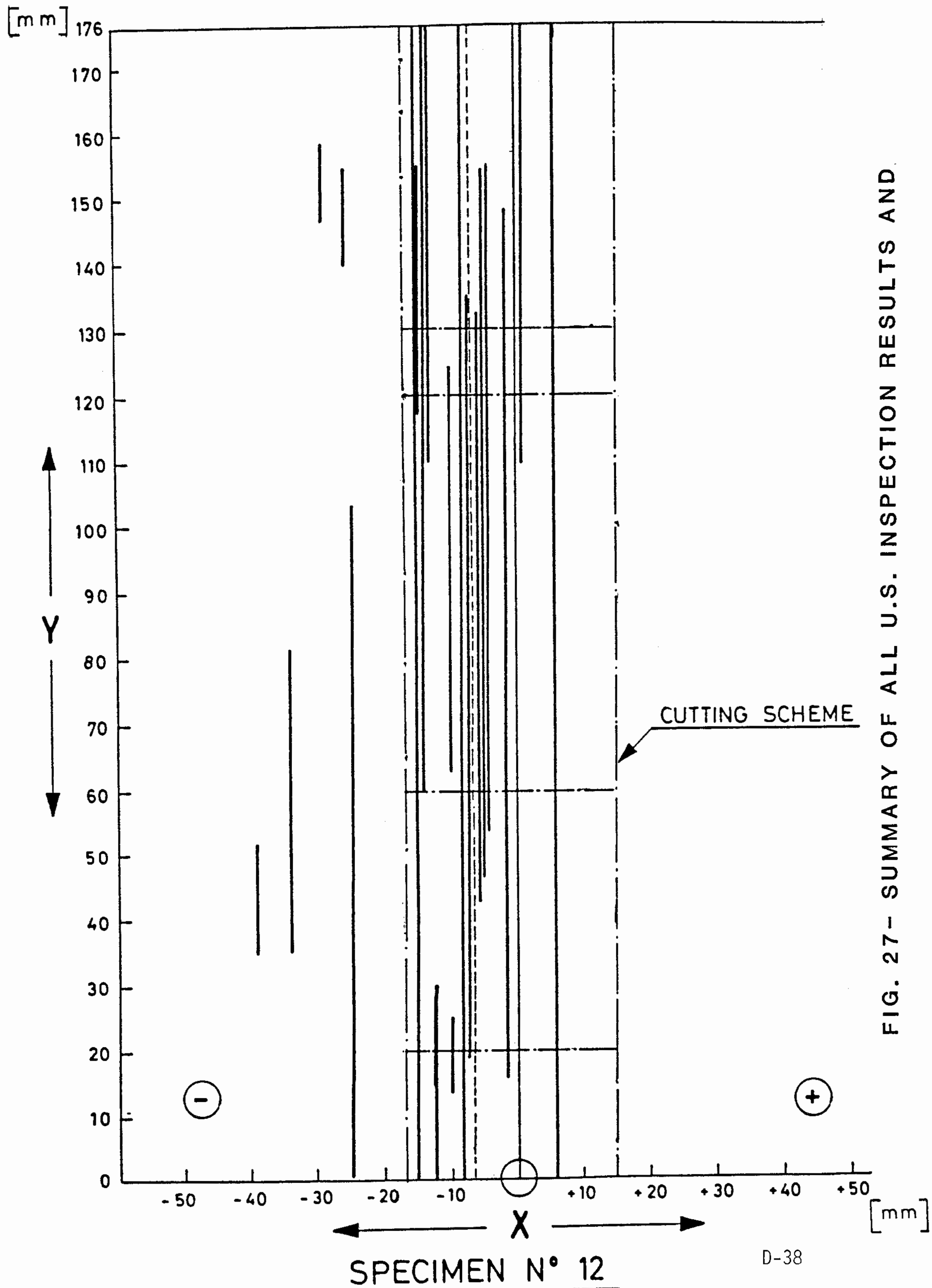
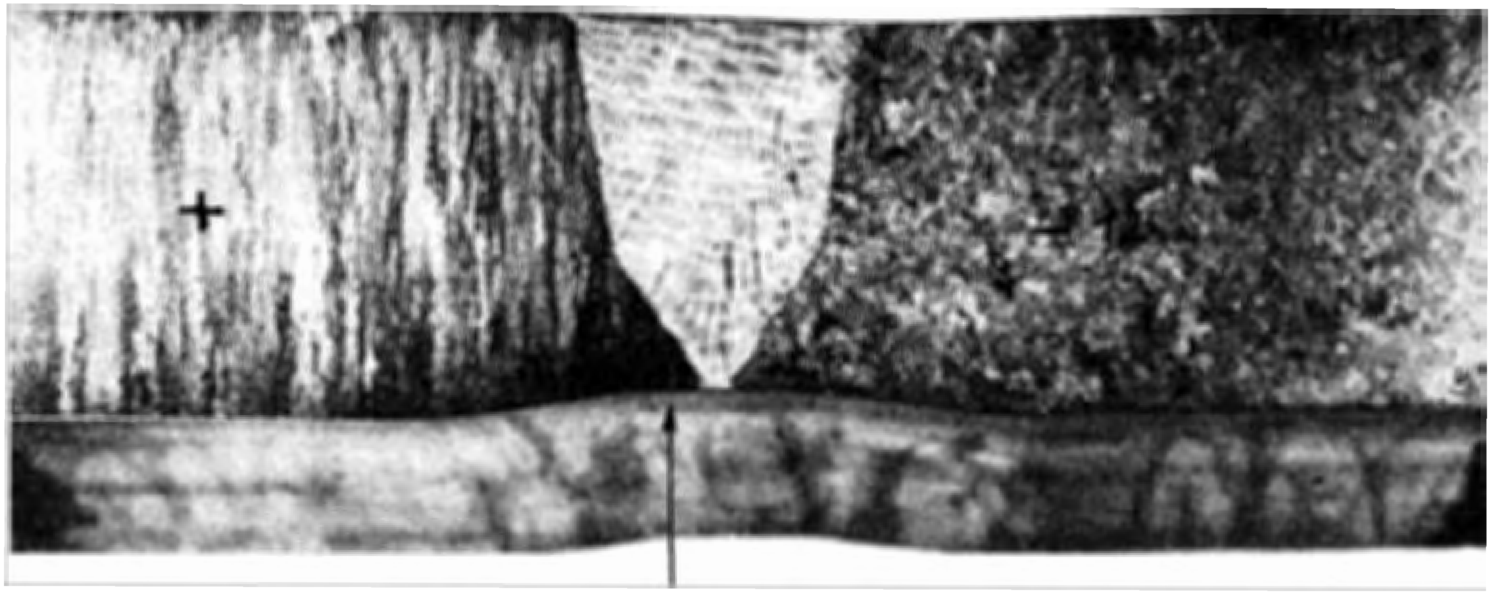


FIG. 27- SUMMARY OF ALL U.S. INSPECTION RESULTS AND CUTTING SCHEME OF SPECIMEN N° 12



SPECIMEN: 12 SCRIBE LINE SCALE: 1:1

FIG.28-MACROGRAPH OF THE WELDING ZONE OF SPECIMEN N°12

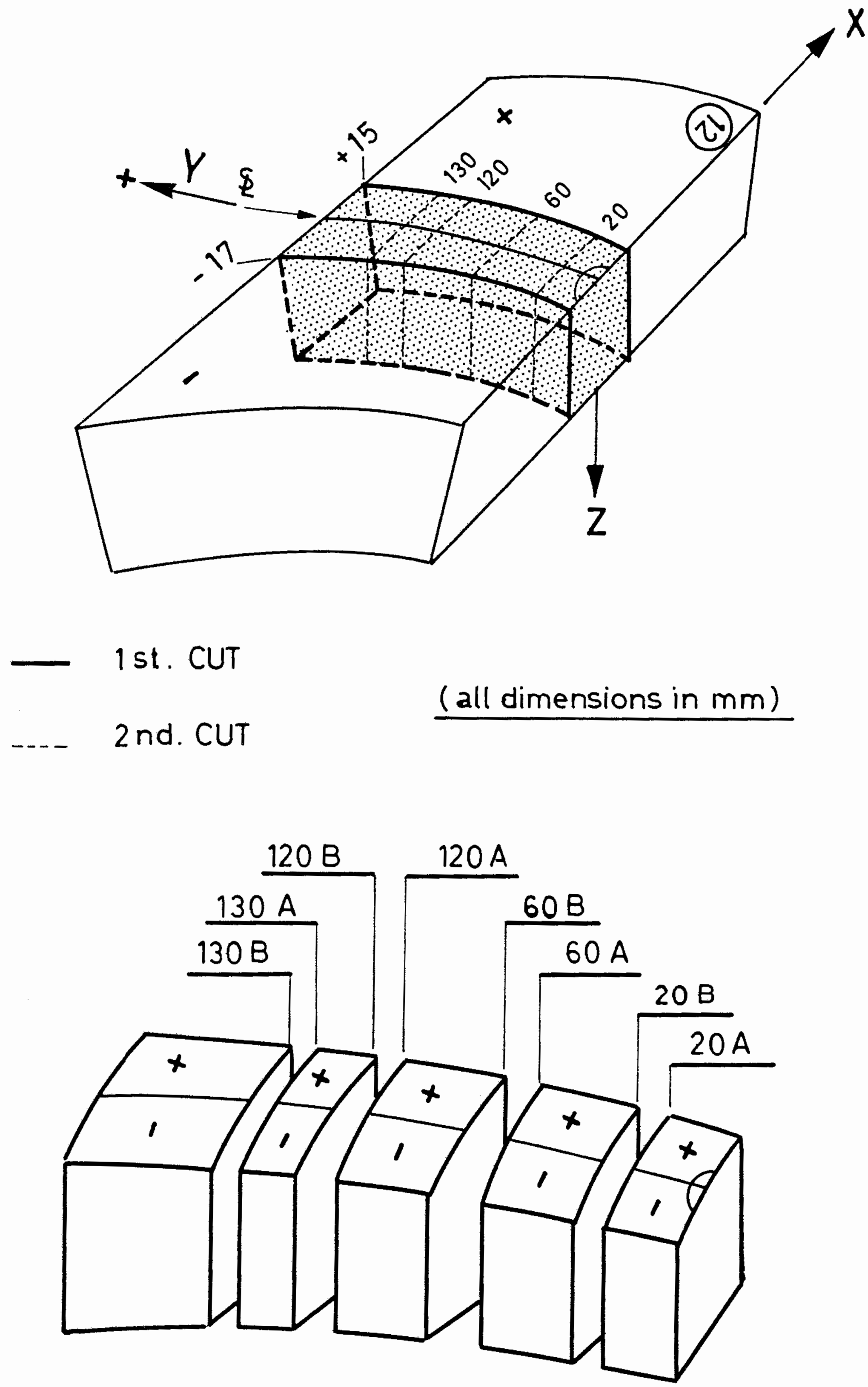


FIG. 29 - CUTTING SCHEME OF SPECIMEN N° 12

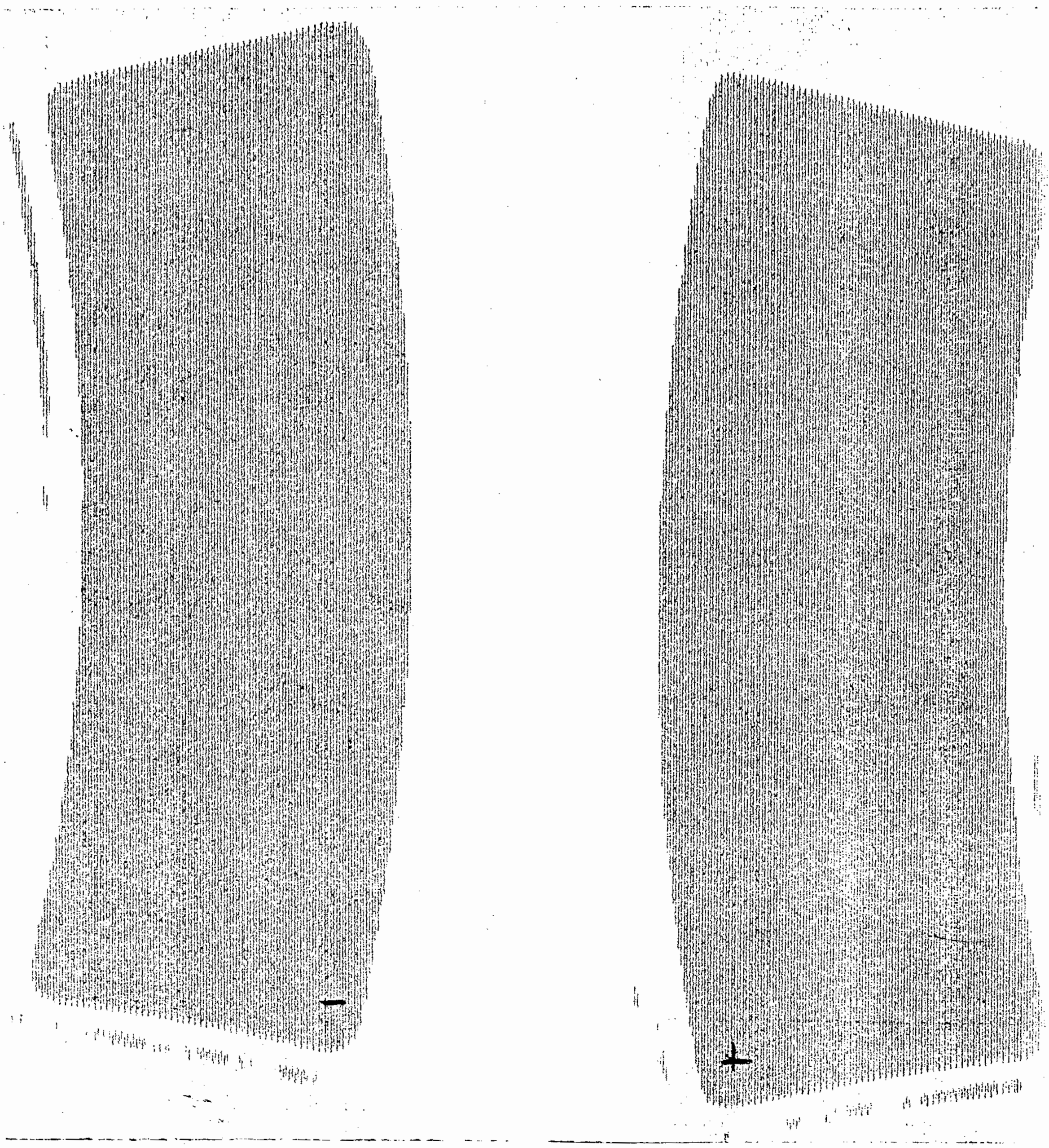


FIG.30- U.S. INSPECTION OF SLICE -17/15 OF SPECIMEN 12

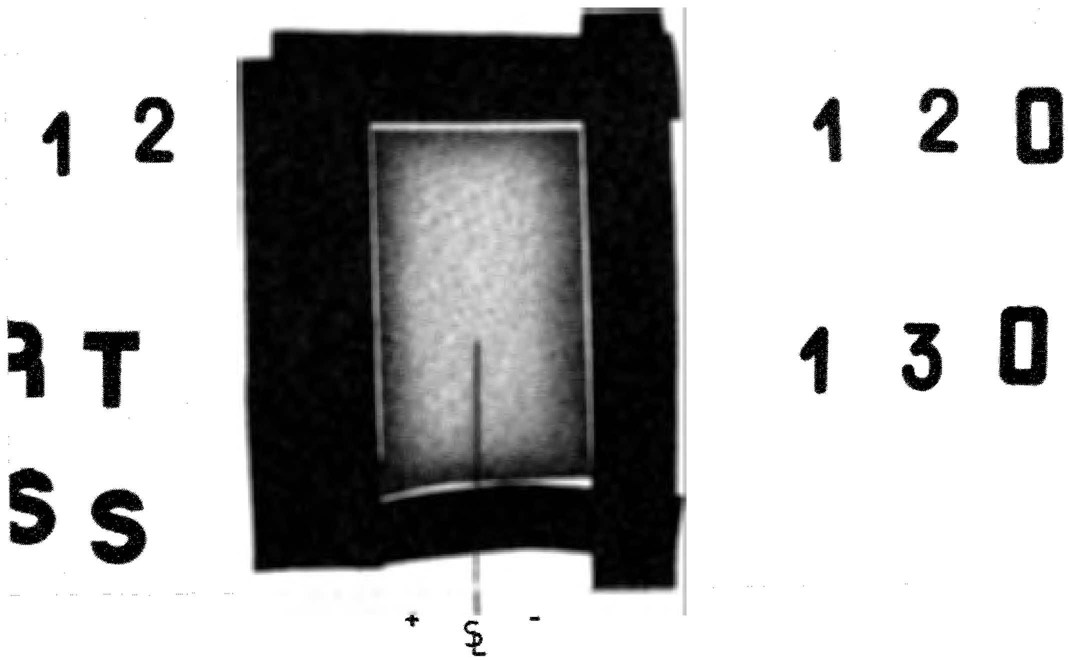
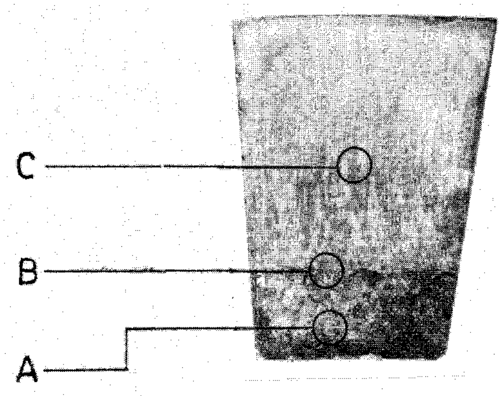


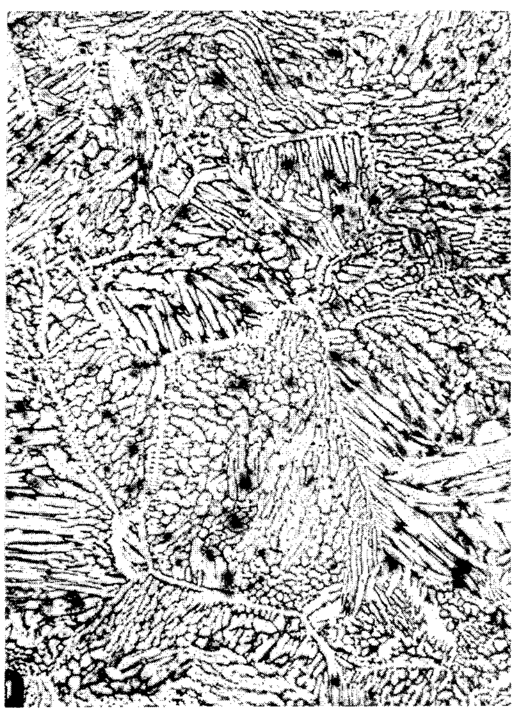
FIG. 31- RADIOGRAPH OF SLICE 120/130 OF SPECIMEN N° 12

SPECIMEN:12

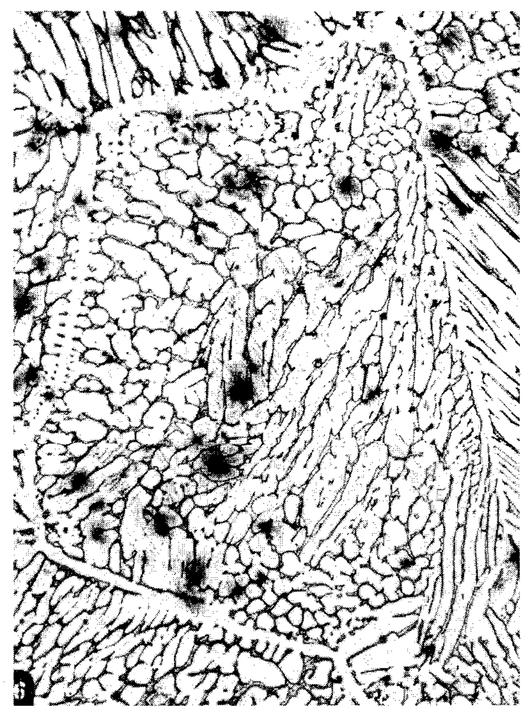


SCALE 1:1

MACROGRAPH OF FACE X --17 (SLICE END/130 B)



DETAIL A x20

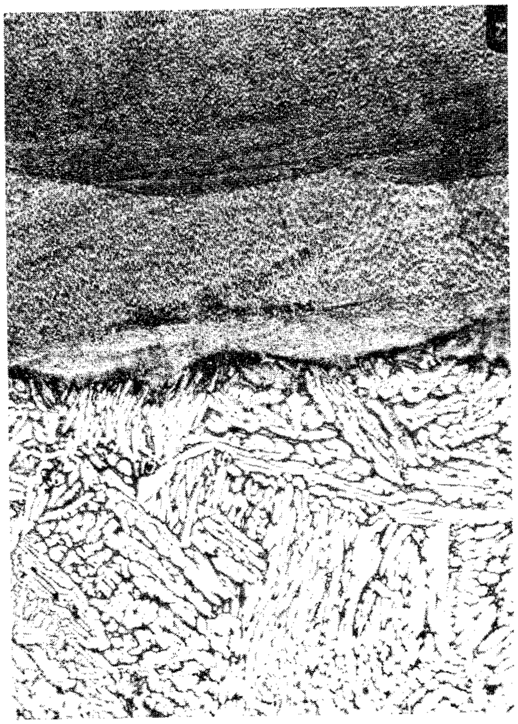


DETAIL A x40

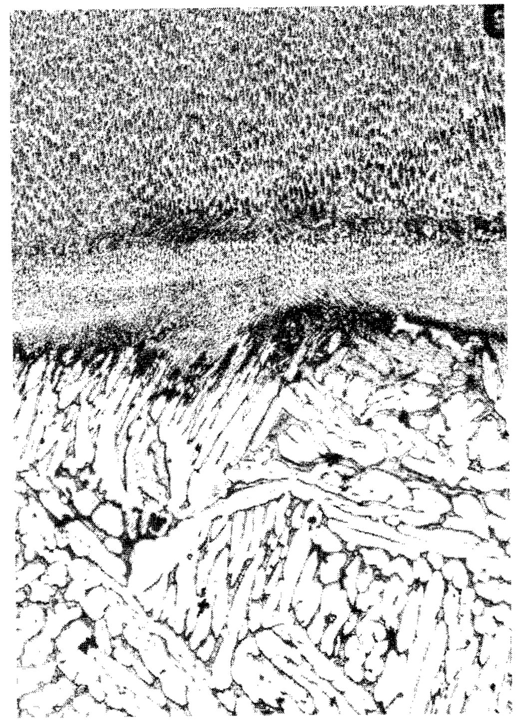
FIG. 32 METALLOGRAPHIC INSPECTION OF

FACE X -- 17 (SLICE END/130 B)

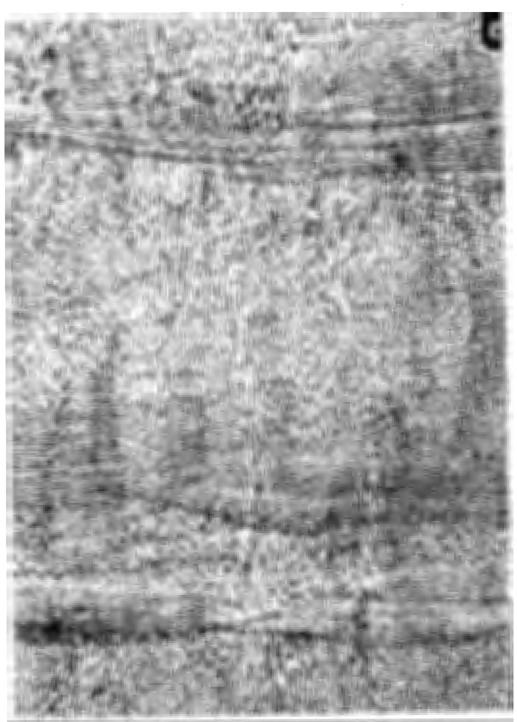
SPECIMEN:12



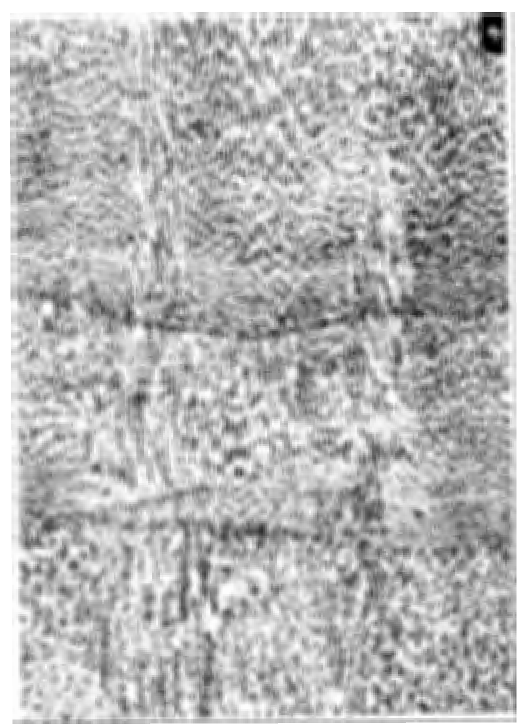
DETAIL B x20



DETAIL B x40



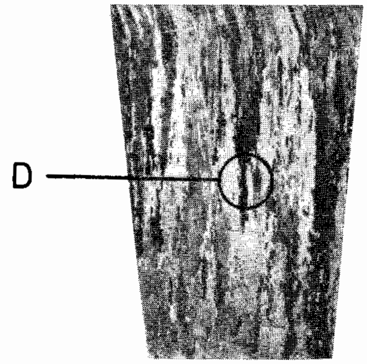
DETAIL C x20



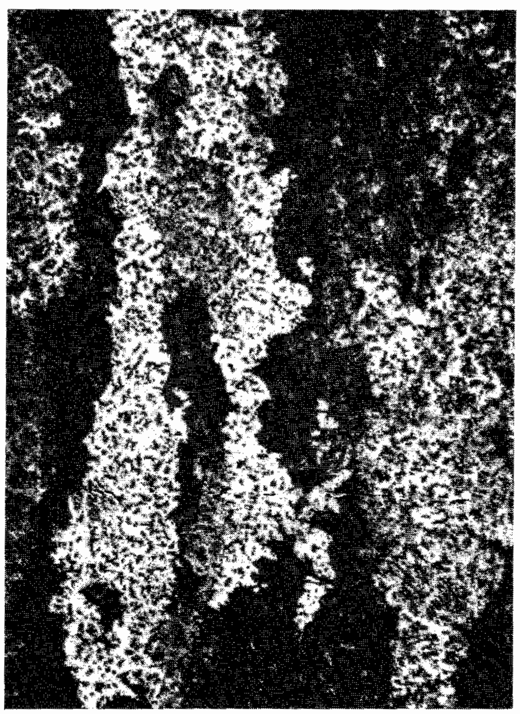
DETAIL C x40

FIG. 32a

SPECIMEN: 12



MACROGRAPH OF FACE X-+15 (SLICE 130 B/END)



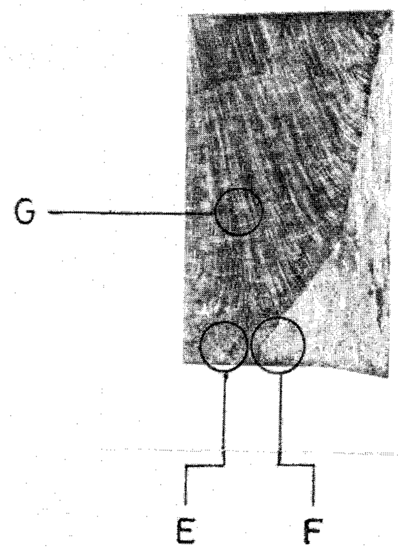
DETAIL D x20

DETAIL D x40

FIG. 33 METALLOGRAPHIC INSPECTION OF

FACE X-+15(SLICE 130 B/END)

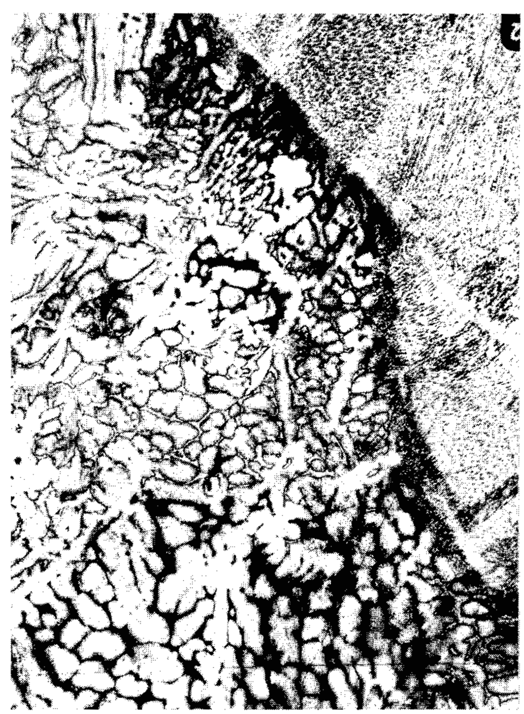
SPECIMEN:12



SCALE 1:1

MACROGRAPH OF FACE Y-130 B

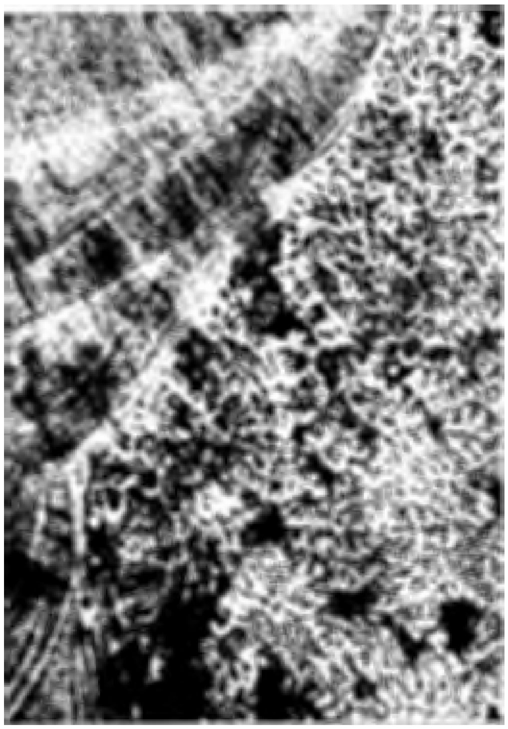
DETAIL E x20



DETAIL E x40

FIG.34 METALLOGRAPHIC INSPECTION OF FACE Y-130 B

SPECIMEN:12



DETAIL F x20

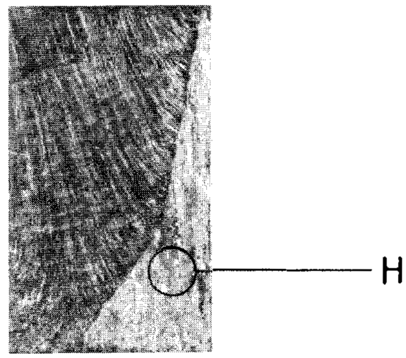
DETAIL F x40

DETAIL G x20

DETAIL G x40

FIG. 34 a

SPECIMEN:12



SCALE 1:1

MACROGRAPH OF FACE Y- 130 B

DETAIL H x20

DETAIL H x40

FIG. 34b

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

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E. Burck*

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13. ABSTRACT (200 words or less)

This report presents the results of the Centrifugally Cast Stainless Steel Round Robin Test (CCSSRRT). The CCSSRRT is the first phase of an effort to investigate and improve the capability and reliability of NDE inspections of CCSS. This phase was a screening test to identify the most promising procedures presently available for CCSS. The next phase will be a more in-depth program. Fifteen centrifugally cast stainless steel pipe sections containing welds and laboratory-grown thermal fatigue cracks in both columnar and equiaxed base material were used. These pipe specimens were inspected by a total of 18 teams from Europe and the United States using a variety of NDE techniques, mostly ultrasonic. It was anticipated that the anisotropic and coarse-grained structure of the specimens would present the inspecting teams with the problem of not only detecting the cracks but also of properly classifying uncracked material. Thus, measurement of team performance included results in both cracked and uncracked material. Some procedures showed promise; however, because of the high number of false crack calls reported by many of the inspecting teams it was difficult to demonstrate that some of the procedures could effectively discriminate between thermal fatigue cracks and uncracked CCSS. The results of the CCSSRRT make it apparent that a more detailed study on the capability and reliability of procedures to inspect stainless steel materials is needed to better understand the specific material and flaw properties and how they affect the outcome of an inspection.

14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS
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