THE USE OF ACOUSTIC EMISSION AS A WELD QUALITY MONITOR

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ABSTRACT

Acoustic emission monitoring is discussed to provide a general understanding of this technique used as a weld quality monitor. The most important feature of the acoustic emission technique as opposed to other nondestructive testing methods is that the data is real-time; thus, one can more effectively determine the causes of the weld defects. The wide-ranging applications of this technique are illustrated by examples of real-time data from submerged-arc, gas tungsten arc, and spot welding. Acoustic emission can be used to detect defective welds and roughly indicate the extent of the defects; moreover, crack growth can be related to other dynamic conditions of the weld. As a supplement to established weld inspection methods, acoustic emission monitoring can result in reduction of re-work costs and improvement of weld quality.

THE USE OF ACOUSTIC EMISSION AS A WELD QUALITY MONITOR

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INTRODUCTION

Acoustic emission monitoring adds a new dimension to the nondestructive inspection of welds. The purpose of this paper is to provide a general understanding of the acoustic emission technique used as a weld quality monitor. The development of acoustic emission technology is briefly summarized, a representative acoustic emission pulse is described, and typical weld monitoring instrumentation is discussed. The wide-ranging applications of acoustic emission monitoring are illustrated by examples of real-time data from submerged-arc, gas tungsten-arc, and spot welding. Cracks, porosity and inclusions can be detected in real-time as the weld metal cools. The ability to relate defect formation to dynamic conditions in a weld is illustrated by the measurement of crack development temperature.

CONCLUSIONS

The wide-ranging applications of acoustic emission as a weld quality monitor are indicated by the results obtained in our experiments with spot welding, submerged-arc welding, gas tungsten-arc welding, and brazing. The most important feature of this technique as opposed to other nondestructive testing methods is that the data is real-time. Knowing the time at which weld defects occur, one can determine more effectively the causes of those defects. Production line applications of acoustic emission weld monitoring are practical now, but empirical calibration is required for each application. The technique is not qualified as a final inspection test, but when used to supplement established weld inspection methods acoustic emission monitoring can result in reduction of re-work costs and improvement of weld quality.

PERSPECTIVE

The term "acoustic emission" was used by early researchers to describe the sounds emitted by materials during plastic deformation or fracture. Schofield[1] and other pioneers in acoustic emission found that when a metal was stressed in noise-free surroundings, low-level sounds were emitted from the metal. Failure of the test specimen could be predicted by monitoring the increase in intensity of the acoustic emissions. To detect these low-level acoustic emissions, however, it was necessary to exclude external sounds such as conversation, foot steps, and machinery noise from the vicinity of test specimen. Field application of acoustic emission appeared to be impractical because of the interference of external noise.

Recent experiments at Battelle-Northwest[2] and other laboratories indicate that acoustic emissions can be detected in the field by monitoring frequencies much higher than those audible. The acoustic energy released when a metal yields is spread over a wide frequency range, extending beyond 30 MHz. The term "acoustic emission" has been redefined, therefore, take into account to this broad frequency range. As we use it now, "acoustic emission" refers to the pressure waves released in a material as the material is fractured or deformed.

Within the range of frequencies released upon fracture there is an optimum band of frequencies limited by the low frequency machinery noise and the attenuation of higher frequencies in the material. This optimum band spreads approximately from 100KHz to 2.0 MHz.

Field applications of acoustic emission monitoring are entirely practical now even in noisy factory environments. Some of the applications now under development include the detection of flaws in pressure vessels and piping while undergoing hydrostatic test, detection of onset of failure in fatigue tests, and detection of weld defects as they form during welding.

ACOUSTIC EMISSION CHARACTERISTICS

The mechanism by which acoustic emissions are generated is essentialy the same for all cases. Stress builds up around a discontinuity or flaw until it exceeds the yield strength of the material. At this point, a rather sudden yielding relieves the stress concentration. It is this sudden relief of the concentrated stress that gives rise to the pressure waves defined as acoustic emissions.

An oscillogram of a typical acoustic emission burst is shown in Figure 1. The sharp leading edge of the signal represents the initial stress relief impulse while the remaining oscillations are caused by multiple reflections within the plate. This pulse was amplified 10,000 times to an amplitude of about 6 V peak-to-peak. The duration of the pulse was approximately 10 msec.

INSTRUMENTATION

The acoustic emission pulse illustrated in Figure 1 was caused by a transverse crack during a welding operation similar to that shown in Figure 2. The sensor is a Lead-Zirconate-Titanate (PZT-5A) transducer of the type used in ultrasonic test equipment. The PZT-5A type transducers were selected for high sensitivity and operating temperature range (up to 650°F). The welding equipment is an automatic gas-tungsten arc welding machine which was used for a series of experimental welds.

The sensor location with respect to the weld line is not critical. Acoustic emission signals suffer negligible attenuation as a result of corners or bends in the signal path. Thus, any convenient location will suffice that is sufficiently removed from the heat affected zone to prevent overheating of the sensor or couplant. In the above example (Figure 2), the sensor was placed approximately 2 in. from the heat affected zone near the midpoint of a 36 in. long weld seam. The sensor was coupled acoustically to the plate by a quick-setting epoxy which is useful up to 300 °F. High temperature silicone grease or contact pressure coupling are used for higher temperature applications up to 600 °F.

Acoustic emission pulses detected by the sensor are amplified and processed electronically to provide a chart recorder presentation. A block diagram of an acoustic emission monitor system is shown in Figure 2. The recorder displays the "acoustic emission rate" or "energy release rate." This quantity is obtained by combining the effects of emission pulse amplitude, duration, and repetition rate. As indicated in the block diagram, the amplified signals are integrated over a selected time interval by a clock-controlled integrator. At the end of each clock period the value of the integral is stored in the sample-and-hold circuit. The integrator resets immediately to accumulate a new value, while the value stored in the sample-and-hold circuit is displayed by the chart recorder for one full clock period. The recorder displays the rate of change of the integrated input signals or the "acoustic emission rate." The advantage of the clock-controlled integrator is that increasing the clock period smooths the acoustic emission rate output but does not affect the integrator linearity. A sample acoustic emission rate chart is shown in Figure 4. This record was made during welding by the submerged-arc process. Comparison of the two traces shown here demonstrates the sensitivity of the acoustic emission monitor system.

APPLICATIONS OF ACOUSTIC EMISSION MONITORING

SUBMERGED-ARC WELDS*

Submerged-arc welding is one type of weld that we investigated. The two traces shown in Figure 4 represent only a portion of the 54 in. length of a butt weld made in 6-in.-thick steel plate. Acoustic emission was monitored during 75 passes on this weld. The background emission represents fracture of the slag that forms over a submerged-arc weld bead.

*This investigation sponsored by NORTEC, Inc., Richland, Washington

Over a smooth weld bead such as that produced by Operator B, the slag lifts away easily from the weld surface as it cools, producing very little acoustic emission. On the other hand, if the bead is heavy and tends to ripple, such as that produced by Operator A, the slag fractures extensively as it lifts away from the weld surface. It is important to note that the high background level produced by Operator A tended to mask the transverse crack; but the low background level obtained by Operator B allowed the acoustic emission from the transverse crack to stand out prominently.

The transverse crack initiated in the first inch of weld metal and continued to propagate through the weld metal deposited by both operators. Contaminants were added to the weld metal to cause defects. We found that cracks, porosity, or inclusions were indicated by a significant increase in the acoustic emission level. This increase in level does not occur immediately, but approximately 45 sec. after the arc has passed the defect region. The time delay depends upon the cooling rate of the weld metal, but once this time delay is known a defect can be located approximately.

AUTOMATIC GAS TUNGSTEN-ARC WELDS

We have also investigated acoustic emission from defects in welds made by the automatic gas tungsten-arc process. Figure 5 shows some results obtained on 1/8 in. thick 304L stainless steel.[3] This was a V-groove butt weld using filler metal which required only one pass to complete. As the graph indicates, cracks were induced at two locations along the weld by contaminating the weld metal with small bits of titanium. This weld was 36 in. long and arc travel was approximately 4.5 in. per minute, so about 8 min. were required to complete the weld. Acoustic emission rate is shown here as a function of time to demonstrate the time delay between welding the contaminated sections and the development of cracks. The defect marks on the graph indicate the time at which the arc passed over the contaminated sections. Peak emission rate for the two defects occurs between 30 sec. and 1 min. after welding.

The acoustic emission rate from several welds of this type was recorded and the cooling rate of the weld metal was obtained from a thermocouple in the fusion zone. Figure 6 shows the relationship between the acoustic emission rate and the temperature at which the defect is formed. The cooling rate was measured from the melt. This graph indicates a peak in the emission rate at around 400° C. The peak emission rate presumably occurs at different temperatures for other materials and weld geometries. The important point demonstrated by this graph is that acoustic emission can be used to relate crack growth to other dynamic conditions of the weld.

MANUAL GAS TUNGSTEN-ARC WELDS

Acoustic emission monitoring can also be used with manual welding. Figure 7 shows some results obtained from 1/2 in. thick stainless steel coupons.[4] The welds were manual gas tungsten-arc V-groove butt joints 2 in. long. The weld on the left was contaminated with titanium to produce extensive cracking in the center region. The weld on the right has one crack near the center and a hairline crack near the surface on the left side. The point of interest here is that neither of these defective welds were detected by radiography, while the acoustic emission monitor indicated in excess of 10,000 emissions for the weld on the left and 200 for the weld on the right.

We also found, as illustrated in Figure 8, that porosity could be detected by acoustic emission. Three welds contained extensive porosity as indicated by the radiographs and the photomicrographs. Evidence of cracking is present only in weld number 9, but more than 400 acoustic emissions were recorded from each weld. From Figures 7 and 8 we must conclude that acoustic emission can be used to detect defective welds and at least roughly indicate the extent of the defects, but it cannot differentiate between types of defects.

These results have been verified on a number of other materials, e.g., aluminum, titanium, Inconel 718, and 4130 steel. Cracks and porosity in brazed joints in mild steel were also detected.

SPOT WELDS

A brief investigation of spot welding[5] as another application of acoustic emission yielded slightly different results. Figure 9 shows that acoustic emission can be used to determine the nugget diameter of spot welds. Two thin strips of 6061 aluminum were joined by a series of spot welds. The acoustic emissions were detected by a sensor mounted on one strip.

We found that acoustic emissions from a spot weld occur in three separate groups. The first group occurs when the electrodes clamp the parts to be welded, the second group occurs as the electrodes discharge and material becomes plastic, and the third group occurs when the electrodes release the parts after the weld is completed. The acoustic emission shown here, which is related to nugget diameter, is from the third group only. Electrode contact area as well as nugget diameter are related to the extent of plastic flow of the material during the weld. The amount of acoustic emission generated appears to be related to the area of surface contact between the electrode and the material. This is supported to a certain extent by the one point that falls completely off the graph. This weld was made purposely near a previously completed weld. The welding current was shunted through the nearby weld so that fusion did not occur. The electrode contact area and the number of acoustic emissions, however, were comparable to that obtained from a large nugget weld. This demonstrates that the acoustic emission observed is indirectly related to the nugget diameter.

SUMMARY

The results obtained from our experiments with spot welding, gas tungsten-arc welding, and submerged-arc welding demonstrate the potential of acoustic emission monitoring as a nondestructive test for welds. The real-time nature of the acoustic emission data sets this technique apart from other nondestructive methods used for weld inspection. Since the acoustic emission from weld defects is transient, empirical calibration is required for each application. Defects can be located approximately but the type of defect cannot be determined.

Our research effort is at present, directed toward detailed analysis of specific welding applications and the development of a technique to accurately locate defects which cause acoustic emission.

References

1. B. H. Schofield. Acoustic Emission Under Applied Stress, ARL-150. Aeronautical Research Laboratory, Office of Aerospace Research, Wright Patterson Air Force Base, Ohio, December 1961.

2. P. H. Hutton. Detection of Incipient Failure in Nuclear Reactor Pressure Systems Using Acoustic Emission, BNWL-997, Pacific Northwest Laboratories, Richland, Washington, April 1969.

3. W. D. Jolly. "Acoustic Emission Exposes Cracks During Welding Process." The Welding Journal, Vol. 48, p. , 1969.

4. C. K. Day. An Investigation of Acoustic Emission from Defect Formation in Stainless Steel Weld Coupons, BNWL-902, Pacific Northwest Laboratories, Richland, Washington, January 1969.

5. W. D. Jolly. The Application of Acoustic Emission To IN-Process Weld Inspection, BNWL-SA-2212, Presented at 1969 Spring Conference of the ASNT in Los Angeles, California, March, 1969.

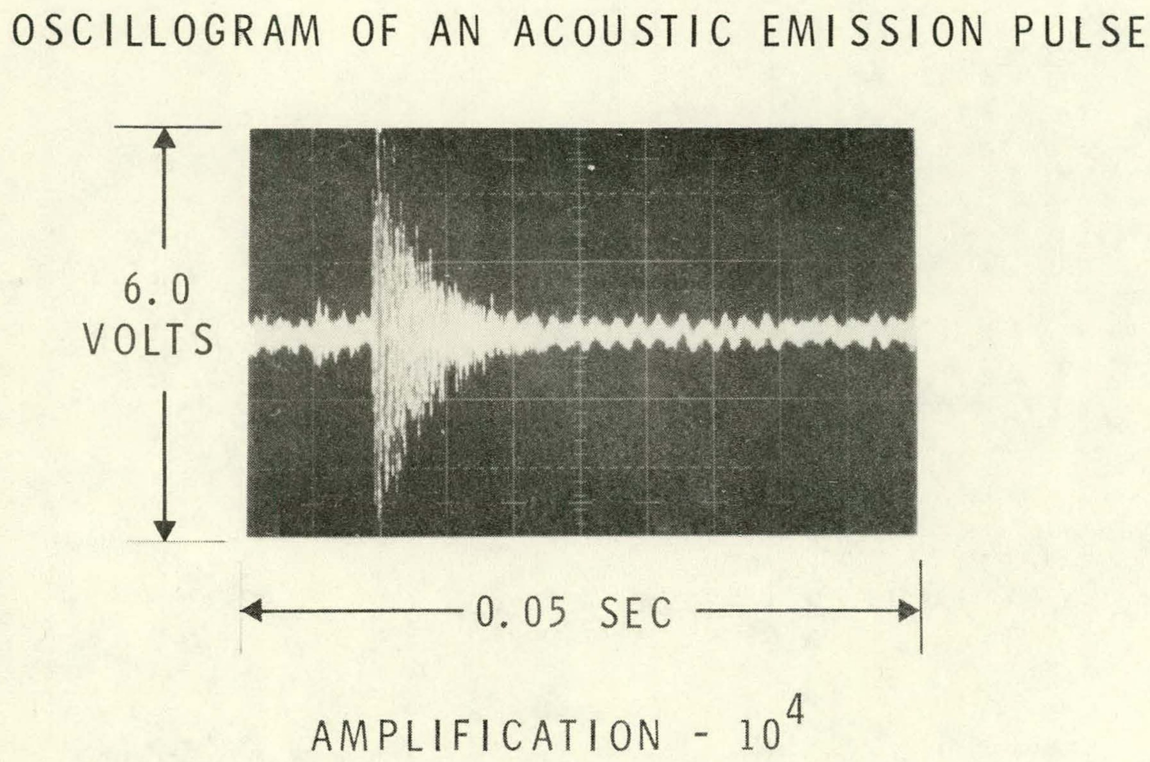


FIGURE 1. A Typical Acoustic Emission Pulse From a Weld Crack.

ACOUSTIC EMISSION SENSOR MONITORS QUALITY OF MACHINE WELD

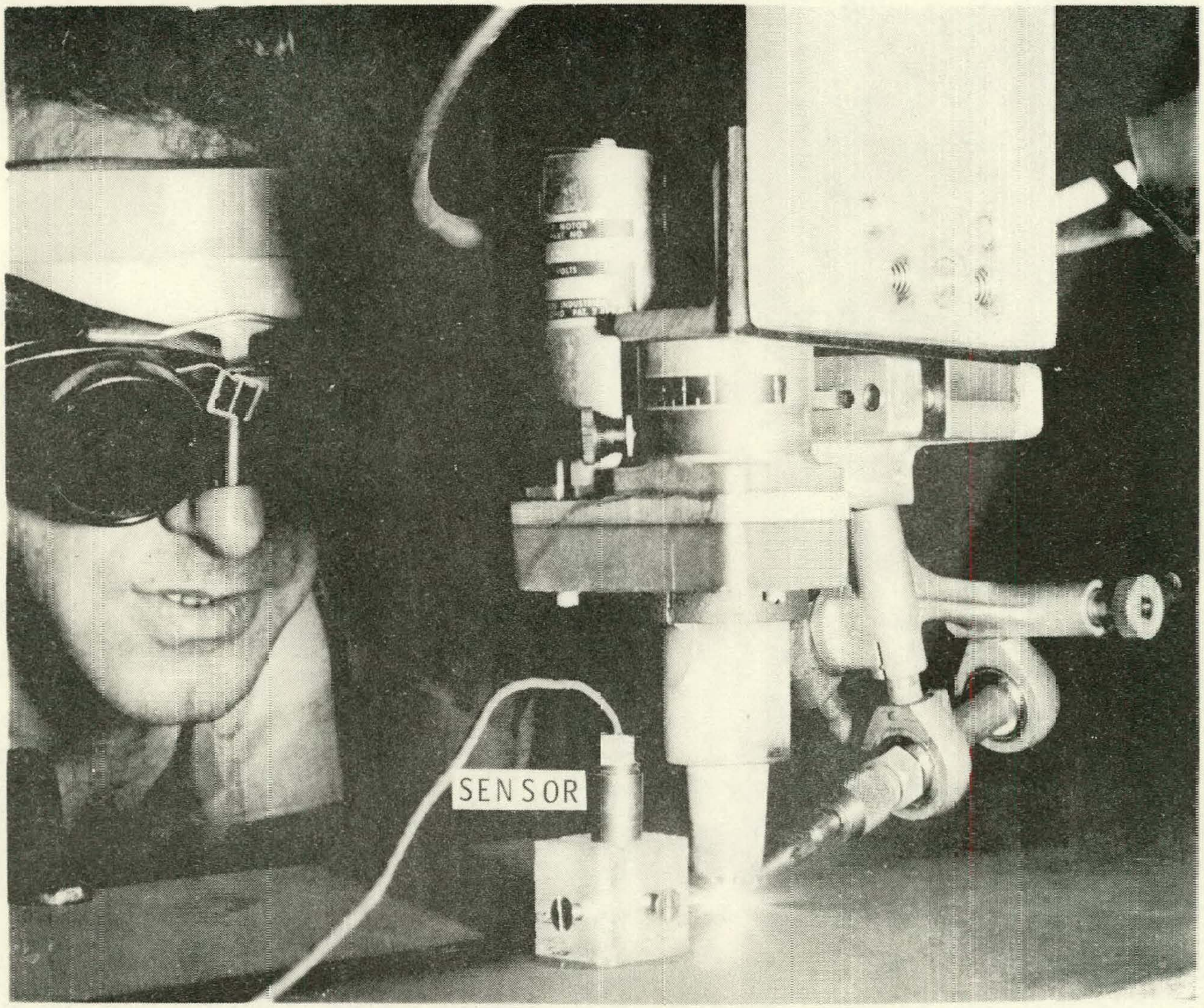


FIGURE 2. Welding Set-Up Illustrating the Location of the Acoustic Emissions Sensor.

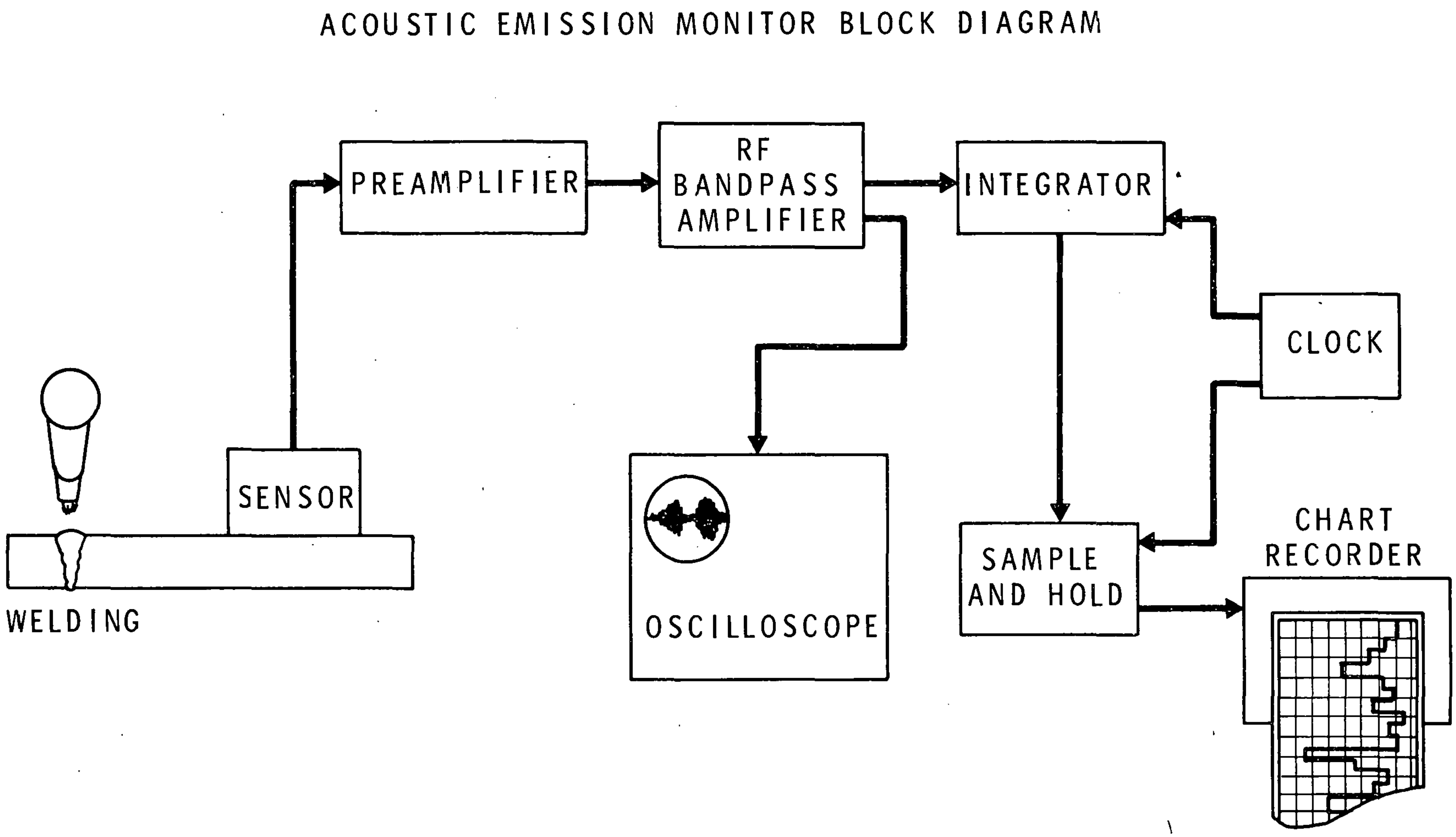


FIGURE 3. Block Diagram of the Acoustic Emission Weld Monitor System.

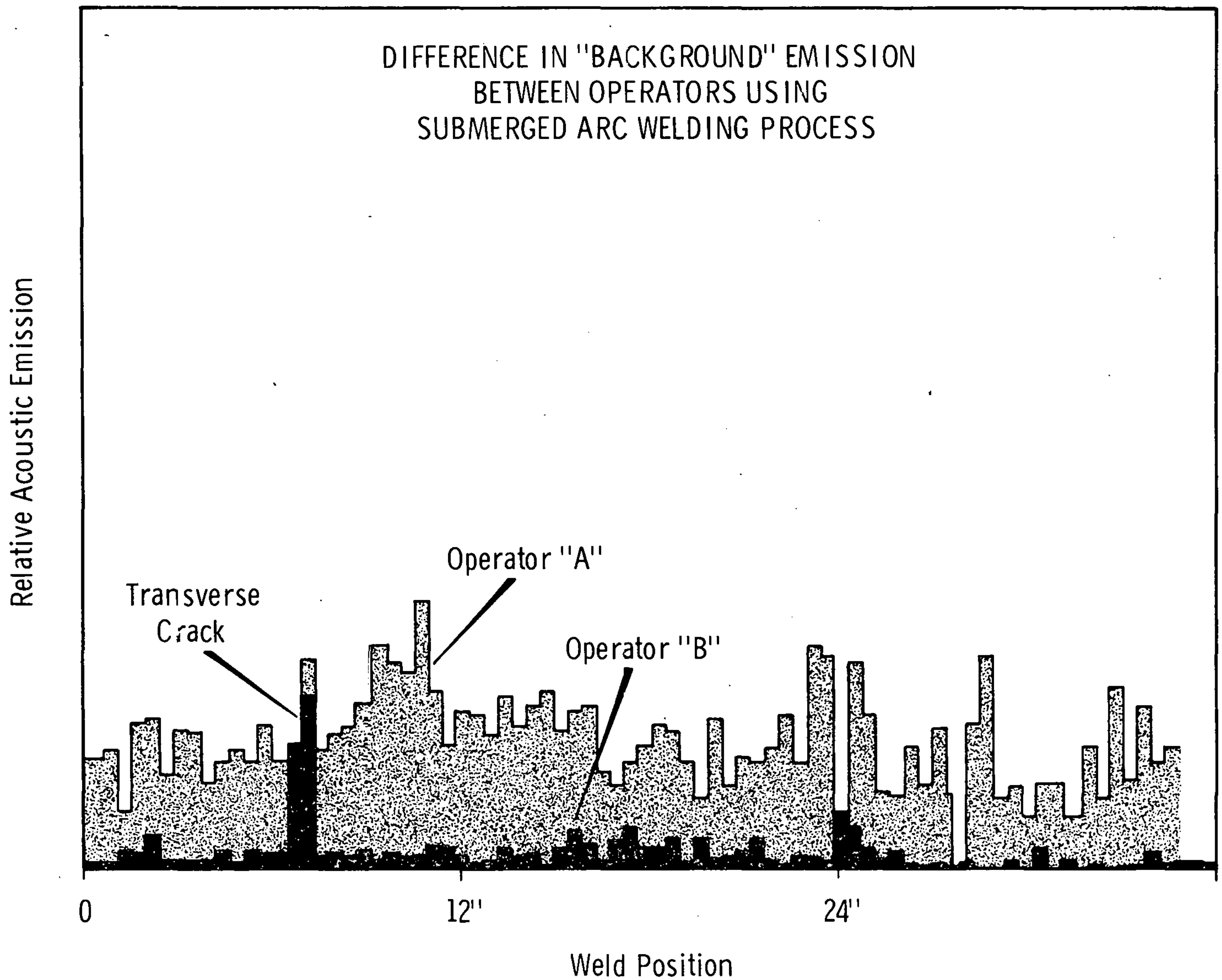


FIGURE 4. Acoustic Emission Chart from Submerged Arc Welding Showing Transverse Crack and Sensitivity to Bead Conformation.

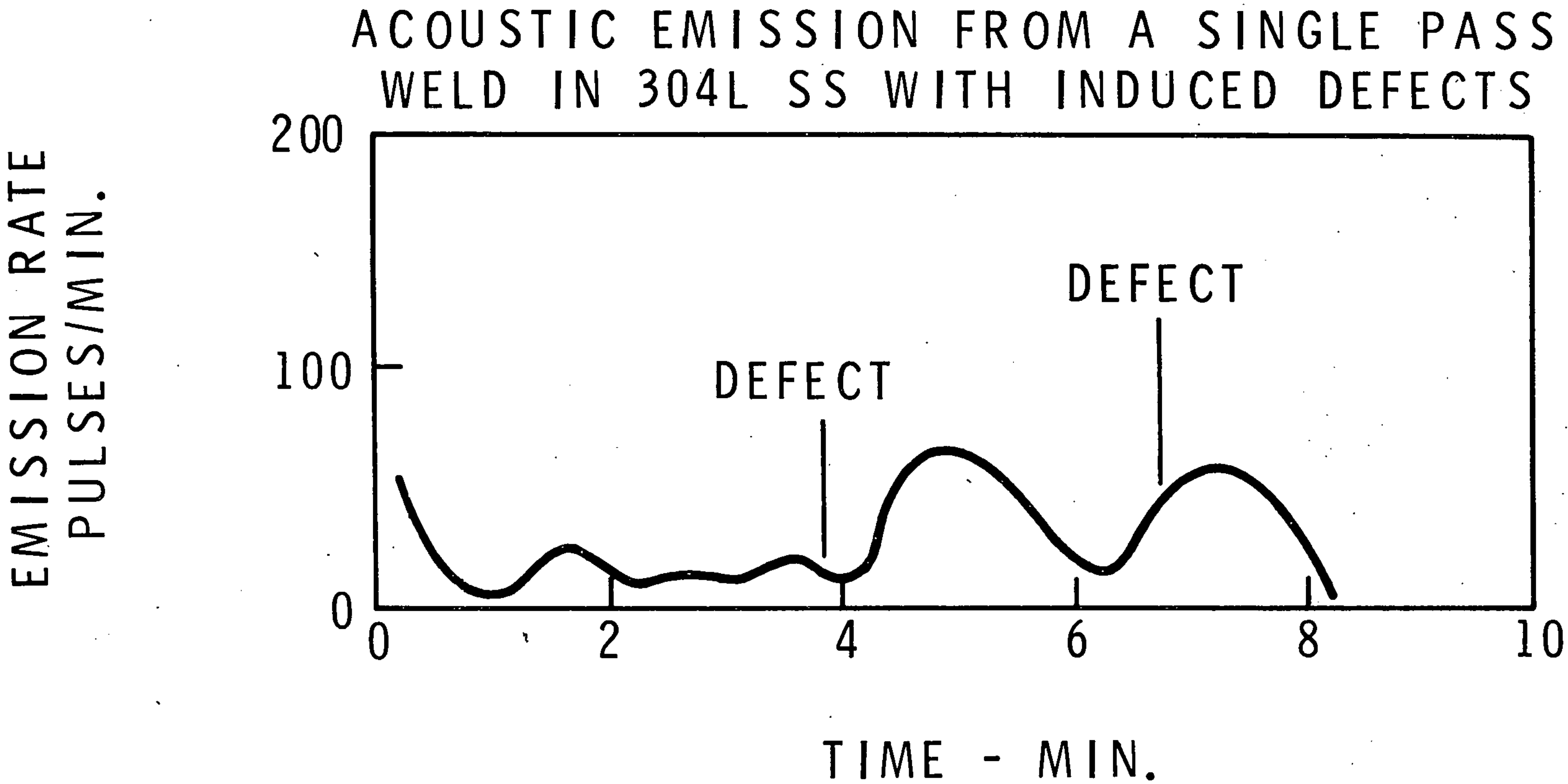


FIGURE 5. Acoustic Emission Chart from Weld in 304LSS Illustrating Delay Between Welding and Crack Growth.

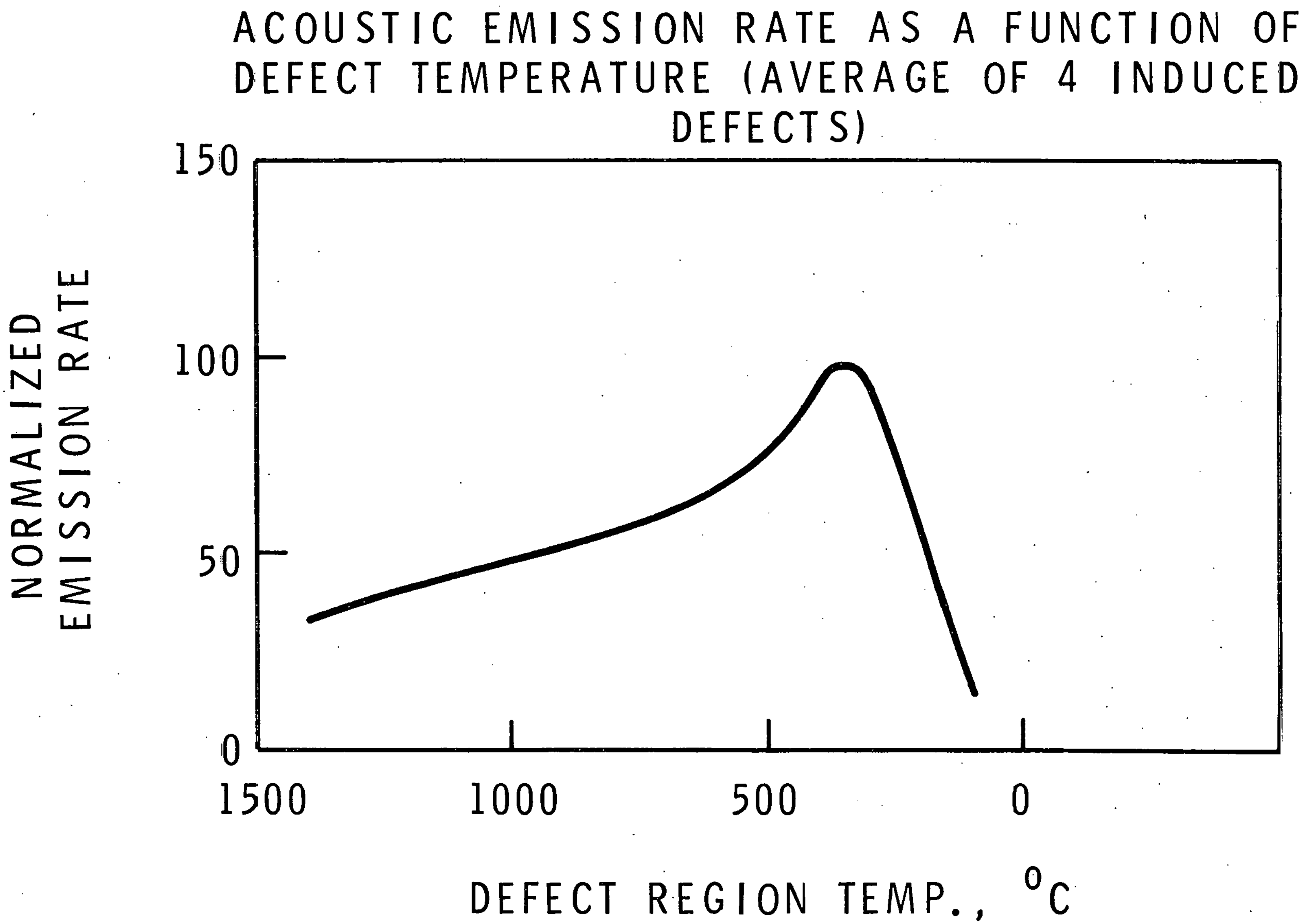
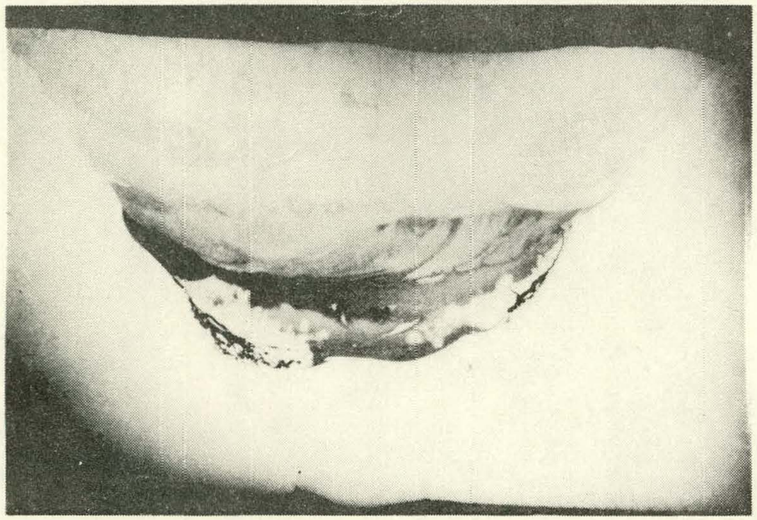
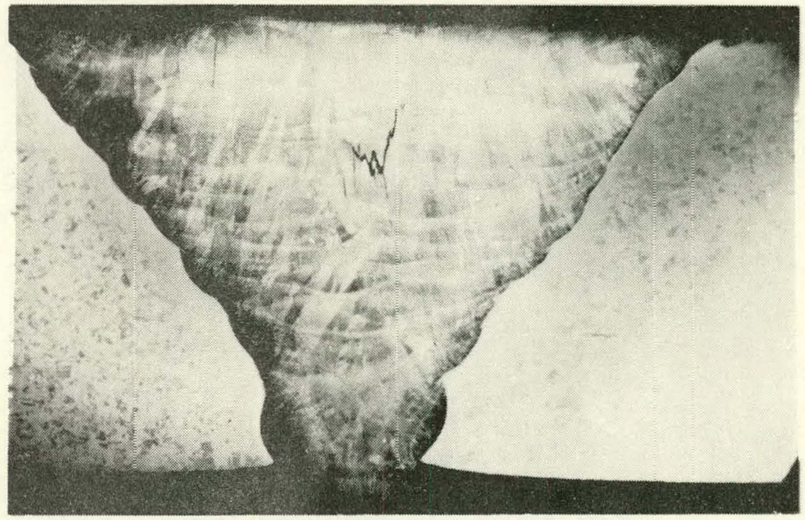


FIGURE 6. Acoustic Emission Rate vs Defect Temperature for Welds in 304L SS.

CRACKS NOT DETECTED BY RADIOGRAPHY



10,300 EMISSIONS

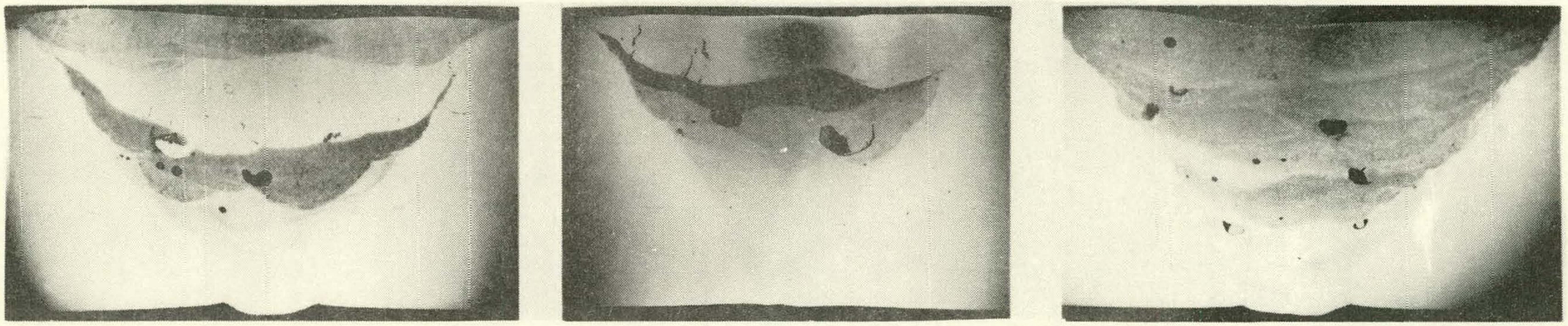


200 EMISSIONS

FIGURE 7. Sections of Manual Welds in Stainless Steel Showing Relation Between Total Emission and Cracks.

ACOUSTIC EMISSION RELATED TO POROSITY

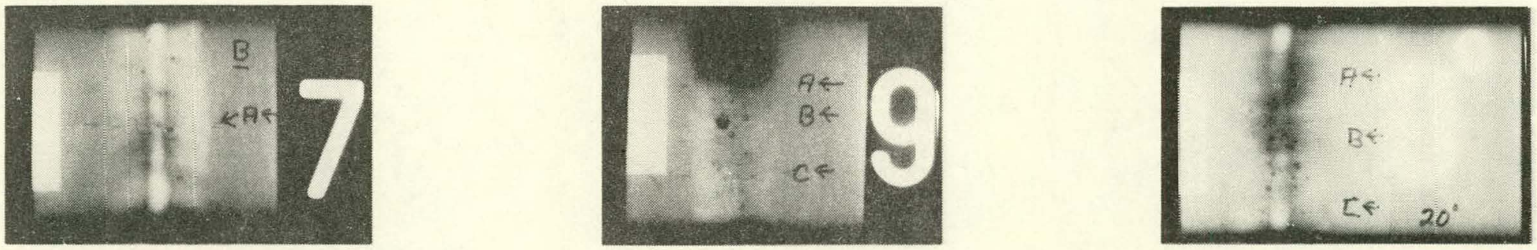
PHOTOMICROGRAPHS



WELD 7
426 EMISSIONS

WELD 9
466 EMISSIONS

WELD 20
411 EMISSIONS



RADIOGRAPHS

FIGURE 8. Sections of Manual Welds in Stainless Steel Showing Total Emission Response from Porosity.

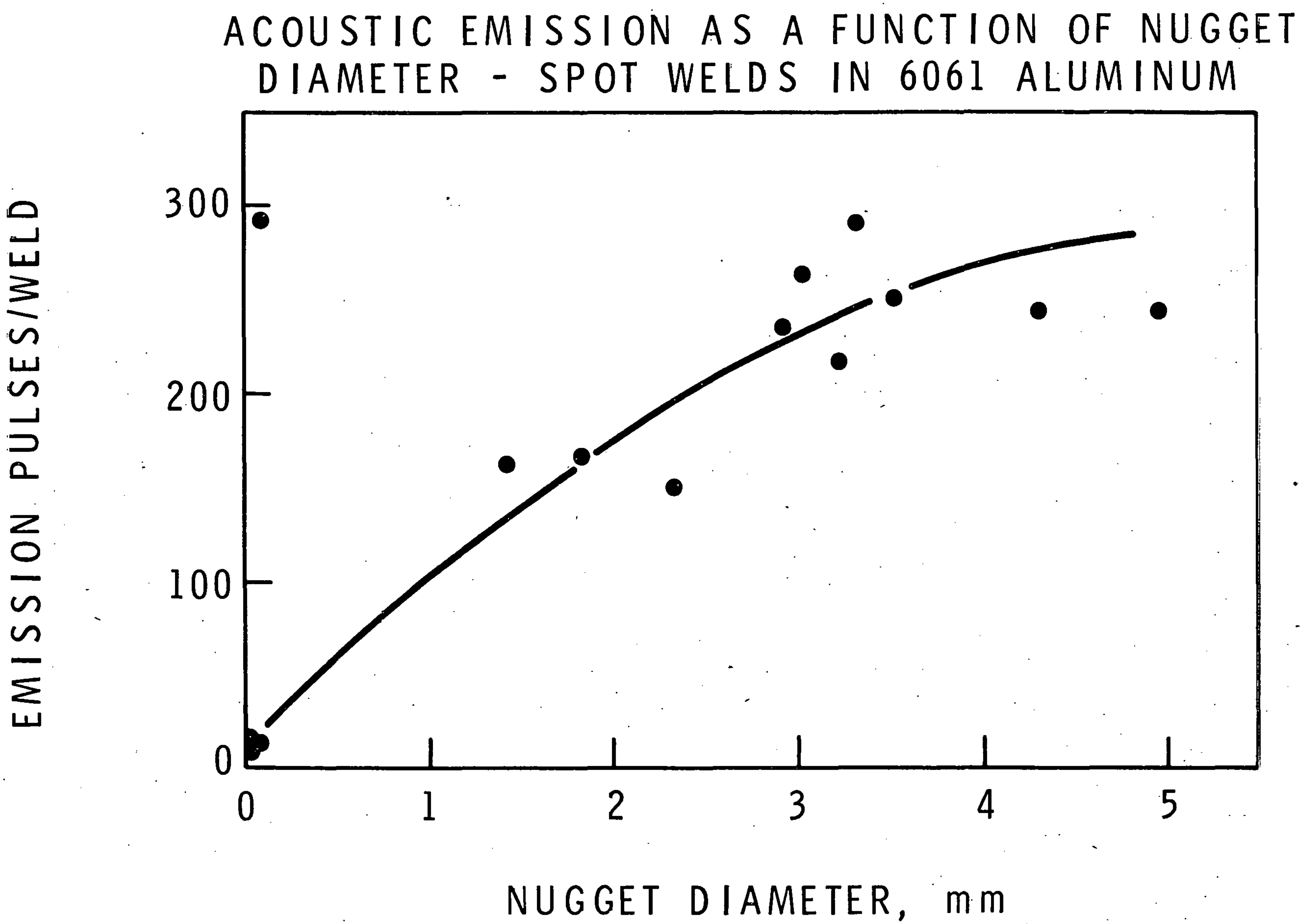


FIGURE 9. Acoustic Emission Response Related to Nugget Diameter in Spot Welds.