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UPSET WELDING PROCESS FOR 21-6-9 SPHERICAL VESSELS (U)

by

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SUMMARY

An upset resistance welding process was developed to fabricate high quality spherical vessels from forged 21-6-9 stainless steel. The two hemishells of the vessels were joined at the girth using solid-state upset welding. Vessels passed nondestructive examinations (X-ray radiography, proof and leak tests, volume and dimensional measurements) and destructive examinations (burst tests and metallography). A set of six high quality vessels was produced. These vessels are 1.86 inches in diameter with a threaded boss and tube on top.

INTRODUCTION

Resistance upset welding is being evaluated as an improved process for fabrication of small vessels. This welding process is attractive because it is reliable and employs equipment that is easy to operate, maintain, and control. Furthermore, the solid-state welds produced by this process have improved mechanical properties and metallurgical structure, compared to fusion welds.

Application of upset welding to forged 21-6-9 stainless steel spheres relies on previous development of upset welding for small cylindrical and spherical vessels, Ref. 1. The process was first developed for cylindrical parts and then for spherical vessels 1.4 inches in diameter fabricated from bar stock 304L stainless steel, Ref. 2. The largest parts to which the process has been applied are spherical vessels 2.5 inches in diameter fabricated from 304L bar stock, Ref. 3.

VESSEL DESIGN, MATERIAL, AND MACHINING

The vessels were designed to be spherical on the internal and external surfaces with a tube projecting from a threaded boss at one end, Figure 1. Vessels are made from Type 21-6-9 stainless steel and are 1.86 inches OD with a 0.2 inch wall. Vessels were assembled by first machining the two hemispherical halves, then joining these halves using resistance upset welding, and finally attaching the tube using a resistance projection weld. The details of this assembly are documented in an engineering drawing, Ref. 4, parts of which are shown in Figs. 1 and 2.

Material for the spherical bodies was supplied by the Rocky Flats Plant. Individual forgings of 21-6-9 stainless steel were used to make each hemishell for the spheres. All parts were chemically cleaned, using a Nitradd solution, Ref. 5, prior to welding .

Tubes were machined from 0.5 inch diameter 304L bar stock supplied by the Equipment Engineering Section. This same lot of bar has been used for tubes for about 20 years. Small bore (0.042 inch ID) tubes were machined to the drawing in Ref. 6 . The small bore, in contrast to the more standard 0.062 inch ID bore, was used to assure that the burst strength of the tubes exceeded the burst strength of the spherical bodies. Hardness of several tubes was measured as Rockwell-15T 83.6 (Rockwell-B 78.5). All tubes were X-ray radiographed in three orientations to assure that each tube met a minimum wall thickness criterion of 0.035 inch and a concentricity criterion of within 0.005 inch. Of the twenty four tubes in the set machined for use with the spheres, seven were rejected for not meeting these criteria (a rejection rate typical for tubes machined by local shops).

Final machining of the welded vessel required that the outer spherical surface be concentric with the inner spherical surface. Initially this was very difficult to achieve. Referencing from the bottom of the vessel during final machining and incorporating appropriate dimensional limits during initial machining and welding, as shown in Fig. 2B, solved this problem.

Fixtures for welding the vessels must carry the welding force and current and must align the hemishells. To accomplish this, electrodes made of strong, but yet electrically conductive material, contain the hemishells. The electrodes are held in alignment by a sleeve surrounding them. Electrodes are made from Class II copper faced with TC-20 at the surface adjacent to the weld joint. The electrode design is detailed in Ref. 7 and the sleeve for alignment of the electrodes is detailed in Ref. 8. Fixtures for making the girth welds are shown in Fig. 3A. Fixtures for welding of the tubes to the bodies are specified in Ref. 9 and are shown in Fig. 3B.

A spacer for the inside of the spheres was designed and demonstrated during welding of several test pieces, but was not used for the final set of spheres. Its design, Ref. 10, has a notch to accommodate the inward weld upset. Alignment of the notch with the weld joint was maintained during welding of test pieces using a rod through the tube extending into the hole in the spacer. The rod was removed after welding, releasing the spacer since its alignment was no longer required.

DEVELOPMENT OF WELDING PROCEDURE

The first three welds of the 1.86 inch spherical configuration were made using parts machined from 21-6-9 bar stock to conserve the forged material. Welding currents were determined and a force of 25,000 pounds was found to work well on the bar stock parts. Typically higher forces at about the same current are needed to produce good welds on harder forged material. The force was increased to 35,000 ± 300 pounds for the forged material and this force was maintained for the remainder of the welds throughout the program. The method of current measurement was changed during the early part of this program necessitating comparisons between the different measurement methods, Ref. 11. The welding current used for the final set of parts was 57,000 ± 500 amperes as measured on a Duffers meter whose coil surrounded the entire secondary loop of the welding machine. This current was achieved on the Large Resistance Welder using a heat setting of 70% and a transformer tap setting of 1. The time of the weld cycle was maintained the same throughout the program at one second, applied in six pulses of 10 cycles each with three cool cycles between each pulse.

Tubes made from 304L were welded to the 21-6-9 bodies using a projection weld. The projection weld has no counterbore in the body to accommodate the tube; tubes were welded to the flat surface of the body. Parameters for joining the tube to the body were 1,000 pounds force with a current of 6800 amperes for 25 cycles (of 60 Hertz). Welds were made in a vacuum of less than 50 microns. This projection weld has not been used in production, but has been recommended for production, Ref. 12.

Assembly of the vessels progressed from the two machined body parts, Fig. 4A, to the welded assembly, Fig. 4B, and then to the final machined part, Fig. 4C. The size of the external upset produced by welding the body at the girth, visible in Fig. 4B, is not controlled since it is removed by the machining operation. The size of the internal upset is controlled by a combination of the configuration of the chamfer on the inside of the weld joint (see Fig. 2A) and the welding parameters. It is desirable to have some internal upset as the extra thicknes can be used to confirm adequate weld upset using x-ray radiography.

DESTRUCTIVE EXAMINATIONS

The principal destructive methods used to evaluate the upset welds in the spherical vessels were metallography and burst tests. Examination of metallographic sections indicated a good weld with a moderate internal upset and excellent bond quality. The low magnification photographs in Fig. 5A show the configuration of the solid-state weld. At higher magnification, Figs. 5C and 5D, the presence of a small notch at the inside surface of the bond line is evident. This notch is undesirable but has not been shown to have any detrimental effect on weld performance. At 200x magnification, Fig. 5B, the excellent nature of the bond line is evident. Good grain growth across the bond line has eliminated the presence of a visible interface between the two hemishells. A hardness traverse, shown in Fig. 6, was made across one of the weld sections. The hardness across the weld area (approx. KHN 330 [Rockwell-C 29]) is nearly the same as that of the forged 21-6-9 vessel material, demonstrating that the weld area strength is considerably higher than would be expected had a fusion weld been used to fabricate the vessels. It can also be noted that the hardness of the two forging pieces used for this particular vessel differs by about 50 KHN.

A metallographic section of a projection weld joining the tube to the body is shown in Figure 7. As a destructive demonstration of projection weld quality, several tubes were bent through 90 degrees. As can be seen in Fig. 8A, the projection weld does not fail even when placed under the severe stress of bending or of internal pressure.

Four vessels were pressure tested to failure and all burst in the same manner. Two were pressurized pneumatically (with gas) and two were pressurized hydrostatically (with oil). Burst location was in the weld area as shown in Fig. 8A. Failure location was partially along the weld interface and mostly through the weld heat affected zone, Fig. 8B. The weld area failure location is due to a combination of vessel design and part hardness (hardness can be correlated with strength, see Ref. 13). Welded vessels are typically designed with a reinforcement at the weld to accommodate the lower strength found in fusion welds. The design of the spherical parts does not have such a reinforcement, providing the potential for failure in the weld area rather than the vessel body. Although upset welds do not have the low strength annealed microstructure that fusion welds have, the weld area hardness is less than or equivalent to the forged (high strength) hardness of the base material. The slightly reduced strength in the weld area compared to the forging strength causes the failure location to occur in the weld area.

FABRICATION OF HIGH QUALITY VESSELS

Upon completion of weld procedure development and the destructive demonstration of weld quality, a set of six vessels, Fig. 9A, was made by the final procedure. Critical dimensions of each hemishell were measured before welding to assure conformance to the drawing. Welding parameters for this set of vessels for both the upset girth weld and the projection tube attachment weld were, for all welds, within the ranges given previously.

This set of vessels was examined nondestructively by several methods. Results for each method are listed in Table I, along with destructive test results. An explanation of each nondestructive test is given below:

Shrinkage - This is the amount the length of the part decreases during welding. It is obtained simply by measuring the part length before and after welding, but is also reflected in the head motion recorded during welding. The consistent results obtained for the twelve welds made at the procedure conditions indicated the consistent nature of the upset welding process.

Internal Volume - The internal volume was measured by weighing the vessels before and after filling them with water following the procedure in Ref. 14. The consistent results again indicate the reproducible nature of the upset welding process.

Leak Test - A helium leak test to 10^{-8} cc/sec confirmed that consistently leak tight welds were produced.

Proof Test - A pressure test confirmed the weld strength.

X-ray Radiography - Satisfactory internal configuration of the upset welds was determined by examination of x-ray radiographs. See Fig. 9B.

CONCLUSIONS

Fabrication of a set of vessels using the resistance upset welding process demonstrated the excellent quality of 21-6-9 parts produced by this process. The vessels are strong, dimensionally consistent, and of reproducible quality.

ACKNOWLEDGEMENTS

This program was carried out by the Equipment and Materials Technology Department of the Savannah River Technology Center. Many individuals participated in the successful completion of the program. Primary among these were Buck Yongue and Trughvan Usry who performed most of the welding and testing of the vessels, Tony Curtis who performed most of the metallography, and Willis Lucas who preformed most of the machining.

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7. "1.86 Sphere Electrode, Drawing SSK4-7-256, June 13, 1984.

8. "Girth Weld Sample Fixture - Guide Sleeve Assembly", Drawing SSK5-1898, Subassembly A, June 10, 1983.

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TABLE I

TEST RESULTS FOR SPHERICAL VESSELS

Type Test	No. of Vessels	Result
Shrinkage	12	0.161 ± 0.005 in.
Internal Volume	9	26.5 ± 0.3 cc
Leak Test	12	No Leaks
Proof Test	12	No Failures
X-Ray	12	OK
Hydrostatic Burst	2	Weld Zone
Pneumatic Burst	2	Weld Zone
Metallography	2	Excellent Bond

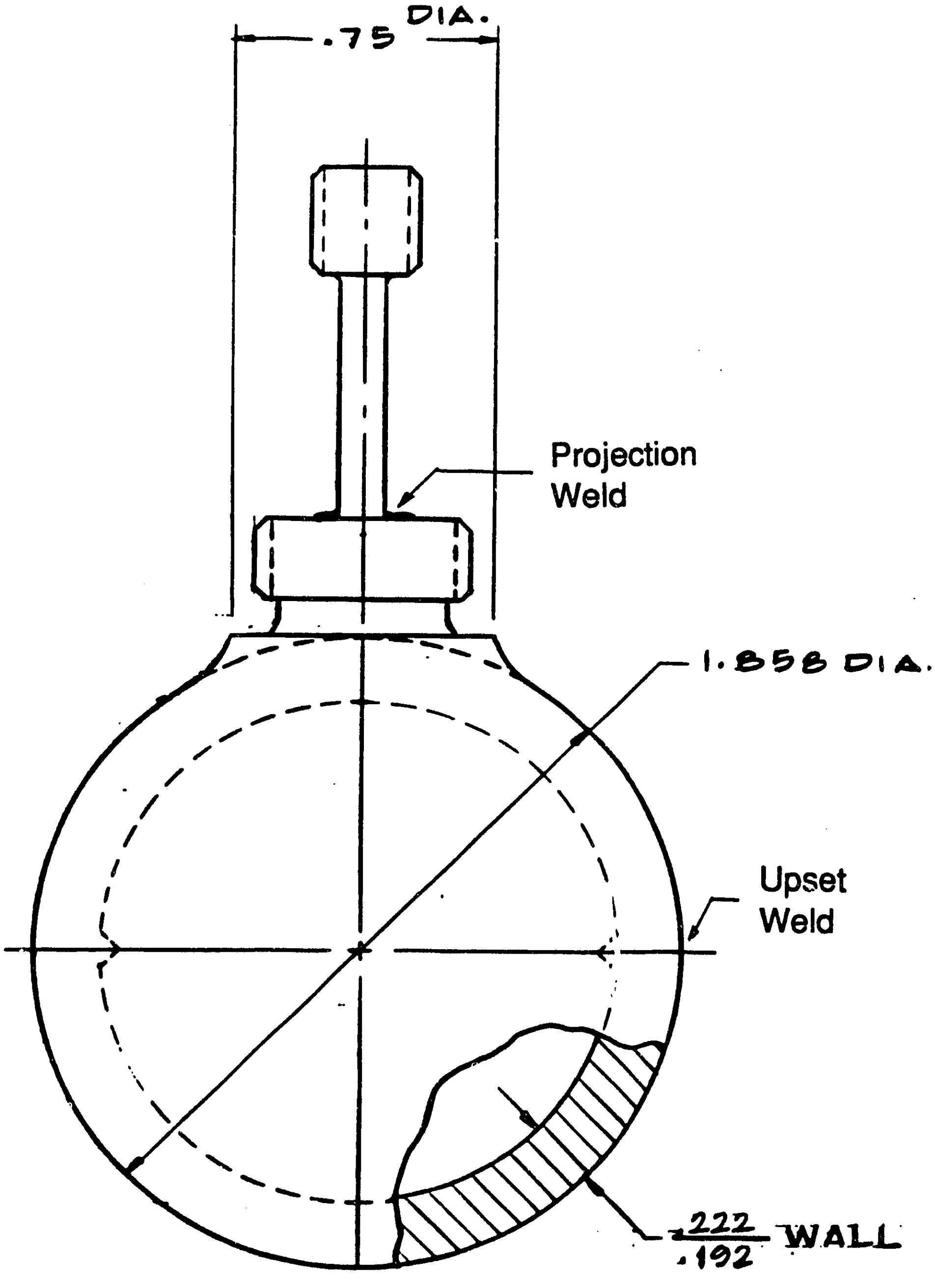
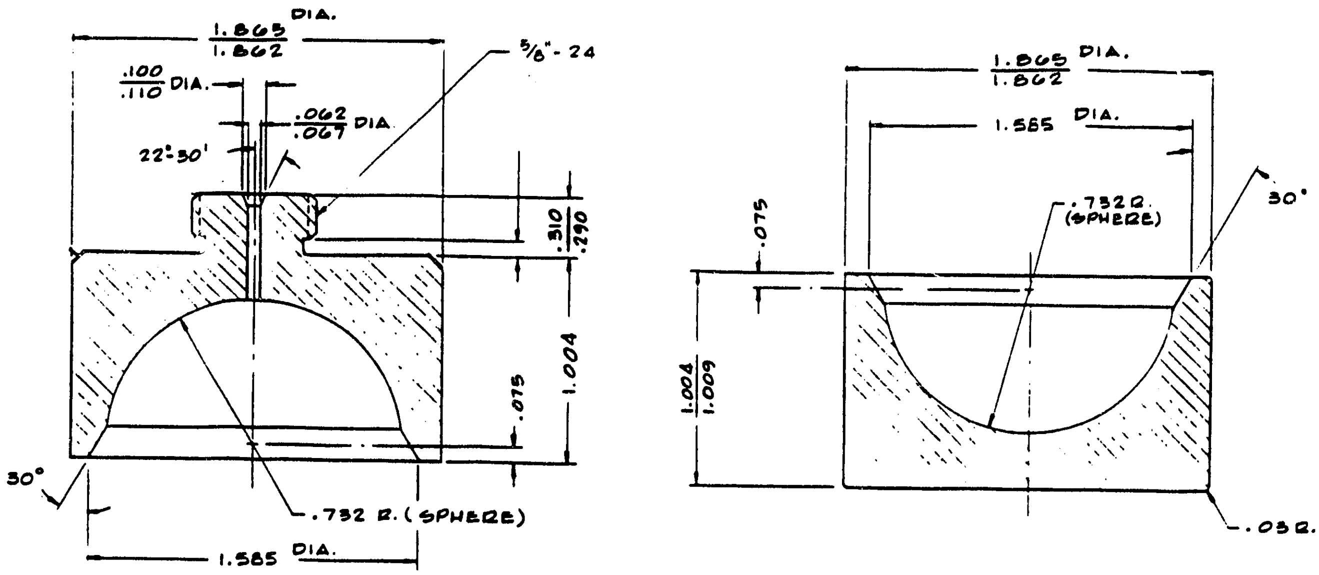
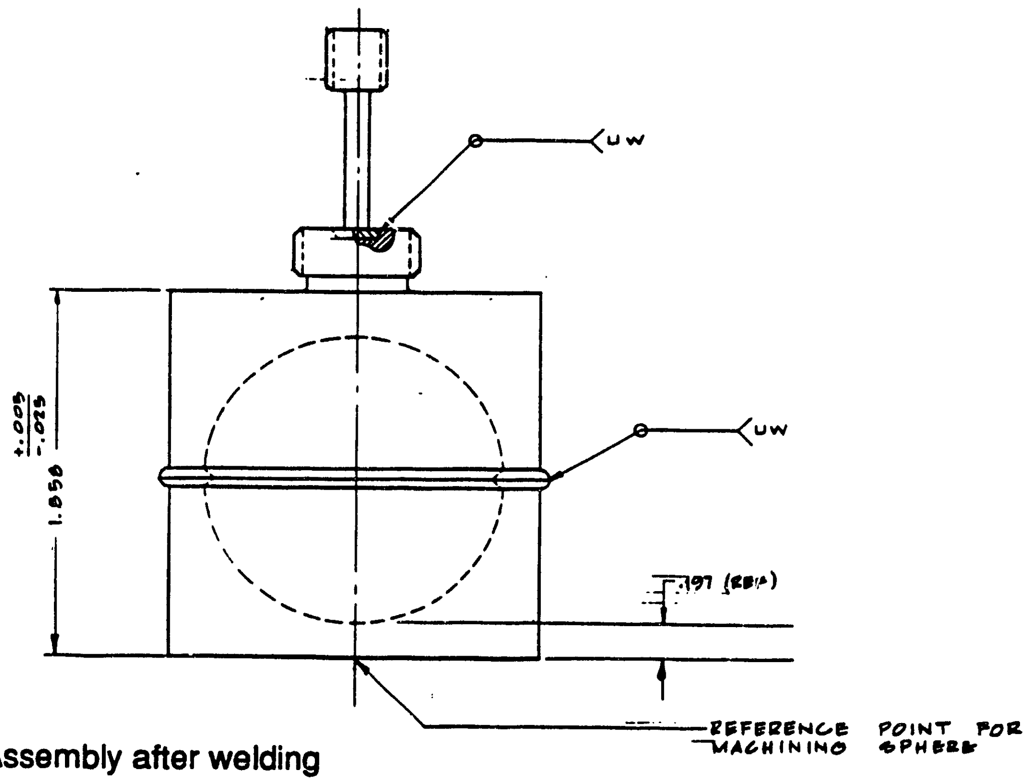


Figure 1. Schematic of upset welded spherical vessels.



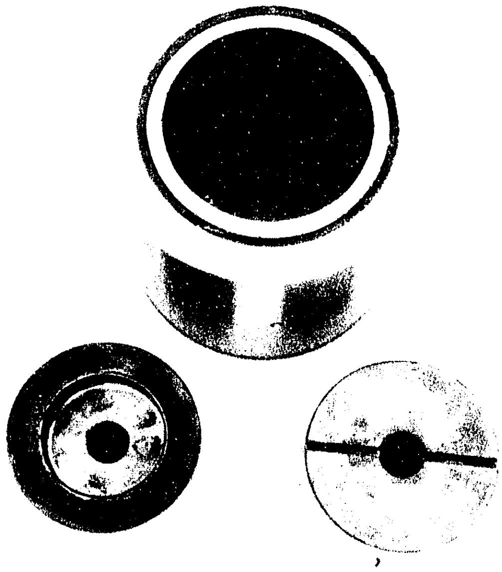
A. Top and bottom hemishells before upset welding.



B. Assembly after welding

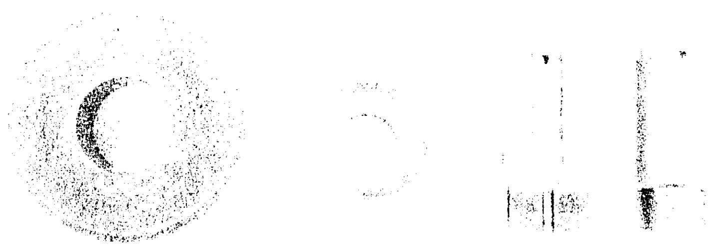
Figure 2. Schematic of vessel preparation.

EE48447-A



A. Girth weld; top: alignment sleeve; Bottom: electrodes (0.3X, EE48447-A)

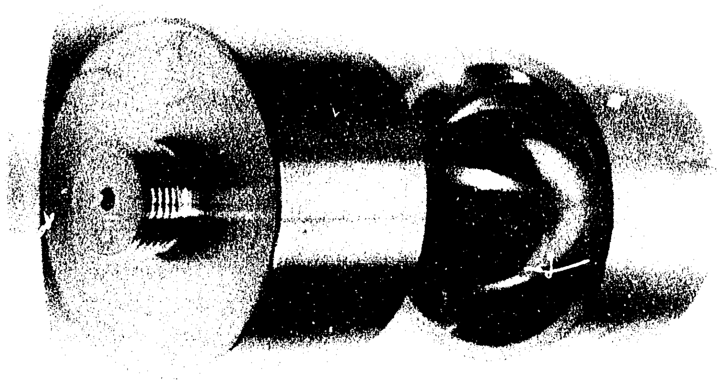
EE48446-A



B. Projection weld; left to right: alignment sleeve, threaded holder, split electrode (0.5X, EE48446-A)

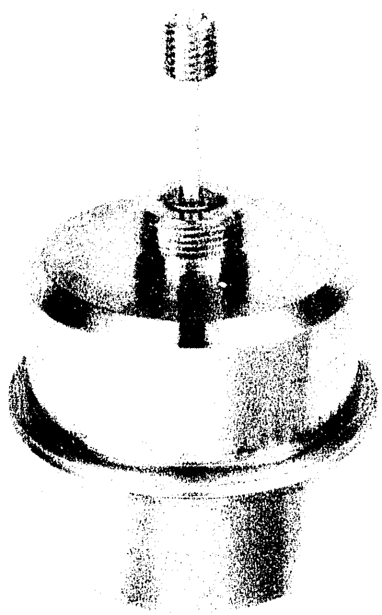
Figure 3. Welding fixtures.

EE41782-A



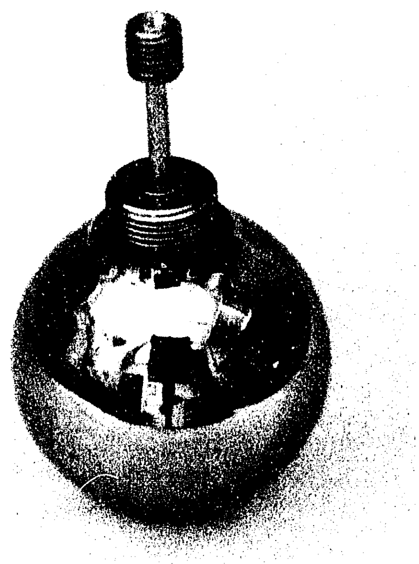
A. Hemishells before welding (1 X, EE41782-A)

EE49018-A



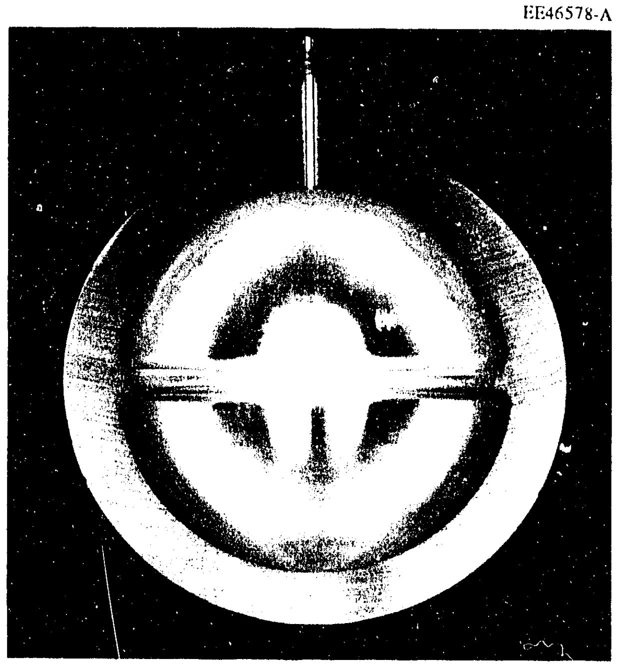
B. As-welded (1X, EE49018-A)

EE49025-A

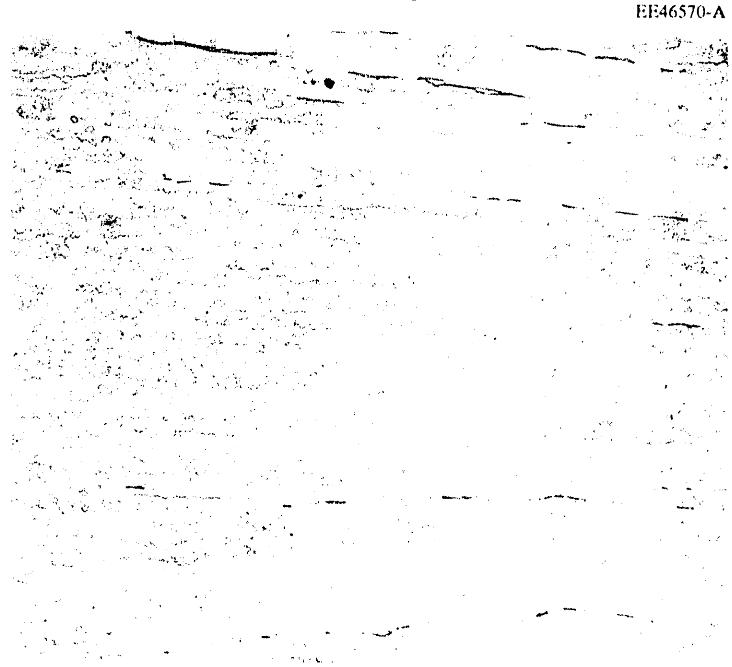


C. Machined vessel (1X, EE49025-A)

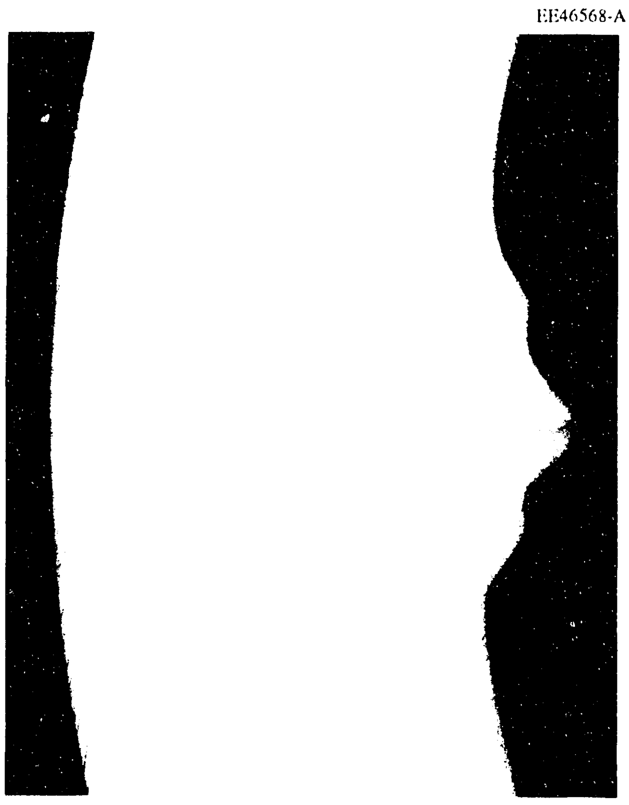
Figure 4. Assembly of spherical vessels.



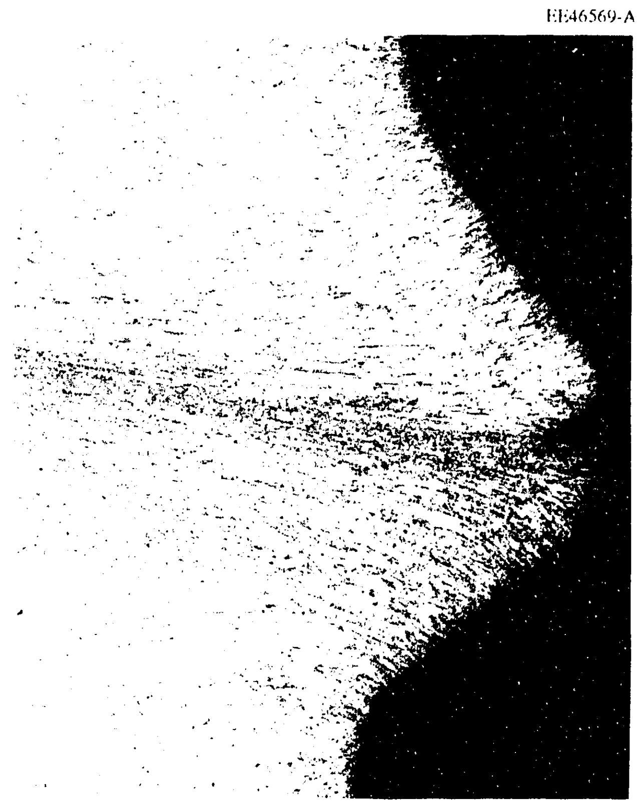
A. Sectioned vessel (1.5X, EE46578-A)



B. Weld interface (200X, EE46570-A)



C. Weld area (12X, EE46568-A)



D. Inside surface (50X, EE46569-A)

Figure 5. Metallographic sections of spherical vessel.

EE52253-A

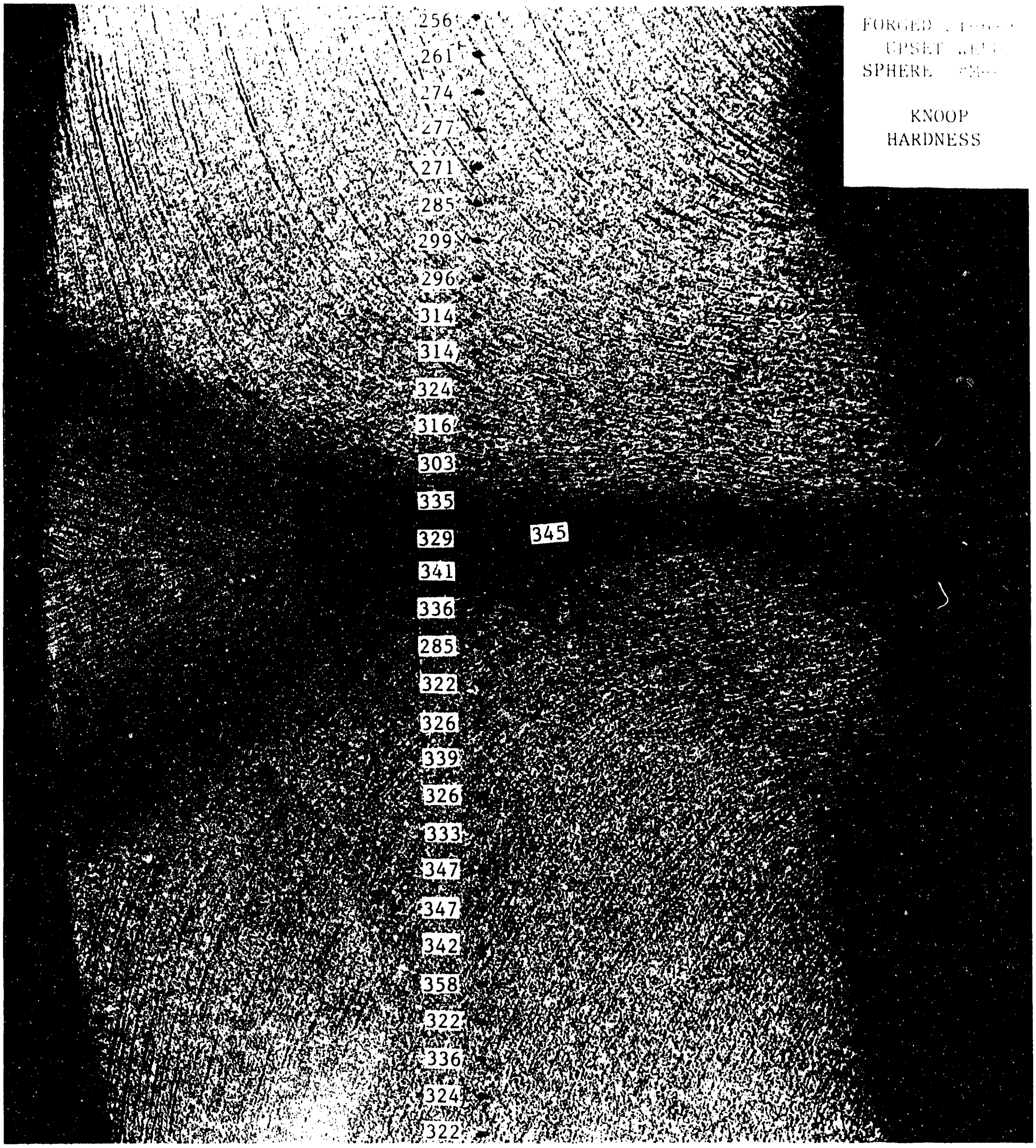
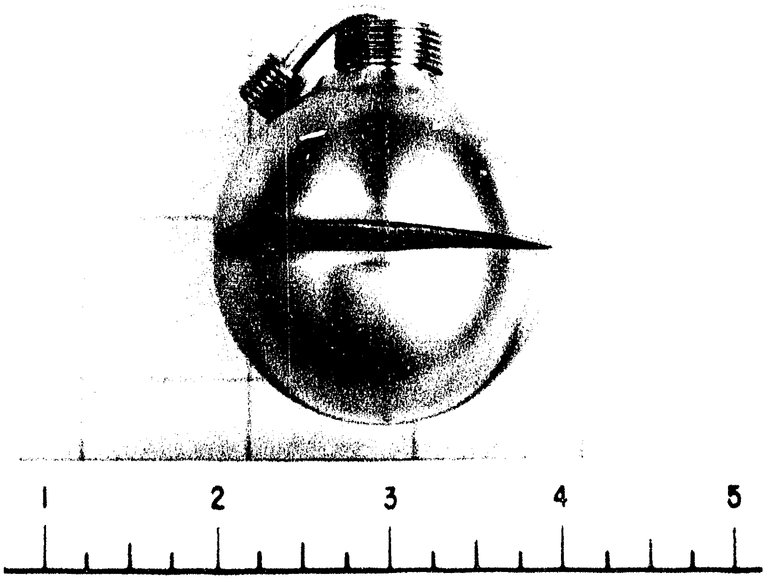


Figure 6. Hardness traverse across weld area. (25X, EE52253-A)

EE46591-A

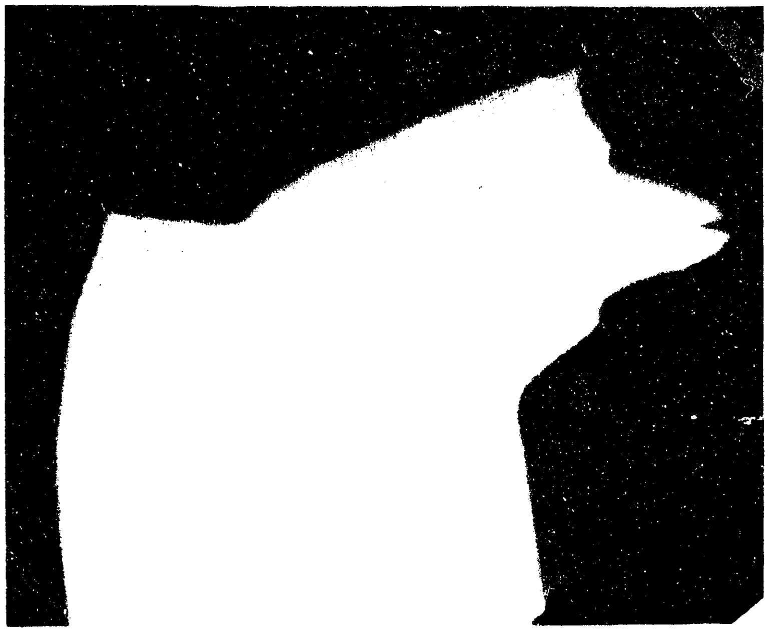
Figure 7. Tube attachment weld. A projection weld joins the tube to the body without a counterbore. (12X, EE46591-A)

EE48432-A



A. Vessel after burst test and tube bend test (0.9X, EE48432-A)

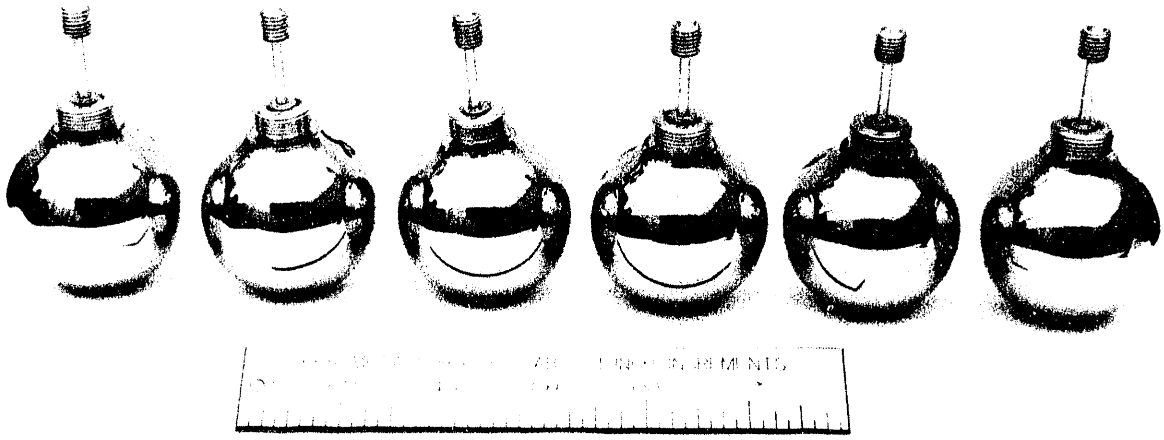
EE46716-A



B. Section through burst vessel showing failure path (along top of piece) through weld interface (left) and weld heat-affected zone (right) (10X, EE46716-A)

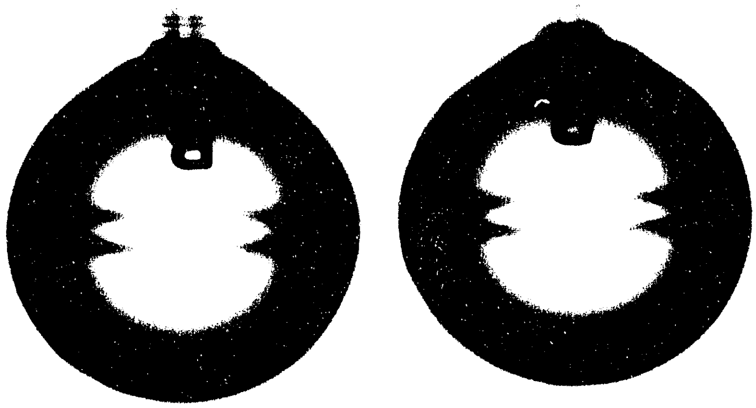
Figure 8. Burst test of spherical vessel.

EE49075-A



A. Appearance of vessels (0.5X, EE49075-A)

NFN



B. X-Ray radiograph showing internal upset configuration of girth weld.

Figure 9. Quality set of spherical vessels.

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