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TITLE: APPLICATIONS OF EXPLOSION-WELDED TRANSITION JOINTS

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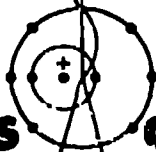
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APPLICATIONS OF EXPLOSION-WELDED TRANSITION JOINTS

ABSTRACT

Explosion welding is presented as an alternate process of joining dissimilar metals. The process is compared with brazing, the most appropriate process for comparison, and the bond zone obtained through explosion welding is characterized. Several applications are described where transition joints were made from explosion-bonded dissimilar-metal combinations for subsequent assembly through fusion welding.

INTRODUCTION

There are many techniques for joining dissimilar metals whose physical and metallurgical characteristics might render them incompatible and, among the commonly accepted processes, brazing is probably the most frequently used. The brazing operation may, however, introduce undesirable joint characteristics or processing problems; e.g.,

1. A third metal, the braze alloy, must be added
2. The base metal properties are affected in accordance with the process temperatures
3. The mechanical properties of the joint are anisotropic
4. The braze joint properties are critically dependent on the joint design, and the prior cleaning and processing procedures
5. Brazing can be extremely time consuming and expensive

Explosion welding of dissimilar metals has emerged as an alternative to brazing. It has been demonstrated that the process can be used to metallurgically join virtually any wrought metal or alloy to itself or to other wrought metals or alloys of vastly different physical and chemical properties.^{1,2} It has also been shown that a third compatible interlayer material can be included between two dissimilar metals in order to preclude the formation of brittle intermetallic compounds resulting from in-service exposure to elevated temperatures.

Applied research on explosion metal welding in the early 1960's resulted in commercial-scale implementation of the process. To give just two examples, many pressure vessels and tube sheets, fabricated using dissimilar metal clads, are now in use in the chemical industry.^{1,2,3} Interest in explosion clad bimetal is now world-wide.

Application for the basic patent pertaining to explosion-bonding of metals was made in 1960. Entry into the U.S. market has thus been legally restricted for the last 17 years. However, since the patent expires in 1977, unrestricted participation will be open to interested parties.

Explosion welding normally produces an autogenous weld joint with excellent mechanical properties and imposes significantly less stringent requirements on preparatory procedures. The process is repeatable, reliable and

economically attractive. Explosion welding is, however, geometry limited; i.e., it is adaptable to processing only semifinished symmetrical shapes which can easily be restrained, such as flat plate and sheet, bars, rings, cylinders and pipe.⁵ For joining components of more complex geometries, a transition joint is first machined from an explosion-bonded bimetal composite, and similar metals on either side of the explosion-welded interface are welded using conventional fusion techniques. Numerous transition pieces can be obtained from one explosion-bonded plate and the quality of the transition piece can be ascertained beforehand by extensive nondestructive and destructive testing.

EXPLOSION WELDING

During the last decade, the heuristic approach for explaining the explosion bonding process has adequately interpreted the observed physical phenomena and has yielded a working model of the process.^{1, 6-13} However, some aspects, such as wave formation and associated wave crest perturbations reminiscent of Helmholtz instabilities, have yet to be adequately explained.

The working model of the explosion bonding process, shown schematically in Fig. 1, is based on hydrodynamics. The flyer and base plate jets impinge at a predetermined angle at the collision point to form a reentry jet which emanates from the high pressure collision point. Once steady state conditions are achieved, the explosive detonation velocity becomes equal to the collision point velocity. A basic feature of the entire process is that the collision of two propelled jets (plates) and, therefore, the detonation velocity, be subsonic with respect to the sound velocity of the metals involved. The presence of oblique shock waves is not compatible with the formation of a reentry jet and bonding. In practice, the desired explosive detonation velocity was found to be much lower than the metal sound velocities, specifically in the range of about 1800 to 2300 m/sec.¹⁴ Representative bulk sound velocities of several metals and alloys are given in Table I.

The limitations in clad dimensions are generally governed by physical material-handling capabilities and volume of explosive that may be detonated at a given location. Generally, greater edge non-bond losses are associated with thicker flyer plates. Therefore, there might be a trade-off between losses in the more noble clad metal and desired clad thickness.

Virtually any wrought metal or alloy may be clad. It is recognized that some metals have a low ductile-brittle transition temperature. To circumvent this, the clad assembly may be heated prior to detonation of the explosive. Using such a technique, the author found it possible to bond a tungsten sheet to a stainless steel backer without failure (Fig. 2). Performing the cladding operation at ambient temperature using tungsten or TZM molybdenum alloy results in crack formation due to preferred orientation and delamination.

In addition to flat sheet and plate, explosion bonding may be used to join dissimilar metals in tubular or cylindrical configurations (Fig. 3). Metals showing little or no mutual solubility may also be bonded using explosives. For example, tantalum may be bonded to copper and the resulting clad may be subsequently cold-reduced in thickness by rolling (Fig. 4). A thickness reduction of approximately 50% after explosion welding results in a flat

interface.

A non-standard fixture, shown schematically in Fig. 5, was used by the author to measure the tensile strength of several bimetal composites. Results of these tests are given in Table II. These results indicate that the strength of the explosion-welded bond zone is usually greater than that of the weaker of the two metals being joined.

The flyer plate may be positioned at a preset angle with respect to the base plate or parallel to it at a predetermined stand-off distance. The latter is more desirable in practice since it results in a more uniform bond zone configuration. The collision angle in the parallel case forms as the flyer plate is propelled through the stand-off distance. The explosive is initiated at one end of the assembly; this detonation geometry imparts an oriented character to the bond zone. A longitudinal view of the bond zone reveals a characteristic sinusoidal wave with vortices reminiscent of Helmholtz instabilities. Dissimilar metal bonds usually result in the presence of vortices that are possibly due to a velocity and density mismatch between flyer and base materials (Fig. 6).

Waves form between two impinging metallic plates if they are propelled at subsonic speeds and impinge at a dynamic angle of between about 4.5 and 17.5 degrees.⁹ At 0 degree angle, jetting and, therefore, bonding do not take place. Below about 4.5 degrees, the bond zone is straight and usually contains entrapped jetted material, which forms an interlayer. This material, because of very rapid solidification, is non-stoichiometric in composition. Above about 17.5 degrees, the bond zone is again straight but does not contain entrapped material. Also, holding other conditions constant, cladding harder metals and alloys will result in lower amplitude waves.

Within the stated limits, greater dynamic angles are associated with larger wavelengths and amplitudes. Experiments performed by the author show that amplitude-wavelength ratios (α/λ) vary from about 0.25 to as high as 0.45. The author also observed that a secondary wave may form as these ratios approach 0.45 (Fig. 7).

The area immediately adjacent to the bond zone undergoes severe and very localized distortion. This is evidenced by the presence of twinning, Newmann bands and grain deformation. The presence of larger amounts of entrapped melt can also cause incipient recrystallization in the worked materials and solidification defects in the melt (Fig. 6).

APPLICATIONS

In recent months, explosion-bonded dissimilar metal transition joints have been successfully used in fusion welding applications in a number of Los Alamos Scientific Laboratory (LASL) joining requirements. An inventory list of bimetal plates, which have been or will be used for in-house activities, is given in Table III. The joint quality of these clads was ascertained by ultrasonic scanning and destructive testing of randomly selected samples. The following examples will outline some of the LASL applications on which this technology has been demonstrated.

1. Ion Source for Intense Neutron Facility

LASL's Intense Neutron Source (INS) is scheduled for completion in 1980. The INS will provide a high density flow of 14 MeV neutrons; i.e., the same energy level as will be generated in a fusion reactor, and will be used to study materials irradiation effects. The high energy neutrons are generated by the interaction of a gaseous deuterium stream with a beam of tritium ions. Prototype components for the tritium ion source have been built using an explosion-welded transition joint of OFHC copper/alloyed steel. The geometry and weld joint details are shown in Fig. 8. Brazing would have introduced undesirable filler metal constituents, which reportedly would affect the operational characteristics of the source. Electron beam fusion welding was investigated, but the weld zone exhibited the expected cracking problems. The fabrication was successfully completed using the explosion-welded bimetal ring and electron beam welding the Cu/Cu and steel/steel joints on either side.

2. Thermocouple Probes

Tantalum metal is commonly used for thermocouple sheaths in high temperature monitoring devices. Tantalum tubing can easily be brazed to the stainless steel thermocouple flanges and feed-through adaptors. Recently, however, it was necessary to provide a number of thermocouple probes with the tantalum sheath aligned very precisely with respect to the stainless steel adaptors. A support fixture would have been required to allow brazing and some preliminary attempts using an induction brazing unit failed to produce an acceptable component. The problem was solved by using a tantalum/type 304 stainless steel transition joint and electron beam welding the similar metal joints using only the standard welding fixture. Details of the assembly are shown in Fig. 9.

3. Loss-of-bond Experiments in EBR II Reactor

Fuel elements are currently being fabricated for an experiment designed to determine the consequences of a "loss-of-bond" event from sodium bonded mixed carbide fuel elements. The experiment is necessary to show the viability of the sodium bonded concept for commercial applications; i.e., the loss of the high conductivity sodium bond from the fuel element at full reactor power may result in melting of fuel and shroud materials. The operation of the experiment depends on the successful melting of a transition joint (tantalum/copper-manganese/tantalum) by fission energy generated in an enriched uranium heater. A tantalum/stainless steel transition section is also used in the construction. The fuel element body is described in Fig. 10. In this case, the main advantage of a transition joint is that one explosion-welded plate provided sufficient transition material for all test samples required for the program. The alternative approach (brazing) would have involved quality-assurance approval of the braze alloy and braze process, and there were substantial problems in defining a specific remelt temperature for the braze alloy (Cu/Mn). The Cu-38 wt% Mn alloy was cast in the LASL CMB-6 Foundry Section, rolled to 0.56 mm sheet and sandwiched by explosion bonding between two tantalum plates one of which

was 3.2-mm and the other 6.4-mm-thick. The loss-of-bond device was then machined from the composite.

4. Los Alamos Meson Physics Facility (LAMPF) Biomedical Target Assemblies

A target assembly for use in biomedical research experiments at the LAMPF contains a target holder that consists of type 316 stainless steel outer jackets; electron beam welded to the target body sleeve, which contains the target material itself (ATJ or ZTA graphite). The sleeve materials used are OFHC copper, K-monel, and Berylco 25. The sleeve material in each case is cold-worked and/or heat treated to obtain maximum strength, and the sleeve is shrink-fitted to the graphite target. The sleeve then has to be joined to the outer jacket without degrading the strength of the materials involved. Explosion-welded transition joints are the most satisfactory way of joining the type 316 stainless steel to the copper and copper-alloy materials.

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BIBLIOGRAPHY

1. Holtzman, A.H. and Cowan, G.R.; "Bonding of Metals With Explosives; Welding Research Council Bulletin; Bulletin No. 104; April, 1965.
2. Linse, V.D.; Wittman, R. H.; and Carlson, R.J.; "Explosive Bonding"; Defense Metals Information Center; Memorandum 225, 1967.
3. Carpenter, S.H. and Wittman, R.H.; "Explosion Welding"; Annual Review of Materials Science, Vol. 5, 1975.
4. Cowan, G. R. et al; "Explosive Bonding"; U. S. Patent No. 3,137,937; filed Oct. 26, 1960; issued June 23, 1964.
5. Popoff, A.A.; "Explosive Welding Process"; U. S. Patent No. 3,140,537; filed June 30, 1961; issued July 14, 1964.
6. Cowan, G. R.; Bergmann, O.R.; and Holtzman, A.H.; "Mechanism of Bond Zone Wave Formation in Explosion-Clad Metals", Met. Trans., Vol. 2, Nov. 1971.
7. Bergman, O.R.; Cowan, G. R.; and Holtzman, A. H.; "Experimental Evidence of Jet Formation During Explosion Cladding", Trans. Met. Soc. AIME; Vol. 236, May, 1966.
8. Cowan, G. R. and Holtzman, A. H.; "Flow Configurations in Colliding Plates: Explosive Bonding", J. Appl. Phys. Vol. 34, No. 4, April 1963.
9. Bahrani, A. S.; Black, T.J.; and Crossland, B.; "The Mechanics of Wave Formation in Explosive Welding", Royal Soc. of London, Proceedings,

Vol. 296, A., Jan. 1967

10. Deribas, A.A.; Kudinov, V. M.; and Matveenkoy; "Effect of the Initial Parameters on the Process of Wave Formation in Explosive Welding", *Fizika Goreniya i Vzryva*, Vol. 3, No. 4, 1967.
11. Deribas, A. A.; Kudinov, V. M.; Matveenkoy, F.I.; and Simonov, V. A.; "Determination of the Impact Parameters of Flat Plates in Explosive Welding", *Fizika Goreniya i Vzryva*, Vol. 3, No. 2, 1967.
12. Deribas, A. A.; "Some Phenomena Accompanying High-Speed Collision of Solids", *Proceedings of 13th International Congress of Theoretical and Applied Mechanics*; Moscow, Aug. 1972.
13. Hunt, J. N.; "Wave Formation in Explosive Welding"; *Phil. Mag.*; 18; 1968.
14. Bergmann, O. R.: et al; "Bonding Metals with Explosives"; U. S. Patent No. 3,397,444; filed Oct. 23, 1965; issued Aug. 20, 1968.

TABLE I

SOUND VELOCITIES OF SOME METALS AND ALLOYS, m/sec

Zn	3000	Ti	4800	Monel	4400
Cu	4000	Fe	4800	Hastelloy	4400
Mg	4500	Mo	5200	Austenitic	
Nb	4500	Al	5500	Stainless Steel	4500
Ni	4700	Be	8140	Bronze	4000
		U	2400		

TABLE II

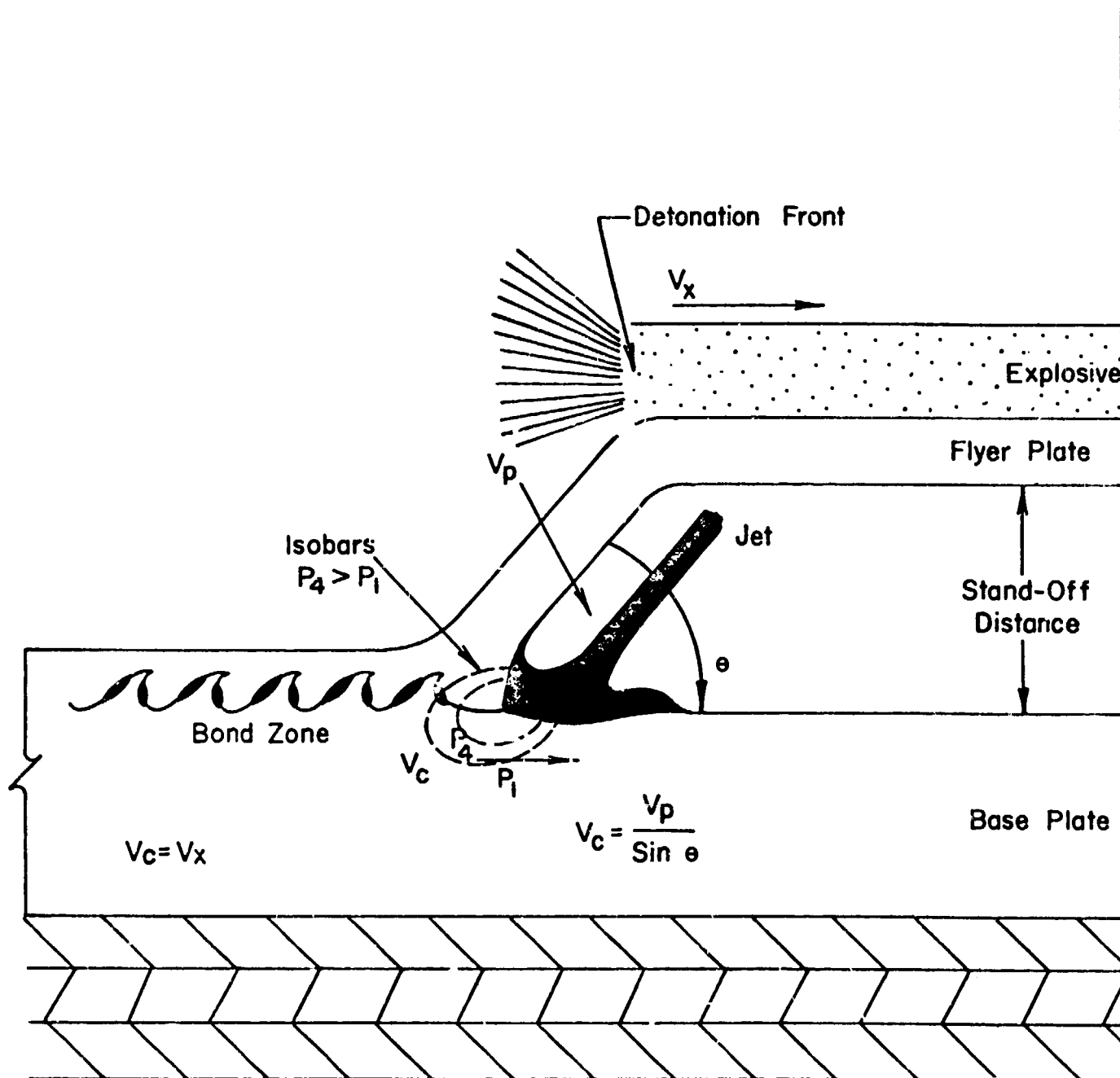
TRANSVERSE TENSILE STRENGTHS OF EXPLOSION BONDED BIMETAL COMPOSITES USING A NONSTANDARD TESTING FIXTURE AND SPECIMENS

Clad No.	Materials		Transverse Tensile Strength	Failure Location
	Clad Metal	Backer Metal		
4	6.5 mm (.255") OFHC-Cu	6.3 mm (.247") Almar 362	243.4 MPa (35,300 psi)	in Cu
25	3.1 mm (.123") OFHC-Cu	5.1 mm (.200") Type 304 Stainless Steel	268.2 MPa (38,900 psi)	in Cu
26	3.2 mm (.127") Be-Cu	5.3 mm (.209") Type 304 Stainless Steel	611.6 MPa (88,700 psi)	in Be-Cu
27	3.2 mm (.125") Monel	5.3 mm (.209") Type 304 Stainless Steel	518.5 MPa (75,200 psi)	in Monel

TABLE III

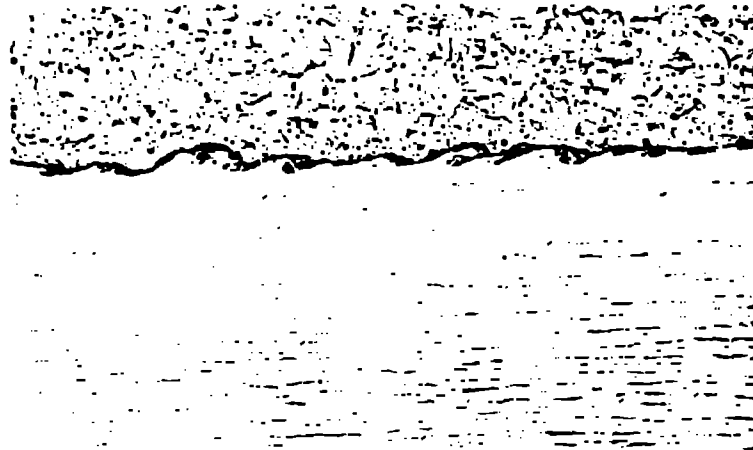
EXPLOSION WELDED DISSIMILAR METAL COMPOSITES
AVAILABLE FOR USE AS TRANSITION JOINTS

Aluminum 5052	ON	304 Stainless Steel
OFHC Copper	ON	Almar 362
Tantalum	ON	304 Stainless Steel
OFHC Copper	ON	" " "
Beryllium-copper	ON	" " "
Monel	ON	" " "
Tantalum	ON	Molybdenum
OFHC Copper	ON	Niobium
OFHC Copper	ON	Molybdenum
Kovar	ON	304 Stainless Steel
Molybdenum	ON	304 Stainless Steel
D-38 Uranium	ON	OFHC Copper
D-38 Uranium	ON	304 Stainless Steel
Tungsten	ON	" " "
Tantalum	ON	304 Stainless Steel (with vanadium interlayer)

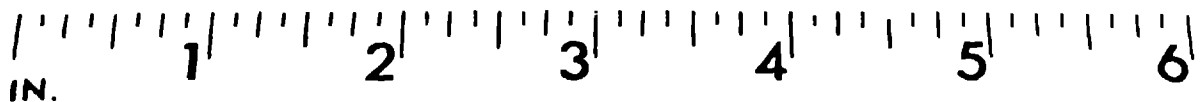
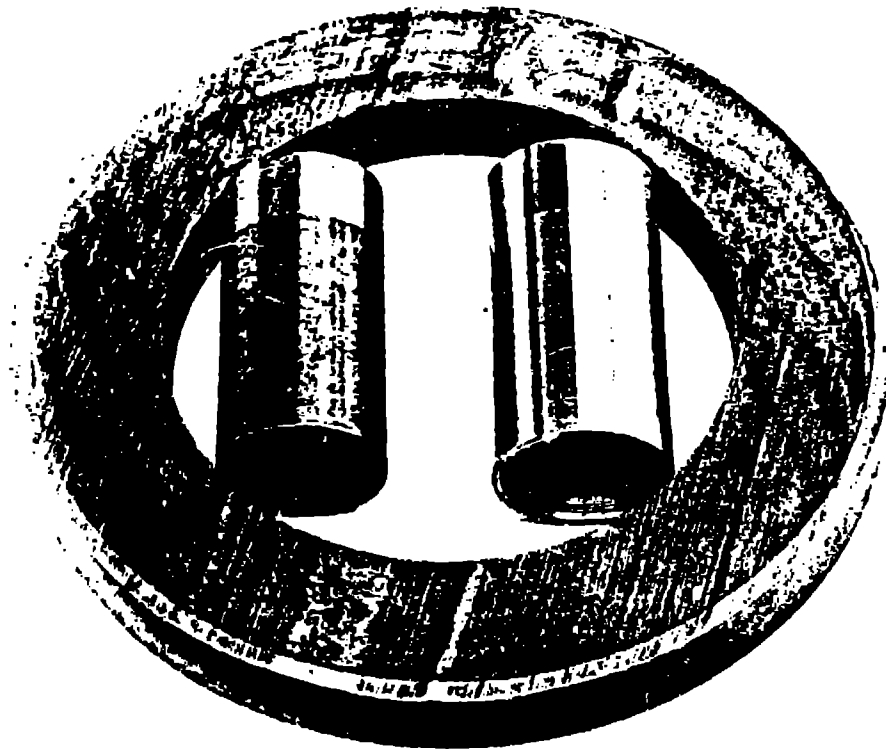


Schematic Of Explosion Welding Process

Fig. 1



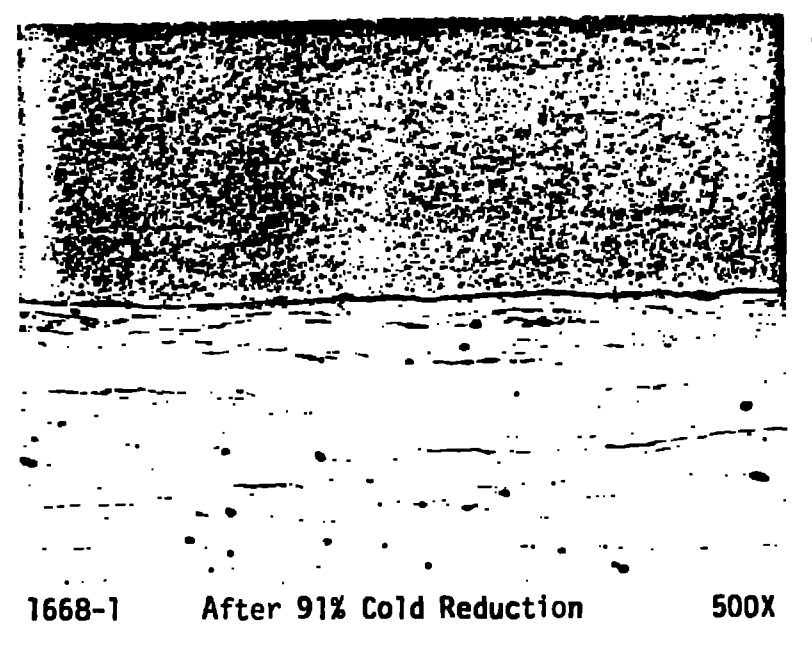
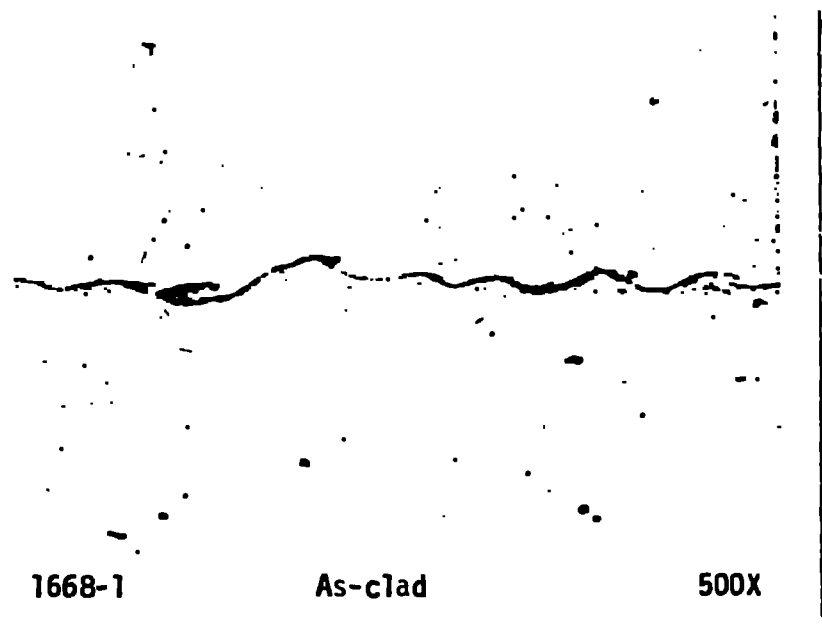
1685-7 Etched for Stainless Steel 250X
Explosion Bonded Type 304 Stainless Steel-on-Tungsten
Fig. 2



Explosion Bonded Bimetal Pipe Section (Type 316 Stainless Steel on Carbon Steel) and Tubular Transition Joints Trepanned from Thick Bimetal Plate (Type 304 Stainless on Carbon Steel and Zircalloy on Type 316 Stainless Steel)

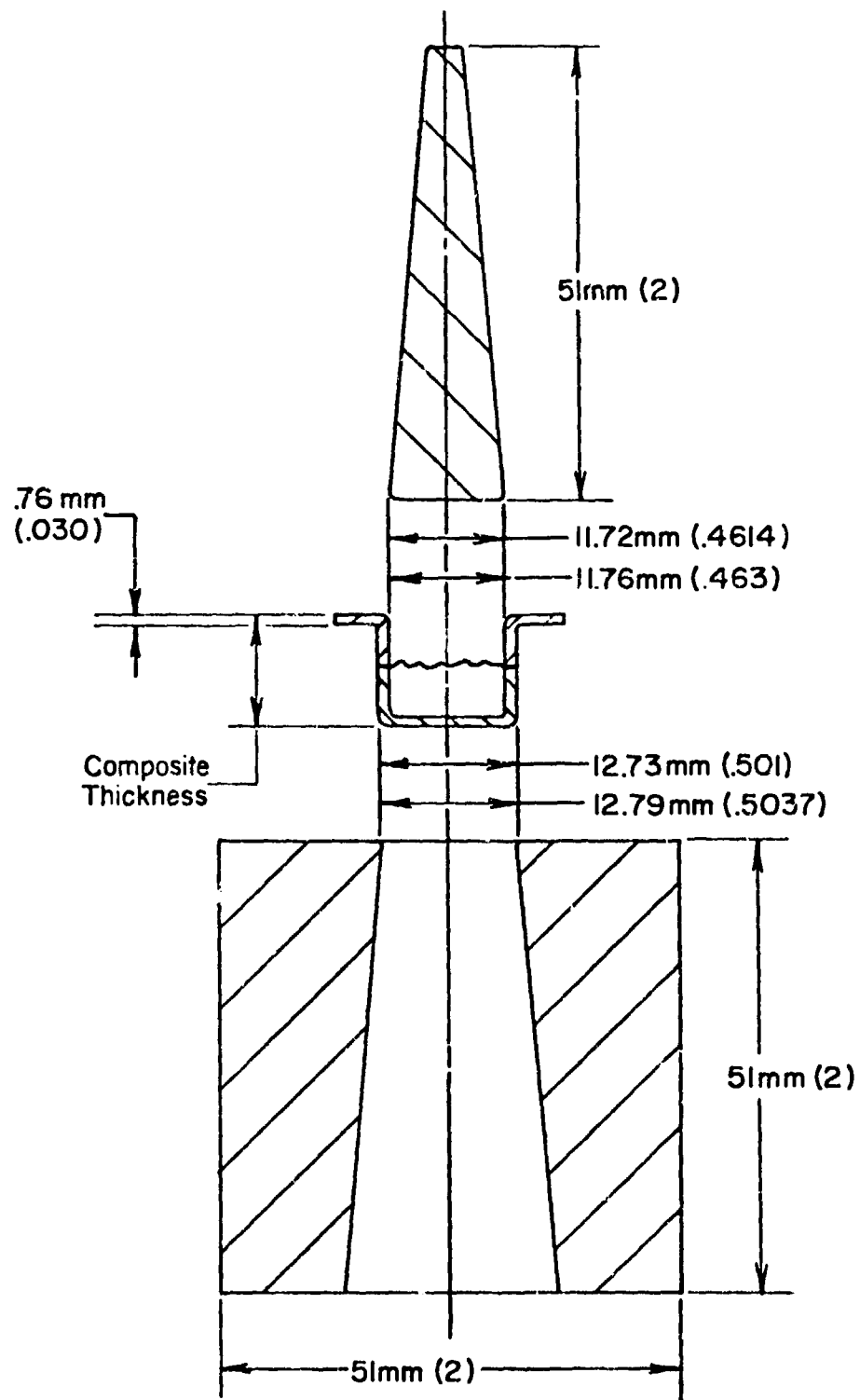
Fig. 3

SAW IN A CUTTING



Explosion Bonded and Cold Rolled Tantalum-on-OFHC-Cu

Fig. 4



Schematic of Nonstandard Fixture and Specimen for Determining Tensile Strength In Transverse Direction of Bond Zone in Explosion Welded Bimetal Composite

Fig. 5

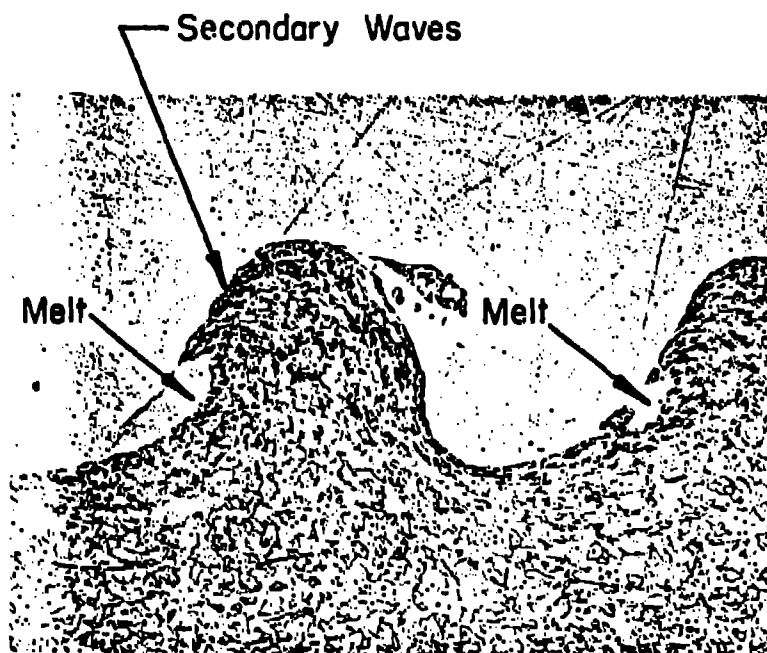


1812-32

250X

Explosion Bonded Molybdenum-on-OFHC Copper

Fig. 6



1745-20

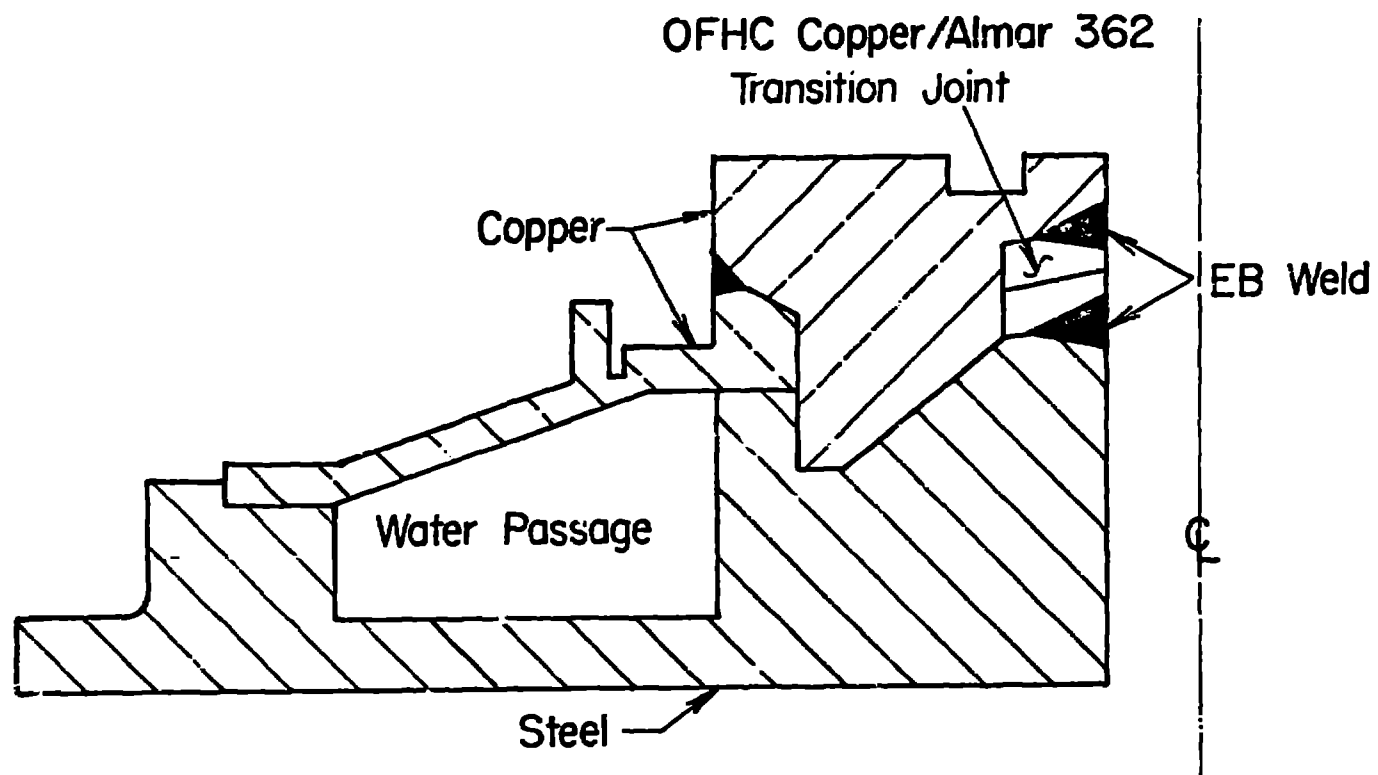
Etched for Carbon Steel

100X

$\alpha/\lambda = .45$

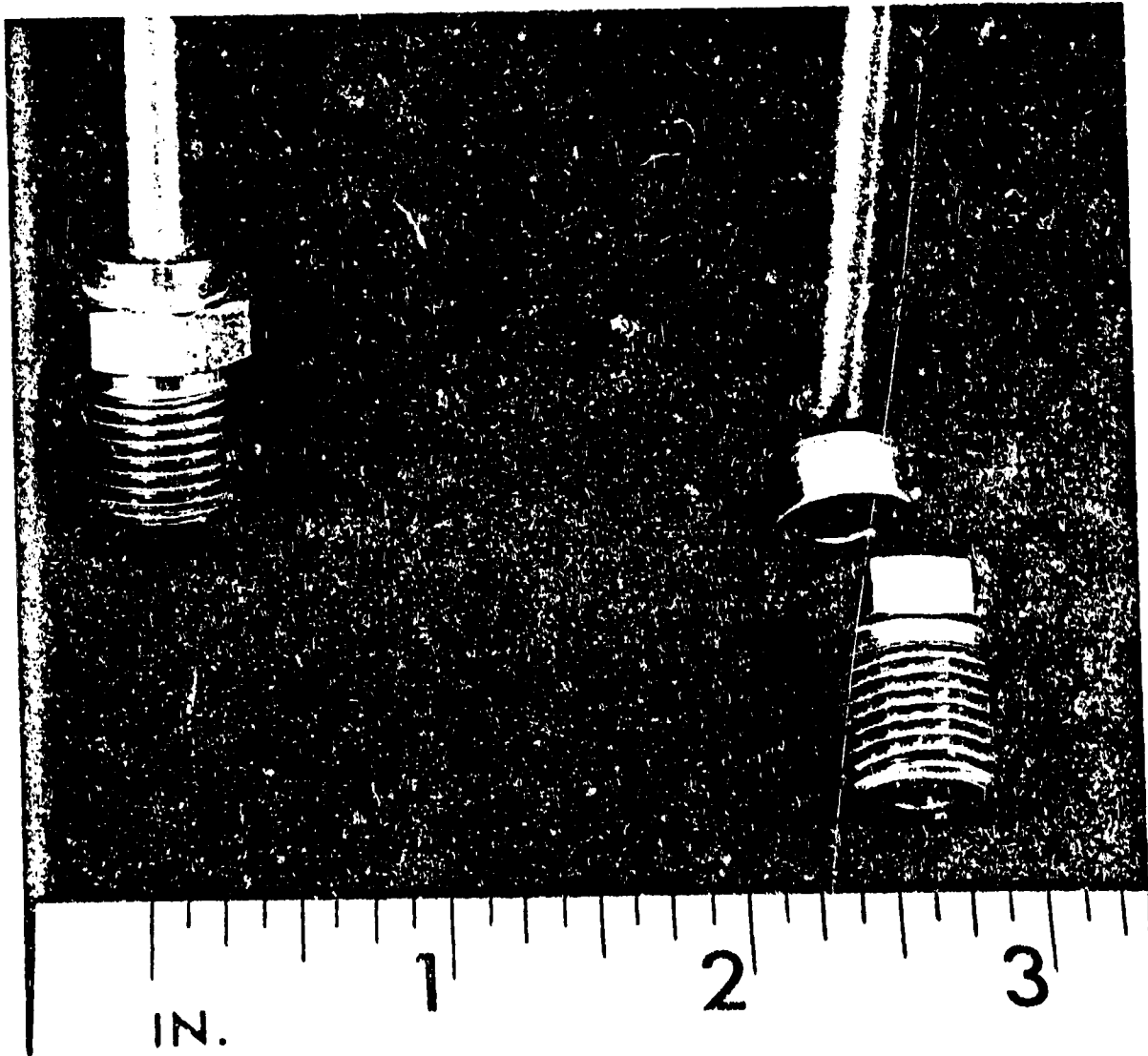
Explosion Bonded Type 304 Stainless Steel-on-Carbon Steel

Fig. 7



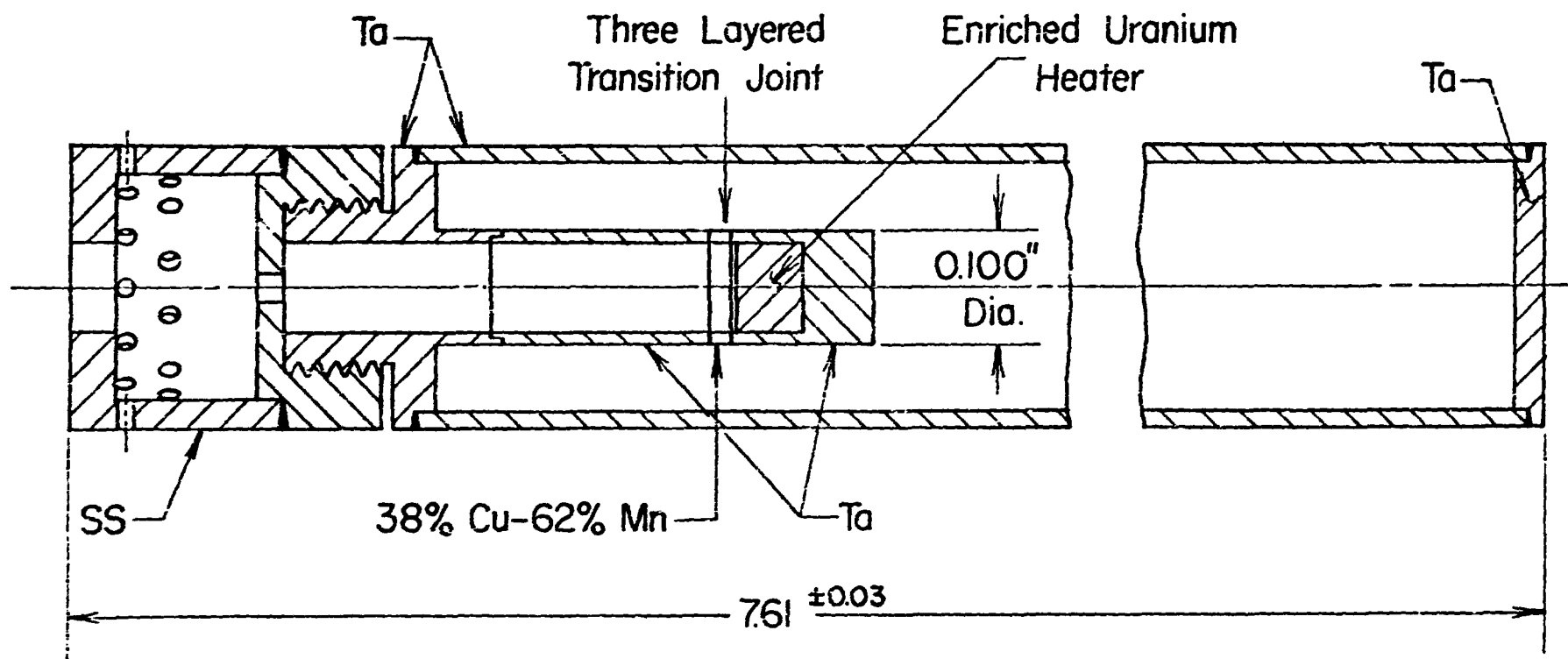
Joint Details Of Section Of Tritium Ion Source For Intense Neutron Facility

Fig. 8



Tantalum on Type 304 Stainless Steel Explosion Bonded
Transition Joint Before and After E.B. Welding

Fig. 9



Fuel Element Body For Loss-Of-Bond Device

Fig. 10