Weldability of Metal and Potential Application of Explosive Welding in Modern Industries

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Welding or joining of metals is probably as old as the invention of metals, when metals, were joined by heating and hammering (forge welding). Despite the early start, progress in the development of welding process was very slow; only in the 19th century, welding of metals was accepted as a potential technology for fabrication of metals, and since then the development work in this field started growing and presently it is considered to be a major fabrication process in the modern industries. With the introduction of more sophisticated and complex materials more and more novel techniques have been introduced for joining metals. Explosive welding is one of the latest techniques in the field of joining metals which can solve many joining problems.

There are several ways in which welding processes may be classified. One of the most convenient methods is, that based on the pressure and fusion characteristics involved in the process, this leads to two main divisions viz., plastic welding or pressure welding process & fusion welding process.

(a) In plastic welding, local application of pressure with or without heat, causes plastic deformation of metal at the interface whereby clean metallic surfaces are brought into intimate contact resulting in a metallic bond. The original layer of non-metallic material at the surface breaks up due to its lack of ducility and remains entrapped along the weld interface. Explosive welding is essentially a solid state plastic welding process.

(b) In fusion welding, the surfaces of the components to be joined are melted by the application of heat and the bond is produced by the subsequent solidification of the molten metal on both sides of the interface. The application of intense heat over comparatively larger volume of metal, high temperature involved, melting, and solidification introduce a lot of metallurgical problems such as change in microstructure, oxidation, thermal gradient, residual stresses and distortion etc. Different metals are affected differently by these factors. The term weldability has been used in welding literature to indicate the relative ease with which metal can be welded, particularly by fusion welding, so as to get desirable property of the weld in structural applications.

Various empirical criteria and tests have been developed to grade steel with respect to weldability in fusion welding. But in solid phase plastic welding processes no such criterion and gradation is relevant. Here the main requirement for welding is that the combination to be welded is capable of withstanding necessary plastic deformation required for bonding.

In the explosive welding process, one of the two components to be cladded is accelerated to a very high velocity by means of an explosive charge, and made to impact the second component at a small angle of incidence (Fig. 1). As a result of this high velocity impact of the plates, a thin metallic jet is ejected from the point of collision as in Fig. 2, which removes a layer from the surface of each of the plates, including surface contaminants and surface oxides. Finally, the virgin surfaces of the plates are brought together by the extremely

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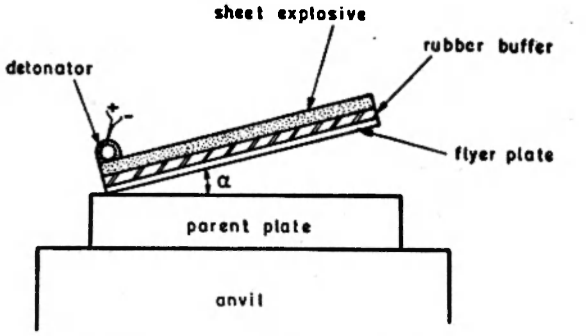


Fig. 1. Schematic diagram of oblique impact technique for explosive welding.

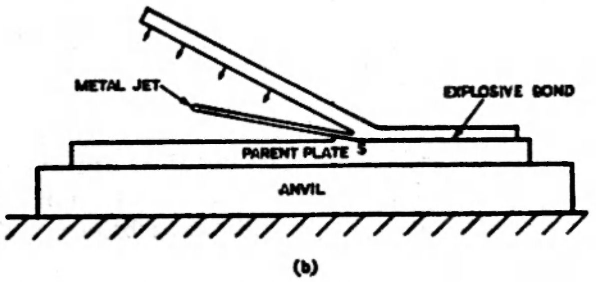


Fig. 2. Schematic diagram of metallic jet formation in explosive welding.

high pressure resulting in a metallic bond. The development of the characteristic wave structure at the interface welding (Fig. 3) is dependent upon jet formation since the wave structure has been observed in non-welding but jetting configurations[1]. The jet consists of materials from both the components, and a portion is expelled and another portion is entrapped in the swirls or eddies on either side of the wave crest. The metal in swirls and eddies on either side of the wave crest is a thorough mechanical mixture of metals from both the components[2] and is occasionally melted when the kinetic energy of the trapped jet is converted to heat. The molten metal is immediately quenched by surrounding metal, thus giving solidified metal pockets at the swirl. The solidified metal pockets at the bonded interface do not significantly affect the mechanical properties of the bond, and moreover by careful control of the welding parameters molten pockets can even be avoided. The bonding at the interface has essentially the characteristic of solid phase welding where there is no diffusion layer along the interface[3]. The bonding is purely metallurgical in nature. Measurement across the explosion weld interface of sample made of alternative layers of Cu and Ni electroplate shows that while there is no overall deformation in the welded combination the layers very close to the interface undergoes severely plastic deformation; layers at a distance of 0.010" on either side of the interface remain practically undeformed. (Fig. 5, 6). The layers close to the interface suffer deformation to the extent of 50 to 150%, but this does not demand a high ductility in the metal to be explosively welded. Metals having as low a ductility as 5% elongation in normal tensile test can be bonded by the explosive welding technique[4]. It is well known that less ductile material shows high ductility under explosive strain rate and high hydrostatic compressive stress which develop during explosive welding. In this respect, explosive welding has an advantage over solid phase welding technique, viz., roll bonding, pressure welding etc., where bonding is not possible because of inadequate ductility or wide difference in ductility of component metals. Cold worked or heat treated metal can successfully be welded by the explossion technique.

Materials which are graded as very poor in weldability in fusion welding processes because of their

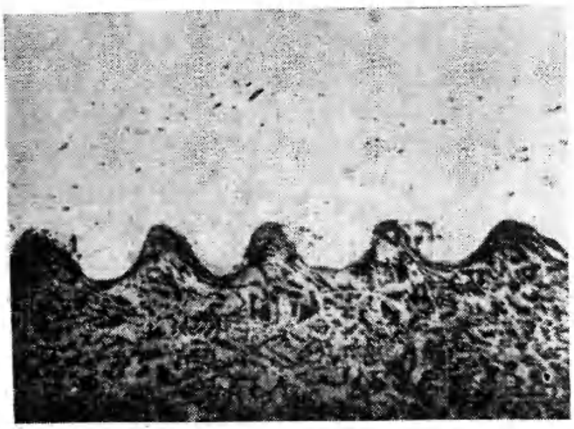


Fig. 3. Characteristic wavy interface in explosive welding (brass—mild steel).

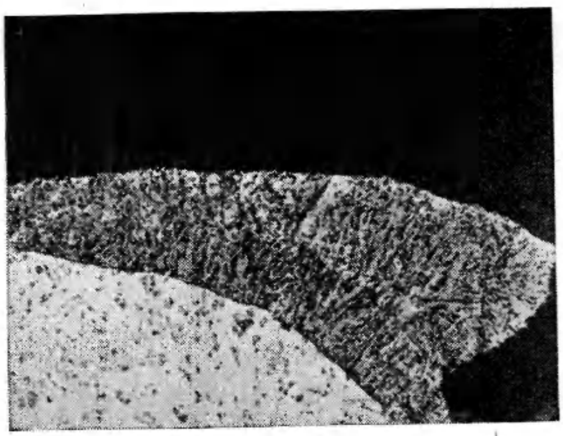


Fig. 4. Evidence of columnar structure at the molten pocket.

chemical composition, do not create any special problem in explosive welding. For example, in explosive welding, chemical composition of steel is not a consideration. All steels can be explosively welded by proper adjustment of welding parameters. The most important material property that is considered in determining the explosive welding parameters is the hardness of metal together with the geometrical size and shape of the components.[5]

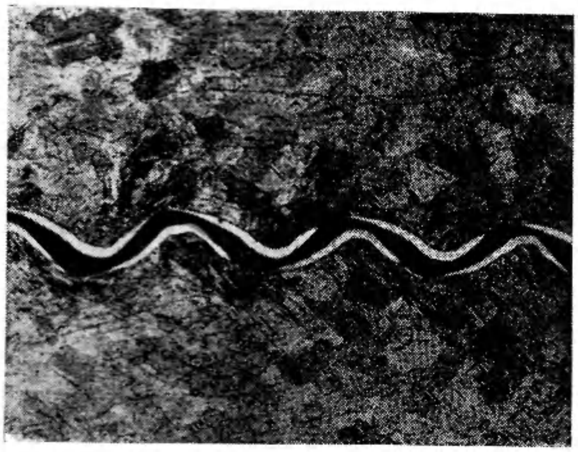


Fig. 5. Bonded copper nickel electroplate showing heavy deformation near the interface.

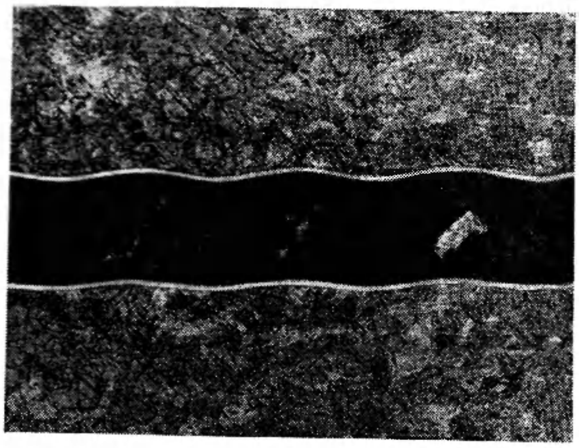


Fig. 6. Bonded copper nickel electroplate showing lesser deformation away from the interface.

In the case of dissimilar metal welding also the explosive method has a distinct advantage over fusion welding as well as other pressure welding processes. It is impossible to weld metals with a vast difference in melting points by fusion welding ; it is also apparent that materials of basically different plastic properties cannot be pressure welded together. With explosive welding, melting is not a necessary condition, nor do the

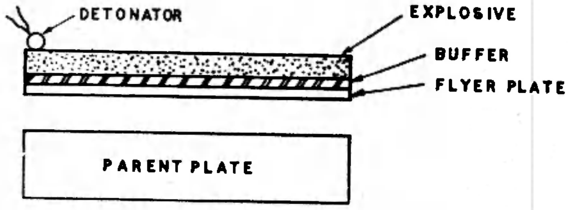


Fig. 7. Schematic diagram of parallel stand-off technique for explosive bonding of large plates.

plastic properties of the two metals being welded impose any limitations on the process. It is, for example, possible to explosively weld a soft low melting point metal such as lead to a hard high melting point metal such as steel. Annealed, cold worked or heat treated components can be explosion welded without significantly altering their properties[6]. The main limitation with explosive welding is that, so far, it has proved possible to weld together only simple geometric shapes such as flat surfaces, as in cladding, tubular cladding, welding of pipes and welding of tube to tube plate; other applications that have been or are being investigated are lap welding of tee junctions, spot welding, wire reinforced composites etc.

Application

(*a*) *Flat Plate Cladding*

The greatest application of explosive welding has been in the production of clad plates. An arrangement for the explosive bonding of clad plate is shown in fig. 7. Explosion bonding of flat sheet has enjoyed considerable commercial success.

The clad plate thickness can range anywhere from 0.001" to over an inch. The limiting thickness of the clad plate is strongly dependent on the material properties. Various clad combinations are being used in chemical and process vessels industries. The authors have developed the explosive welding technique of cladding large plates of various combinations such as stainless/mild steel, copper/Aluminium, steels of various grade/mild steel or alloy steel, copper, brass/mild steel[7] thermostatic bimetals of various types etc[8,9].

Tubular Cladding

Another major application of explosive welding is in the cladding of tubes; arrangement for internal and external cladding of tubes is shown in figures, 8 & 9. Internal cladding of steel tubes with thin layers of

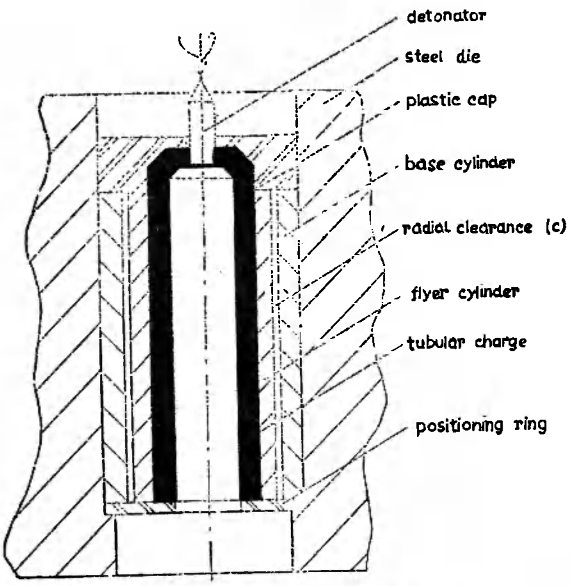


Fig. 8. An explosive welding system for inner lining of pipe.

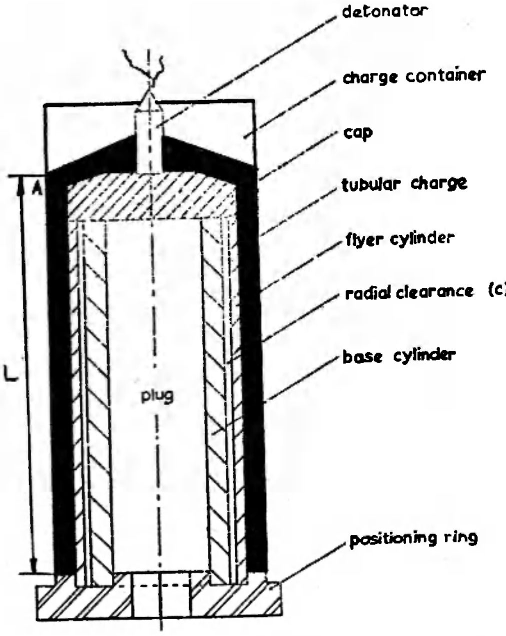
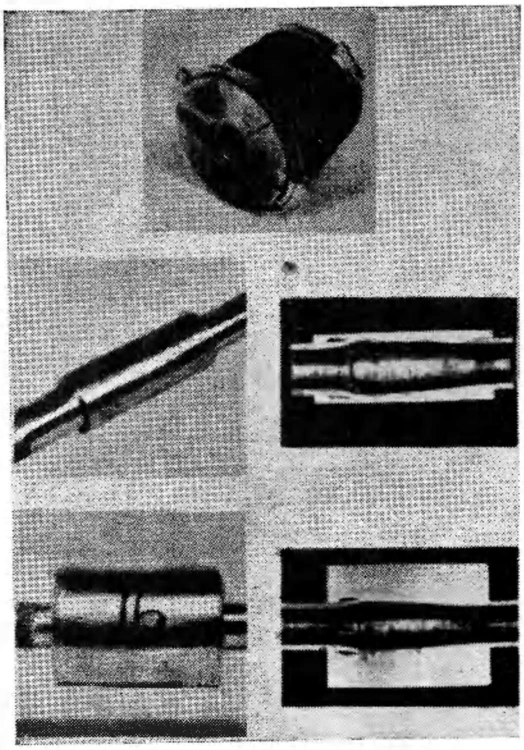


Fig. 9. An explosive welding system for outer lining of a cylinder or pipe.

corrosion resistance materials, such at titanium or tantalum etc., provides tubing suitable for use in chemical process equipments.

A more recent application of explosion welding technology is welding or joining of pipes. Successful welding techniques have been developed in joining pipes upto 12″ diameter. One of the techniques involves a sleeve which is explosively welded over the ends of the pipe (fig. 10). The alternative process is to use



Segmented Clamp (upper) and comparison of joints produced in 1 in. diameter pipes using this Clamp (centre) and using a self-supporting sleeve (lower)

Fig. 10. Sleeve explosively clad over the ends of the pipe.

overlapping ends (fig. 11). The details of joining are available in literature[10].

Welding of Tube to Tube Plates

Another fruitful area where explosive welding has been put to industrial application is the welding of tube to tube plates in boiler and other heat exchanger applications. Yorkshire Imperial Metals Ltd, U.K. was the first to develop the technique for welding tube to tube plates. They fabricated their first heat exchanger by this method in the year, 1966, and since then many heat exchangers have been fabricated. The process they developed is known as Y. impact process which is illustrated in figure 12. The process is an inclined orientation method which is achieved by tapering the hole in the tube plate, and consequently a high detonating velocity explosive can be used, and for small tubes, the charge in a detonation is sufficient. Considerable work in this field has also been carried out by Crossland et al at the Queen's University, U.K.[11].

Welding of tubes to tube plates by explosive welding technique has distinct advantage over the fusion welding

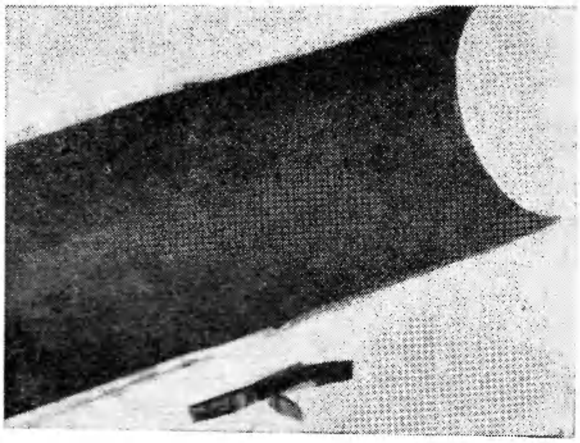


Fig. 11 Clad pipes joint explosively by the process of over lapping ends.

process. For example, fusion welding may lead to solidification tears, residual stresses, porosity and hard zone crackings in many steels, and initial metallurgical conditions such as cold work or heat treatment can be affected by the high temperature in the locality of the weld. The explosive welding technique can overcome these limitations mainly because it is essentially a solid state welding process.

Besides the most important applications of explosive welding for the manufacture of clad plates, tubular cladding and tube to tube plate joining, this process is also utilised to manufacture the coinage composite, transition joints etc.

It may be commented that when welding is considered in a general sense of joining of metals and alloys, the term "weldability" to indicate the suitability of a given material for fabrication by welding appears to be somewhat vague.

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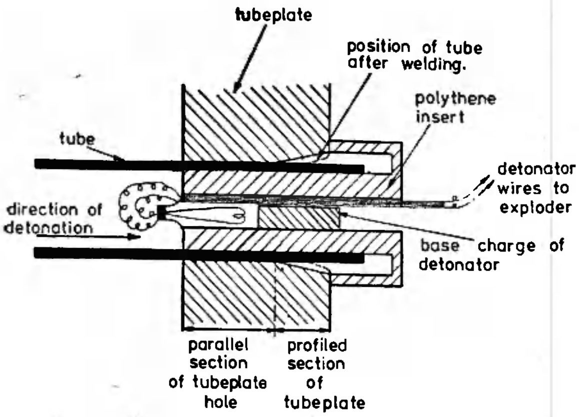
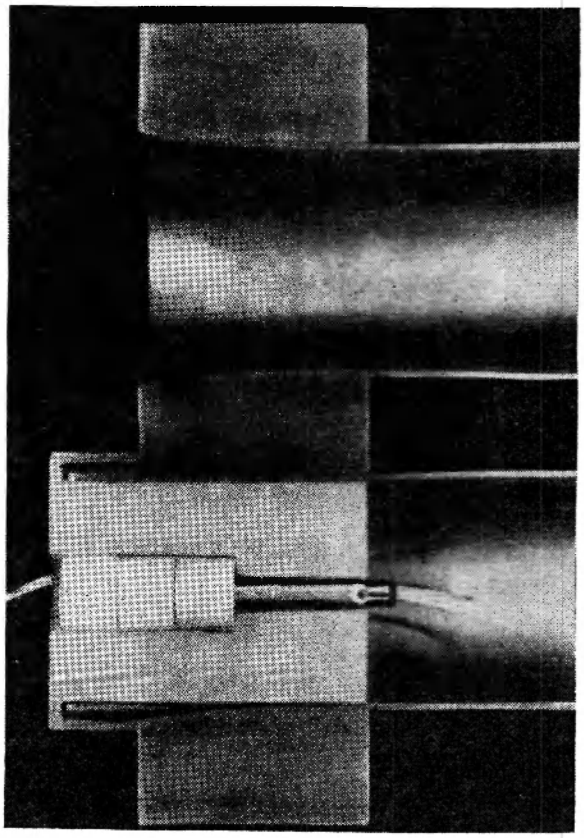
References

1. Abrahamson G. R.—"Permanent Periodic surface Deformation due to a Travelling Jet", Jl. of Applied Mechanics, Vol. 28, December, '61.

2. Baharani, A. S., and Crossland, B., A review of explosive welding research carried out in the Queen's University of Belfast, Proc. of the



Schematic diagram of assembly for explosive tube to tubeplate welding by *YIMpact* process.



YIM pact tube welding process showing detonator and additional pentolite charge. (Yorkshire Imperial Metal Ltd.)

Fig. 12. Diagram of assembly for explosive tube to tube plate welding by YIM pact process.

first Int. Nat. Conf. of the Centre for High Energy forming, Colarado, June, 1967.

3. Trueb, L. F., An Electron Microscopic investigation of Explosion Bonded metals, Trans. Met. Soc. AIME, Vol. 248, June, '68.

4. Carpenter, S., Willman, R. H., and Carlson, R. J.—Proc. Of the 1st Int. Nat. Conf. of the Cent. for High Energy forming 1967, p. 1. 2. 1.

5. Cave, J. A., Banerjee, S. K., Wylie, H. K., and Crossland, B., Recent Experiments in Explosive Welding, Research Report No. 752, The Queen's University of Belfast, U.K.

6. Crossland, B., Cave, J. A., Banerjee, S. K., Wylie, H. K., Explosive Cladding of Large and Relatively Thick Flyer Plates, Proc. Of the Fifth International Conference for High Energy Rate Fabrication, Denver, 1975.

7. Banerjee, S. K., Bhattacharya, J., Ghose, B. N., "Clad metals and its application in Chemical Industries", Proc. Seminar on metals and materials for Chemical industries, Baroda, March '75.

8. Banerjee, S. K., Williams, J. D., Crossland, B. Explosive Bonding of Thermostat Bi-metal, Metallurgia, U.K., March 1970, Vol. 81, No. 485, p. 87-88.

9. Bhattacharya, J., Ghose, B. N., Banerjee, S. K. Proc. 29th Annual Tech. Meeting, Indian Inst. of metals, Nov. 1975.

10. Chadwick, M. D., and Evans,—N. A., Explosive Welding Techniques for joining steel pipes, Int. Conf. on the use of high energy rate methods for forming, Welding & Compaction, University of Leeds, March, 1973.

11. Crossland, B., Bahrani, A. S., Williams, J. D. and Shribman, V., Explosive Welding of Tubes to Tube plates, Welding and Metal Fabrication, March, 1967, Vol. 35, No. 3, pp. 88-94.

PUBLICATIONS RECEIVED

Sl. No.	*Name of Journal*	*Publisher*	*Language*	*Volume Received*
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