Explosive Cladding of Different Materials and Its Mechanism

[1]Anand Kumar Pandey, [2]Neeraj Kumar
[12] Department of Mechanical Engineering, Rayat- Bahara University, Mohali (India)

Abstract: Explosive welding is a solid state joining process used for joining of similar or dissimilar metal combinations. In which explosive energy is used to form a strong metallurgical bond. During the past years, explosive welding has gained high popularity in various industrial field for producing number of bimetallic products. In this paper a brief history and process of explosive welding has been explained. In which basic mechanism of joining, setup for the explosive welding and other critical parameters affecting the explosive welding has also been explained to enable better understanding of welding process. Further commercial significance and the industrial application have been described in brief. This research paper will be helpful to the researchers, scientists and scholars working in this field in order to give a quick overview of the concept and parameters for the explosive welding process.

Index Terms- Buffer sheet, explosive, Jetting phenomenon, stand-off distance.

Introduction

In the field of manufacturing, Joining of material plays an important role in which two plates are clad using high heat and pressure. The joined metals may be either of same or different depends upon the requirement of the customer needs. In which the joining are made by localized merging or combination across the mating point [1]. Before joining the indispensable conditions for any type of welding are that the either surfaces before welding should be totally clean and uncontaminated, also it is necessary that both surfaces should be brought into very close contact with one another [2]. It is impossible to produce such a high degree of uncontaminated surfaces by normal methods of cleaning i.e. mechanical or chemical cleaning. However, under controlled environmental conditions cleaning done in vacuum chambers has been achieved by Bowden and Tabor(1954) and Keller (1963) [1, 3]. It is evident from experiments that if such a perfectly cleaned surface are brought into contact then strong bonding will produced between the two uneven surfaces (asperities) [1]. If such a clean and smooth surface of the metals are brought in contact of each other , interatomic repulsive and attractive forces will come into account and equilibrium will be established. The bond strength between the surface depend on the crystallographic disorientation across the interface and the diffusion and recrystalization which occurs, both of which are The other basic welding process is pressure welding, explosive welding process [4] in which the surfaces to be joined do not attain their melting temperature. [1]. A fine example is provided by the age-old process of forge welding which up to the 20th century was the only welding process in general use. In forge welding the work-pieces are heated to an appropriate temperature then quickly superimposed then hammered together. During this process the mating surfaces are plastically deformed, breaking up the contaminate surface films and creating uncontaminated areas where adhesion can occur. The work-pieces are heated so that it is easier to plastically deform them under a forging hammer [1,5]. Cold pressure welding is possible if the two metals to be welded are squeezed together between indenting dies or rolls, this method is extensively used to clad stainless steel on to steel. Yet another example is provided by friction welding, in which frictional heat is generated at the contacting surfaces between a stationary and rotating work-piece which are pressed together. When they reach a suitable temperature the rotation is stopped while the end load is maintained or increased while the member is allowed to cool.[1, 6, 7] Generally with fusion welding it is difficult to weld metals with appreciably melting-point temperatures and impossible if the boiling point of one metal is higher than the melting point of the other. Even with some metals with a similar melting point there may be serious metallurgical problems such as the formation of intermetallic compounds with undesirable properties. With pressure welding it is not possible to weld metals of substantially unlike hardness as the deformation of one will take place before the other. These problems do not arise in explosive welding [8], and though explosive welding is seriously limited in its field of application, nevertheless it does allow greatly dissimilar metals to be welded together and provide joints of great strength..

1.1 History

The EXW is a relatively new technique of welding in comparison to other welding techniques like Arc welding (developed in 1900AD) explosion welding has been developed after World War II. However its roots are connected to Ist World War, it was noticed that pieces of bomb shell not onlyslicked and embedded to the surface of armor, but they were found to be welded to the surface. It was concluded that this occurred due the action of explosive forces on the fragments. These incident was later on confirmed by conducting experiments in the lab and further a patent was successfully filled and awarded [9] .After that substantial amount of research work has been done in this area and the process is used in different felids to produce welded components and products.

1.2 Explosive welding process

Explosive welding is used mainly for bonding or cladding sheets of corrosion resistant metal sheet to some base metal [4]. Usually base metal on which cladding has to be done is heavier than the material to be welded on it. The process is can be satisfactorily used when requirement for large bonding area are involved. However research is going on joining small area using small and limited amount of explosives and tube cladding and plugging has also been achieved using explosive welding techniques.A schematic diagram, Figure 1 and Figure 2 shows two types of welding setups viz inclined setup and parallel setup respectively. The bottom most layer is called bottom sheet, is kept on a firm base which is sometimes called anvil and the top sheet is inclined to the bottom sheet at a small angle among the surfaces to be welded. An explosive generally in the form of a sheet, is placed above the two layers of metals. This explosive sheet is detonated, as a result compressive stress waves, of the order of thousands of Mega Pascal's, sweep across the surface of the plates [2].This result in formation of metallurgical bonding between the metallic layers.The strength of such bond formed is sufficiently high and enough to use it for various processing like rolling to reduce the thickness, machining to make components in industries etc. Number of different metal combinations can be joined by this process and these have numerous applications in diverse industries.

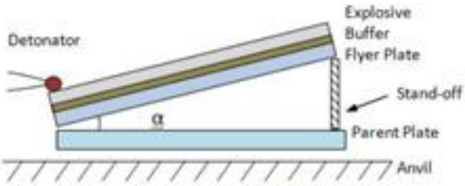

Figure 1: Inclined Welding Set-up

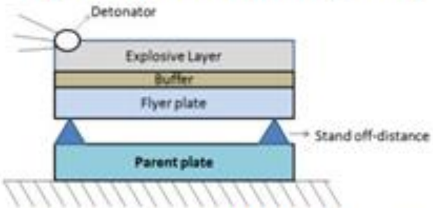

Figure 2: Parallel Welding Set-up

Mechanism of Explosive Welding

The explosive welding mechanism is suitably explained based on the analysis of the hollow charge stated by Birkhoff, Mac Dougall, Pugh and Taylor (1948). Fig. 3 (a) shows the general arrangement of a hollow charge. It can be seen that a conical cavity in the explosive charge is lined with a thin metal liner. When the explosive layer is detonated the detonation wave moves towards theliner, when this wave arrives at the tip of the liner outer surface of the liner is subjected to enormouspressure which result in failure of walls of the liner and drives the liner into inner part of the cone along its axis. The pressure generatedat the region in the linear where the surface of linearcollides (Refer figure. 3 (b)) is extremely high, that is as high as order of tons atmospheres. This pressure is much higher than the shear strength of the material. At such extremely high pressure the material behaves as an in viscid, compressible fluid and the material strength is overlooked. It is evident from the figure 3 (b) that the liner material divides into a high velocity metallic jet and a slower moving slug [1]. This high velocity metallic jet has incrediblepenetrating power, and the hollow charge in fact forms the basis of many types of weapons used for penetrating thick armors and bunkers.

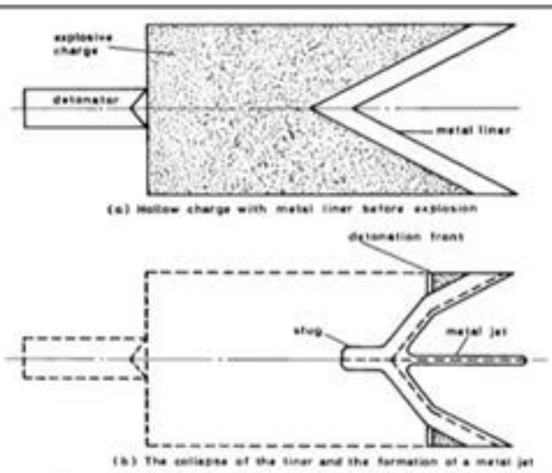

Fig. 3 (a) and (b). Hollow charge with metal liner.

Figure 3 (a) and (b) Hollow Charge before and after explosion [1]

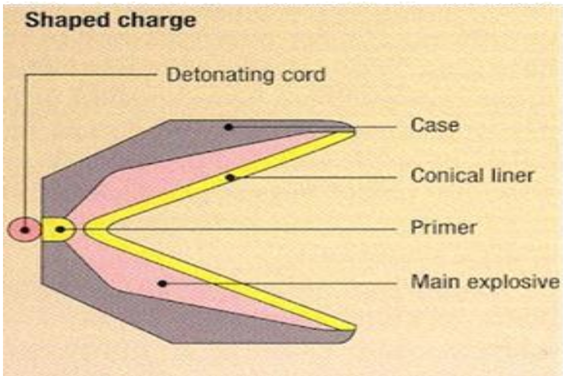

Figure 3 (c) Hollow Charge (Shape Charge) with Metal Liner

In explosive welding we shall see that the forming of a metallic jet is essential to achieve welding. Fig. 5 illustrates the set-up commonly used for cladding; we can see that the flyer plate which is to be cladded on the base material is supported at minimum area, a small angle of inclination is maintained between flyer and base plate (however in case of parallel setup flyer and base plates are kept parallel to each other). Above the flyer plate a buffer is laid (buffer may be a material like rubber or polystyrene) [10], and above that buffer a sheet of explosive is laid which is detonated from one end. As shown in fig. 5 due to detonation of the explosive sheet the flyer plate moves a velocity Vp and collides with the parent plate at an angle β. It will also be noted that as the flyer plate collapseson to the parent plate it moves at every instant as though it is hinged at lower point [1].

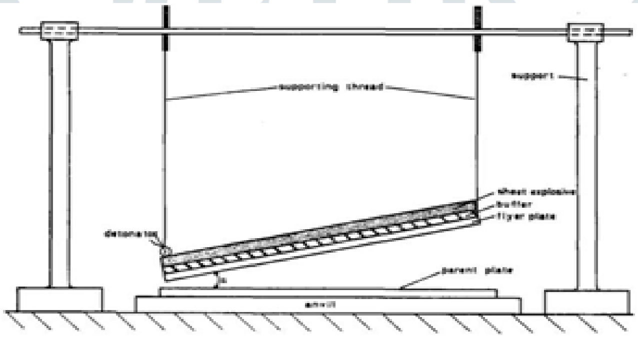

Fig. 4. Set-up for explosive cladding.

The welding setup shown above uses a thin sling to create standoff however some spacer like suitable thickness shim can be used to create appropriate standoff distance.

As soon as the flyer plate collides with the base plate it undergo retardation and tremendously high pressure is produced in the region of impact. The condition is analogous to the hollow charge where, the pressure developed is of very high order relative the shear strength of the materials involved in the process so that they can be considered as in viscid fluid for particular interval of time.

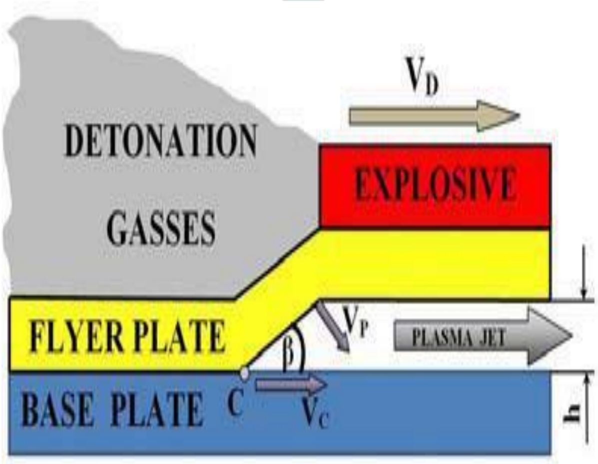

Figure 5: Typical representation of Explosive welding process

V_D - Detonation velocity, Vp –Velocity of plate collision, Vc- Velocity at collision point,β- Collision angle,h- distance between the plates, C-Collision Point

The high velocity re-entrant jet sweeps the surface (Fig 5) of the parent plate and it picks up by surface traction a thin layer from the top surface of the parent plate. Effectively the lower surface of the flyer plate has been peeled off and the top surface of the parent plate has been scraped off, leaving two absolutely clean and uncontaminated surfaces which arebrought together under pressure at the point of impact. The essential conditions for welding are achieved without melting, other requirement to deform the metals plastically to break the oxide or contaminant film on the surfaces. As a consequence limitations imposed by fusion or pressure welding do not apply to explosive welding [11].

Factors Effecting Explosive Welding

3.1 Assuring a Good Weld

In explosive welding the welding operation is a micro second phenomena there is no time to control welding parameters during the process [12]. Thus to produce a satisfactory weld with required strength and properties a careful preprocessingof the materials , assembly and set up must be done before conducting joining operation process through explosive welding.

3.2 Critical parameters which effect the welding

Jet Formation: During the process of explosive welding is one of the critical parameter which effects the quality of weld. Jet is responsible for Wave formation determined by collision angle. Jet is responsible for the formation of waves.The magnitude of pressure must be enough high to overcome the dynamic elastic limit of the material so to obtain a perfect weld.For jetting to be symmetric it must occur from both the plates. It is evidentfrom experiments that higher yield strength of the flyer plate will result in low amplitude wave and plate will not deform properly [13]. Stand-off distance: Appropriate standoff distance will facilitate the formation of required angle for weld. For thin plates Stand-off distance is taken as double of flyer plate (up to 6.5mm.) and for the thicker plates (up to 13mm) standoff distance is taken equal to the thickness of flyer plate [14]. The collision angle (β): Formation of jet is regulated by collision angle jet. The morphology of the welded front form is the result of change in collision angle which is 5 to 25 degree [15]. Velocity of detonation (V.O.D) The VOD of the explosive used should be less than 1.2 times of the sonic velocity of the material [12]. The VOD of the explosive should ranges from 2000 -6000 m/s. As greater VOD may result in high collision angle which may result in undesirable turbulence at interface VOD is the characteristic property of any explosive which is directly proportional to the explosive density.

Various Advantages, Disadvantage & Application of Explosive Welding Process

In general using explosive welding technique any metal can be joined/ welded if it possess sufficient strength and ductility to bear the deformation required at the very high velocity associated with the process. Metals which tend to crack when they are exposed to shock produced during the explosive detonation and collision are not suitablefor welding by Explosive Welding process. It is proved from research that materialsto be welded must have at least 6 % elongation and 13.6 or more charpy V notch impact strength are suitable for welding (EXW) by this method.

	steels	Alloy Steel	SS	AL. Alloy	Cu Alloy	Ni Alloy	Titanium	Columbium	Silver	Gold	Tantalum	Platinum	Co. Alloy	Mg	Zirconium
Carbon steels	*	*	*	*	*	*	*	*	*	*	*			*	*
Alloy steels	*	*	*	*	*	*	*				*		*	*	*
SS	*			*	*	*	*	*	*	*	* *		*		
Al alloys				*	*	*	*	*	*		*			*	
Cu alloys					*	*	*	*	*	*	*				
Ni alloys						*	*			*	*	*		*	
Ti							*	*	*		*			*	*
Cb								*	*		*	*			
Ag									*		*				
Au											*				
Ta							*	*		*					
Pt											*		*		
Co alloys											*				
Mg											*			*	
Zr											*				*

Table 1: Commercially Significant application in explosive welding [16]

• Various combination of metals and alloys can be welded satisfactorily using explosive welding techniques even the materials which cannot be welded or very difficult to weld can be suitably welded using this technique [16].

• Different materials can be welded without application of external heating and flux even no filler material and gas shielding is required [16].

• Clad or weld large areas such as might be experienced in sandwich construction or in the inner or outer lining of cylinders [16].

• The process is economically competitive, in some cases with compared to conventional welding processes like fusion welding.

Disadvantages

The main disadvantage or constrain of this method is that the person performing this process need to have through knowledge and experience of explosive, more over high safety parameters must be maintained while dealing with explosives before performing the related trails /process . Regulations for the use of high explosives may require special licensing [17].

Applications

- Cladding of tubes for nuclear reactors.
- Fabrication of lining of turbine engine half cylinders[18].
- Cladding of cylinder bores and pistons.
- Welding of pipes and tubing [Fig 6 (b)] of dissimilar materials for aerospace and cryogenic applications and cladding of pressure [Fig 6 (a)] and mixing vessels in chemical and petroleum industries [19].

Marine industries for making the structurally sound corrosion resistant aluminum and steel [21].

Figure 6 (a) Titanium Clad pressure vessel (Picture is the property of Coek Engineering NV, Lessel 13-2440, Belgium)

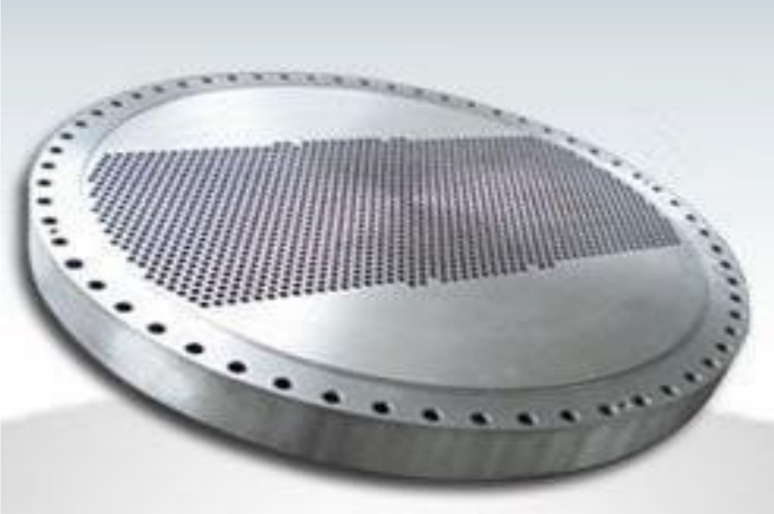

Figure 6 (b): Shell tube

- Heat exchanger having clad tube sheet and shell [21].
- To produce high strength cladding between niobium (columbium) and Aluminum alloy (6061- T651) [22].
- Heater tubes for Feed water [23].
- Joining of dissimilar metals [Fig 6 (c)], e.g. Al & Steel [24].
- Joining of similar metals, e.g. Al to Al [25].
- Metallic sheets having low weight [26].

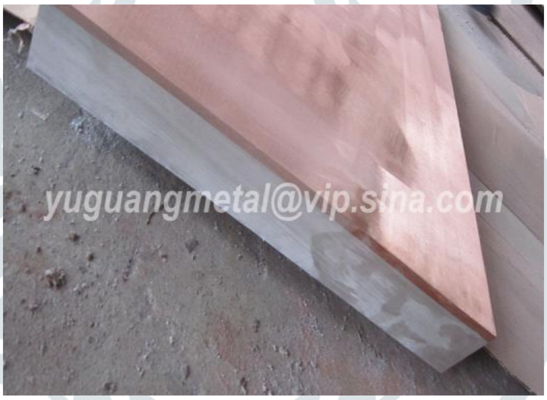

Figure 6 (c): Cu –SS Bimetallic cladded plate (Courtesy yuguangmetal@vip.sina.com)

Conclusions

The jet phenomenon during the explosive welding process plays an important role in removing the contaminant surface layers, which is an essential of any welding process. This process enables strong bond between metals which is difficult or impossible to weld by any other conventional means. So the scope of explosive welding in industrial applications has better future even more than only cladding of plates. It has bright future and endless use in aerospace industry where foil cladding can be used as coating mechanism to impart better properties to the material to withstand oxidation and imparting better high temperature resistance to the parent metal and thus the performance of material is improved.

References

[1] B. Crossland & A S Baharani 919610 , Fundamental ofExplosive Welding , Contemporary Physics.

[2] Crossland, B. (1970). Explosives for welding. Physics Bulletin. 21. 498-502. 10.1088/0031-9112/21/11/016.

[3] Bowdenf,. P., and Tabord, ., 1954, The Friction and Lubrication of Solids (Oxford Kellerd, . V., 1963, Wear, 6,353.

[4] B.B. Sherpa, A. Upadhyay, S. Kumar, P.D. Kumar, A. Agarwal, Materials Today: Proceedings 4 (2017) 1260-1267.

[5] Kalpakjian, Manufacturing Engineering and Technology 5th Edition. 981

[6] David Cutter, What you can do with Explosive welding , Welding Journal , July 2006

[7] N. Bay, Cold Pressure Welding The Mechanisms Governing Bonding (2016) https://www.researchgate.net/publication/273567526

[8] A. Upadhyay, B.B. Sherpa, S. Kumar, N. Srivastav, P. Dinesh Kumar, A. Agarwal, Materials Science Forum, vol 830, Trans Tech Publ, 2015, pp. 261-264.

[9]Explosive Bonding –United States Patent 3137937 [10]Mohammad Tabatabaee Ghomi ,Mälardalen University Press Licentiate Theses No. 106 ,Impact Wave Process Modeling and Optimization in High Energy Rate Explosive Welding , 2009

[11] B. Crossland and J. D. Williams, Explosive Welding, https://htracyhall.org/ocr/HTH Archives/Cabinet % 202 /C/Crossland,%20B / Crossland, %20 B.-3351_OCR.pdf

[12] Colline Merriman " The Fundamental of Explosives , Welding Journal July 2006

[13] N.Raghu, Sanjay K.Rai, Anish Kumar, T.jayakumar, K.V.Kasiviswanathan and Baldev Raj.,Characteristic of explosive weld interfaces. Dec 20-22, 2004 chennai India.

[14] M.Prazmowski, H.Paul, The effect of stand-off distance on the structure and properties of zirconium carbon steel bimetal produced by explosion welding, volume 57, 2012 issue

[15] S.A.A.Akbari-mousavi, L.M.Barrett, S.T.S.Al-Hassani, Explosive welding of metal plates, journal of materials processing technology 202 (2008) 224-239.

[16] Harry J. Addison, Jr., James F. Kowalick ,Winston W. Cavell, Explosion Welding of Cylindrical Shapes (1969) Pitman-Dunn Research Laboratories, Frankford Arsenal,Philadelphia, Pa. 19137

[17] Health and Safety Executive "Explosive Licensing in the UK

[18] Kacar R, Acarer M. An investigation on the explosive cladding of 316L stainless steel-din-P355GH steel. ,J Mater Process Technol 2004; 152:91–6.

[19] G Jutjering , J.C.Williams Titanium. Engineering Materials and Processes (Springer , Heidelberg , 2007

[20] Charles R.Mckenney and John G. Banker, Explosion bonded metals for marine structural application.

[21] N.W.Buijs- Metallurgist at innomet b.v. Explosive welding of metals in a Vaccum environment

[22] T.A.Palmer, J.W.Elmer, D.Brasher, D.Butler, and R.Riddle, Development of an explosive welding,process for producing high strength welds between Niobium and 6061-T651 Aluminum. 252-s,November 2006.

[23] Linda riley, performance engineer and carroll willsie, design engineer, KCPL, Restoring heat transfer,surface to feedwater heaters using explosively welded sleeves at LA cygnet generating station (KCPL)

[24] B.S.Zlobin, Explosion welding of steel with aluminum, combustion, explosion, and shock waves, vol.38,no 3, pp. 374-377, 2002.

[25] F.Grignon, D.Benson, K.S.Vecchio, M.A.Meyers. Explosive welding of aluminum to aluminum:,analysis, computation and experiments. International journal of impact engineering 30 (2004) 1333-1351

[26] Yamato matsui, masahiko otsuka,takeshi hinata, erik carton, shigeru itoh, explosive welding of light,weight metal sheets, 8th international LS-DYNA users conference.