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EXPLOSIVE WELDING OF COPPER TO STEEL

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ABSTRACT: *Explosive welding has mainly found commercial application in large plate cladding of one metal on another, tube to tubeplate welding, cladding one tube on another, plugging of heat exchangers, various electrical connectors, especially those between cooper and aluminium, transition pieces, especially for pipe working cryogenic systems, pipe to pipe welding etc. We used explosive cladding to produce a bimetal Cu+steel for plane bearings required in big electro- hydro- generator construction. The experiments were made with the aim to find out welding parameters which provide minimal reject in production.*

The aim of the paper is to present some results obtained from experimental research in the explosive welding of copper to steel.

Key words: *Explosive welding, plate cladding copper to steel*

1. INTRODUCTION

Explosive welding is a process which for many applications cannot be performed by conventional methods. It is possible to weld metals with very different melting points such as Al and Ta, widely different thermal expansion, such as titanium and stainless steel, and large variations in hardness, such as lead and steel.

Explosive welding has mainly found commercial application in large plate cladding of one metal on another, tube to tubeplate welding, cladding one tube on another, plugging of heat exchangers, various electrical connectors, especially those between cooper and aluminium, transition pieces, especially for pipe working cryogenic systems, pipe to pipe welding etc. To date, the explosion welding process has been employed to bond more than 260 combinations of similar and dissimilar metals.

In explosive welding, for the bonding to take place, the metal surfaces must come together at a characteristic velocity and angle, which must be controlled within certain limits. A very high pressure is developed near the collision point, and the metal surfaces can flow as a spray of metal from the apex of the angled collision. The surfaces are stripped off in the collision and discharged in the resulting jet, thus removing the bond inhibiting surface films. The resulting film free surfaces are pressed in to atomic contact by the very high collision pressure, and a metallurgical bond is formed.

Explosive welding criteria may be expressed in three categories: weld geometry, explosive parameters and material properties.

With regard to weld geometry it has been shown that the plates must come together at an angle to permit formation of the jet.

The most important explosive parameter is the detonation velocity, which determines the collision point velocity. The collision point velocity must be less than the sonic velocity of either the flyer or the base plate.

The most important material properties governing successful explosive welding are ductility and solid solubility.

With regard to the future, explosive welding techniques will be applied in areas where it is difficult to use conventional welding, due to weight of conventional welding equipment, remoteness of operation, problems of logistics, and incompatibility of material properties with conventional welding processes. Fabrication of structures in space, underwater explosive welding for salvage or repair, shipbuilding, building construction, large plate cladding of one metal on another, tube to tubeplate welding, cladding one tube on another, plugging of heat exchangers, chemical and petroleum work and most of the major areas of industry have hundreds of potential explosive welding applications. Currently the largest plates which have been cladded have areas of 30…40 m^2 and explosive charges of up to 1500 kg or more have been used [1].

2. FUNDAMENTAL PROBLEMS

Initial positions of the elements involved in the welding process can be different. In a general form, this scheme includes (fig. 1a): a base plate (parent plate) 1 and a flyer plate 2, inclined to the first at an angle $\alpha \geq 0$. Over the flyer plate is placed directly or through a protective layer (or buffer) 3, the high explosive layer 4, with the detonator 5, necessary to initiate the explosion. The buffer may be: rubber, polythene, cardboard, or even a thick coat of plastic paint, depending on the explosive used. The high explosive, either in the form of a sheet explosive, granular explosive or powder is detoned from the lower edge. [6]

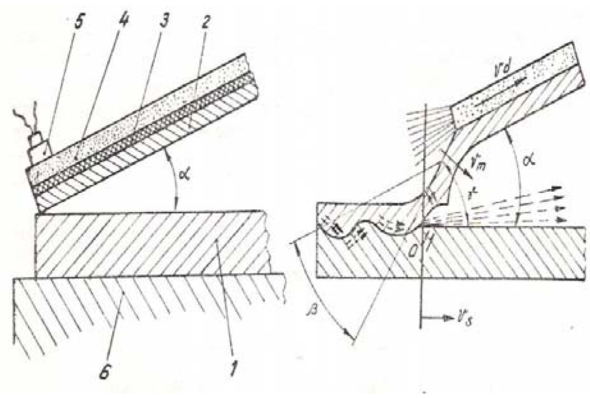


Fig.1. Basic setup for explosive welding: a- prior the detonation; b- an instant after detonation.

The shock wave produced by explosion accelerates the flyer plate at a speed v_m and at an angle (dynamic plating angle) γ, which is kept constant if α=0, or increases during the movement of the detonation front if α>0 (fig.1b). The high-velocity oblique impact between the two components being welded cause the metals to behave like fluids. As a result a high-velocity jet is formed from the two surfaces of both components, which leaves two virgin clean surfaces which are pressed together to form a weld. The weld interface shows well-formed regular waves. Fig. 1 b shows the geometry, short time after the detonation has been initiated, and before the detonation wave has reached the extremity of the charge. Waves between materials of equal density appear to by nearly completely symmetrical, while with materials of different density, such as copper to steel, the waves are asymmetrical.

In the Crosland emitted theory - that appeals jets theory, obtaining a good joint is related to jet formation, which may not take place if the velocity of point O (welding velocity v_s) is not lower than the sound velocity in the two metals. [1] On the other hand, between the welding velocity v_s and the explosive detonation velocity v_d the relationship exists:

$$v_s = v_m / \sin \gamma = v_{d,} \sin (\gamma-\alpha)/ \sin \gamma$$

where the impact velocity

$$v_{m,} = v_{d,} \sin(\gamma-\alpha)$$

Note that, $\sin (\gamma-\alpha)/ \sin \gamma < 1$ for $\alpha >$ 0, so starting from an initial position of plates in dihedral , can be obtained for v_s a lower velocity comparatively of sound metal velocity, even for high explosive with detonation velocity higher at its, on we meet accessible usually.

Explosives with detonation velocity higher than sound velocity in the two metals, even with $\alpha > 0$, can not be used when large surfaces planting is required, such as in the studied case, because with the displacement of the detonation wave, the real impact angle γ increases to the outside of a small interval of values, interval in which the jet forming and proper joints are insured. In such situations it is necessary to work with an initial angle α = 0, corresponding at $v_s = v_d$ in which case, requires the use of explosives with a detonation velocity lower than sound velocity in the same two metals. For this situation corresponds better the use of explosive mixtures which in certain proportions, provides a subsonic detonation velocity and a stable detonation transformation.

Plastic explosives are preferred in sheets, with features that meet user needs, easier to handle. In our case, for easier utilization is adequate to use an explosive mixture of granular ammonium-nitrate - ammonit.

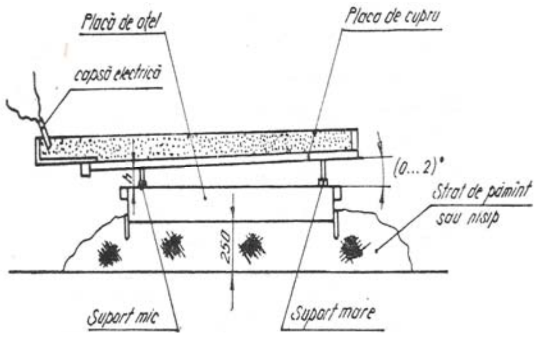


Fig. 3. Explosive device for cladding Cu to steel

3. EXPERIMENTAL RESEARCH

For making the plated product we have used: base plate- mild steel carbon OL37; flyer plate- industrial copper-Cu 9. Base plate (parent plate) material had dimensions as in figure 2, being processed on the surface to be plated at Rz50. Before cladding has been cleaned of impurities with gasoline, acetone and alcohol

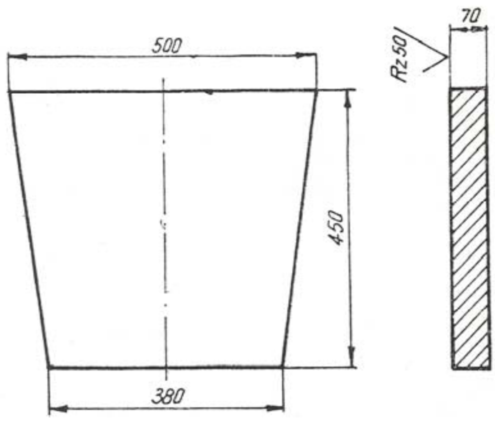


Fig. 2. Shape and dimension of parent plate

Flyer plate material (coated material) with thickness s = 5 ... 6 mm, was cut with added material to contour, compared to the base plate at 20 mm. After an annealing heat treatment, it was chemically etched.

Explosive device was placed on the sand (fig. 3), in a mining area, respecting technical rules for safety explosive material working. Explosive layer composed of ammonium nitrate sensitized with an addition of ammonite, have ensured the stable detonation velocity of 2500 ... 3500 m / s.

Flyer plate was placed on the parent plate, using copper rivets, being achieved between two plates a distance of about 7-8 mm and an angle of 2^0 (fig.3). Explosive charge was detonated with an electric cap placed like in the figure. After the explosion welding, the cladded parts were subjected to an annealing treatment at 450 ^{0}C, for 4 hours and slow cooling.

The mechanical testing of copper and copper alloy/steel composites is covered by American National Standards. The essential problem in the testing of explosive welds is that the cladding is mostly thin, and consequently it is difficult to devise a test to measure the strength on the bond at the weld interface.

In our case, according to the product norm, the weld testing consisted in:

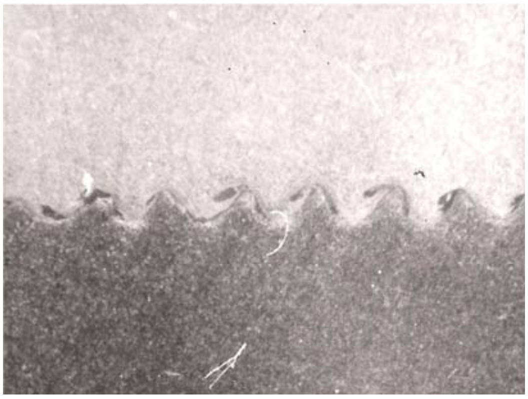
-ultrasonic test after cladding;
-metallographic examination at interface;
-hardness testing in piece section.

Ultrasonic test is capable of establishing areas of no bond. It is not able to detect the presence of a poor metallurgical structure at the weld interface. However, when the weld is defective, the reflection from the weld interface will be larger and the one for the back surface smaller, so the ratio of amplitudes will increase, and this growth will be a measure of the imperfection.

Ultrasonic control data showed small bondless surfaces (less than 2%), in piece corners, caused by interference phenomena and located in the added metal for dimensional working.

The progressive development of interfacial waves after welding process for copper to steel is shown in fig.4.

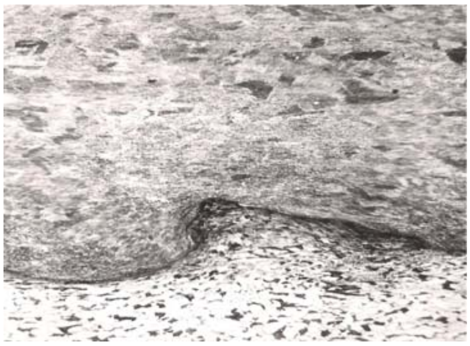
a



b

Fig. 4. Interface zone (x5) in explosive weld of Cu to mild steel: a) transverse section , b) longitudinal section.

Fig. 5 and 6 shows microstructures of bimetal Cu to mild steel after explosive welding. At fig. 4b and 5a is a typical example of waves formation by explosive welding of metal with dissimilar density.



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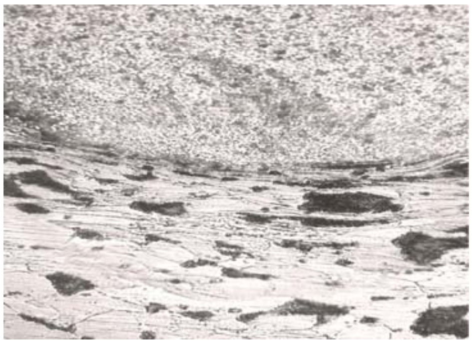

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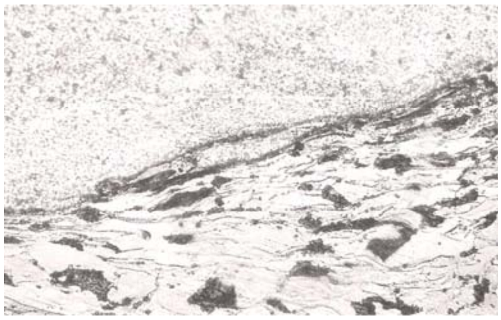
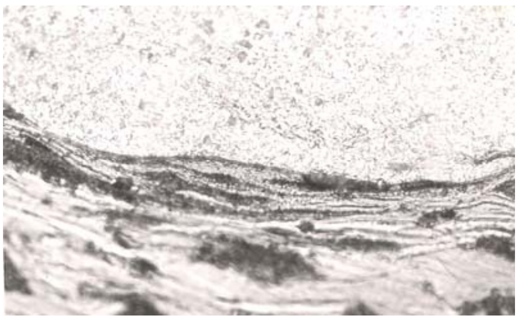


c



d

Fig. 5. Microstructures of joint zone after explosive welding for bimetal Cu+mild steel: a) steel apex of vortex (x100); b) copper entering in the steel plate (x500); c) perlitic structure and deformation bands in steel

(x500); d) mixture Cu+steel and deformation bands (x1000).

Fig. 6. Fused and solidified metal in Cu flyer plate near interface

The flyer plate is subjected to an intense stress wave from the detonation of the explosive layer in contact with it, and subsequently both the flyer plate and the parent plate experience an intense stress wave resulting from the high velocity impact. These intense stress waves give rise to metallurgical changes which results in an increase in hardness, illustrated in fig. 7. The general level of hardness in both plates is increased to interface (fig. 7 *a* and *c*). After annealing at 450^{0}C overall level of hardness is decreasing (fig. 7 *b* and *d*).

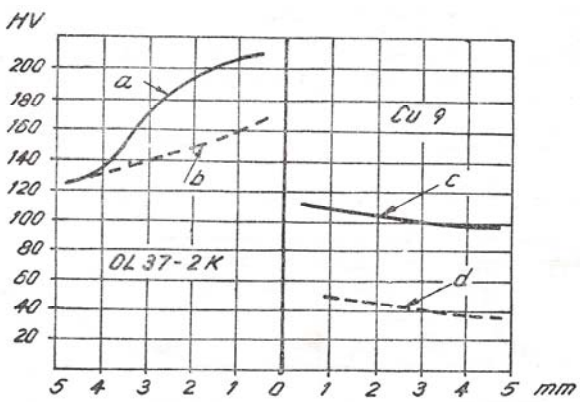


Fig. 7. Hardness profiles in weld by copper to steel:
a and *c* – after explosive welding; *b* and *d* – after annealing

Lastly, the theory explains that, the presence of a high residual concentration of point defects contribute to increase in hardness.

The developed technology was used for the manufacturing of a large number of pieces for Uzinele Resita.

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