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COMPOSITE MULTILAYER STRUCTURES OBTAINED BY EXPLOSIVE METHOD

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Abstract: *The explosive welding process has been understood for decades, the industry has been slow to realize its potential and the possible composites that it makes available. This paper focus on some aspects related to welding process by explosion mechanism in order to obtaining new multi-layer structures used in special industries, such as aeronautics and mechanical engineering.*

Keywords: *composite structures, multilayer structure, explosive welding.*

1. INTRODUCTION

The main advantages of multilayer structures obtained by explosion bond, such us elimination of galvanic corrosion, design control of bonding point, weldable bi-metallic transitions, stronger than friction and diffusion welded joints or reduction of mechanical integration, make this composite materials a solution for special vehicles, like aircraft carriers or space satellites.

Several studies concerning the waves at the welding-interface concluded that the particularities of melted and solidified material cannot be explained neither by the mechanism of welding in the solid state, nor by the dissolving mechanism. The deformation of the granules at the interface and the appearance of the waves define that the phenomenon of welding through explosion is based on a hydrodynamic process of inflows. [1,2,3]

In the process of explosion welding of plates, the kinetic energy transforms into thermic energy (accompanied by energy dissipation) at the welding-interface, enough to cause bilateral dissolves throughout the interface. The diffusion of the materials into liquid state takes place gradually, depending on the structure of the welded materials and the distance from the interface. [4]

To illustrate the process of explosion welding of plates, this paper presents a principle method accompanied by a numerical analysis and a practical experiment.

2. THE PROCESS

The explosive bonding is a welding process that uses controlled explosive energy to force two or more metals together at high pressures (Fig. 1).

The isotropic layers are joined with a high-quality metallurgical bond, leading to a performant composite system. The time necessary in the explosive welding process is very short, so the reaction zone between the constituent metals is at microscopic level. During the bonding process, several atomic layers on the surface of each metal become plasma.

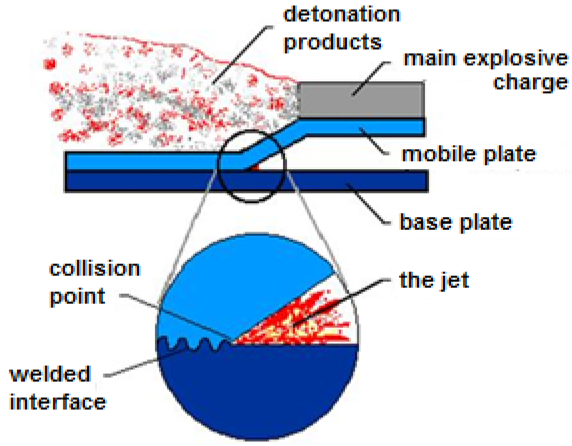


Fig. 1. Explosive bonding process [7]

The collision angle between the two surfaces (typically less than 30°) forces the plasma to jet ahead of the collision front, effectively scrubbing both surfaces.

The remaining thickness stays at near ambient temperature and acts as a huge heat sink. Therefore, the bond line is an abrupt transition from the clad metal to the base metal with virtually no degradation of their initial physical or mechanical properties. The obvious benefit from this process is the joining of metallurgical incompatible systems. Any conventional cladding method, which uses heat, may cause brittle intermetallic compounds to form. [7]

Bonding multiple laminae by explosive welding involves a working knowledge of the process phenomena and the ability to utilize them efficiently. The variables affecting the weld formation must be tightly controlled in order to create the desired composite with quality weld. The characteristics of the wave pattern formed during the explosive process (amplitude and periodicity) are influenced by three major parameters: collision velocity (V_c), explosive load and the interface spacing. To control these parameters means to control the welding process. The wave pattern formed at the bond line is most often described as resulting from a fluid-flow collision. The two constituent metals can be considered to act as viscous fluids in the reaction zone and, just as in describing laminar or turbulent flow, a Reynolds number can be determined for the system. [7]

In a fluid-flow collision, the interface turbulence is controlled by the detonation velocity and the collision angle. The interface morphology is important for some specific applications: maintaining a wavy interface to increase transition joint's shear strength or a flat interface in a system, where a reaction zone is minimized for thermal reasons (Fig. 2).

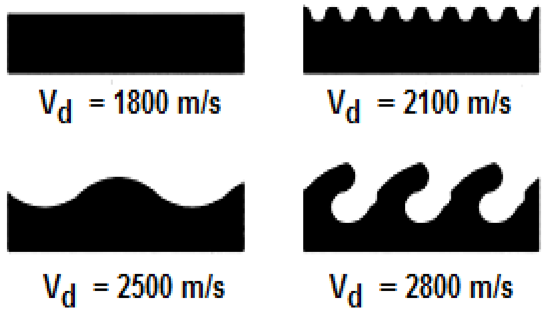


Fig. 2. Explosive Welding Wave Morphology Variation [5]

It has been experimentally established that during the process of welding, important transversal tensions form on the interface, resulting in effect of heating of the interface. This phenomenon could lead to an adequate warming of the superficial shells to produce the welding and can also explain the appearance of the waves at the interface [1].

New testing procedures have revealed that, at the collision of the welding pieces, only a very thin layer of melt forms on the interface. The assigned value of refrigeration of the remained melting layer is 10^5 ^{0}C/s, this value is high because of the line of contact between the components.

The existence of an amorphous layer, inside the welding zone, has been taken into account for different metallic combinations and explained by the scientists as being the main reason of welding through explosion's fundamental mechanism (Mustață, 2003:96-112;Belmas et al.,1996:217-222).

The welding mechanism with jet configuration is able to incorporate the influence of the main technological parameters and can somehow envisage a "working" domain for the welding parameters, for any material combination.

According to these assertions, it is generally accepted that the well-known phenomenon of the point jet formation is a collision and is a fundamental condition for the explosion welding process.

This paper tackles the formed jet that represents the mechanical cleaning agent of the welding areas, removes the impurities and the oxides, allows that the atoms of the two materials collide at interatomic spaces, thus resulting the welding through explosion.

The velocity of a wave is affected by two properties of the material: the elastic properties and its density. The relationship is described by the following equation:

$$v = \sqrt{\frac{C_{ij}}{\rho}} \qquad (1)$$

where C_{ij} is the elastic properties.

The wave speeds differ for different types of solids because of the elastic properties of materials. Elastic properties relate to the tendency of a material to maintain its shape and not deform when a force is applied to it. A material such as steel will experience a smaller deformation than aluminum when a force is applied to it.

At the particle level, a rigid material is characterized by atoms and/or molecules with strong forces of attraction for each other. These forces can be thought of as springs that control how quickly the particles return to their original positions. Particles that return to their resting position quickly are ready to move again more quickly, and thus they can vibrate at higher speeds. Therefore, the waves can travel faster through mediums with higher elastic properties than it can through solids which have lower elastic properties.

Although there are two factors that affect the propagation speed, the elastic properties have a greater influence on the wave speed than the density of the material.

The density of a medium is the second factor that affects the wave speed. Since the density is the mass of a substance per volume, a material that is denser has more mass per volume. Usually, larger molecules have more mass. If a material is denser because its molecules are larger and since the waves are made up of kinetic energy, it takes more energy to make large molecules vibrate than it does to make smaller molecules vibrate. Thus, the waves will travel at a slower rate in the denser object if they have the same elastic properties. If sound waves were passed through two materials with approximately the same elastic properties such as aluminum (10 psi) and gold (10.8 psi), sound will travel about twice as fast in the aluminum (0.632cm/microsecond) than in the gold (0.324cm/microsecond). This is because the aluminum has a density of 2.7gram per cubic cm which is less than the density of gold, which is about 19 grams per cubic cm. The elastic properties usually have a larger effect that the density so it is important to both material properties. [1]

As defined by Crossland [7], the *p* pressure resulted by every material in the collision point, is obtained by the following formula:

$$p = \rho \cdot u \cdot D \qquad (2)$$

where: p is the shock wave pressure at the interface between plates;

ρ - the density of the material;

u - the material speed at which the materials from the interface move;

D - the speed of the shock wave inside the material, this speed is approximately equal with the speed of the sound (the speed of the longitudinal waves).

Taking account of (1), the pressure ratio of the two materials the dependency is given by:

$$\frac{p_2}{p_1} = \frac{\rho_2}{\rho_1} \cdot \frac{v_2}{v_1} \qquad (3)$$

Besides the impact speed between the mobile and the fix material, the welding through explosion is only possible if at the impact level and collision interface plastic leaks exist. In practice, this condition is defined, as follows: the speed of the collision point, sometimes named the welding speed, must have a lower value than the speed of the sound inside the material.

Also, in order for the welding process to be obtained, the angle of dynamic collision β must excel a minimum value. This angle has very low values.

The speed of the collision point is obtained by the following formula:

$$V_c \approx \frac{V_p}{\sin\beta} \quad (4)$$

where: V_c – is the speed of collision;

V_p – is the speed of propulsion;

β – dynamic angle of collision.

The study to obtain some layered materials through the unconventional process mentioned above is essential also because of the energetic independence provided by the technology, such as the adequate energy to detonate an explosive load.

To obtain the process of plating through explosion, after the construction of half-finished materials and bringing them to desirable sizes, the covers of the explosive loadings are being built, with the function to maintain the geometric sizes of the explosive loadings, under the explosive's character and its granulation. In this instance, the boxes belonging to the explosive loadings have been made of cardboard.

After determining the testing conditions, the assembly of the technologic system to create the process of plating through explosion begins. Therefore, the spacers are placed across the base plate.

The experimental technological system, created to generate the process of plating through explosion is shown in fig.1 and fig. 2. (Mustață, 2003:96-112).

The spacers are mechanic elements with the function to create the best distance between the plates to be welded.

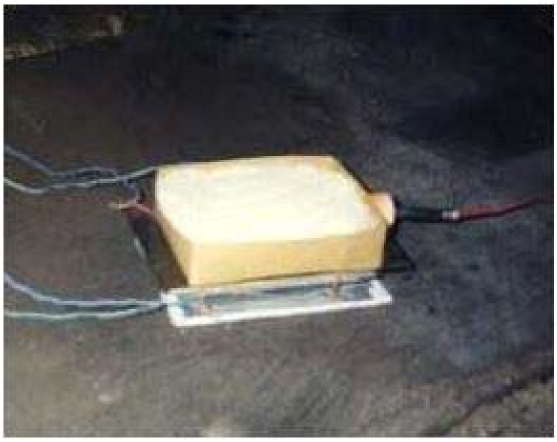


Fig. 3. The experimental assembly used for the process of plating through explosion

The Bi-dimensional Mechanical Model from the simulated Explosion Cladding Process is presented in fig.4. [3]

To obtain a multilayered material structure with specific characteristics, through the process of explosion plating, several attempts have been made with aluminum alloy plates type 3105, 3 millimeters thick; between these plates, a stainless steel fiber has been inlayed, with the role of consolidation (Mustață, 2003:96-112).

To form an explosive weld the following conditions need to occur [6]:

- two surfaces that need to be joined are initially spaced at a small distance (stand-off distance).
- an explosive force brings these two surfaces together progressively through a collision front.
- the collision front's velocity must be lower than the speed of sound in the materials, so that the shock wave precedes the bond being formed. If not, the shockwave would interfere with the contact surfaces preventing the bond occurrence.
- the interface pressure at the collision front must exceed the yield strength of the materials, so that plastic deformation will occur.

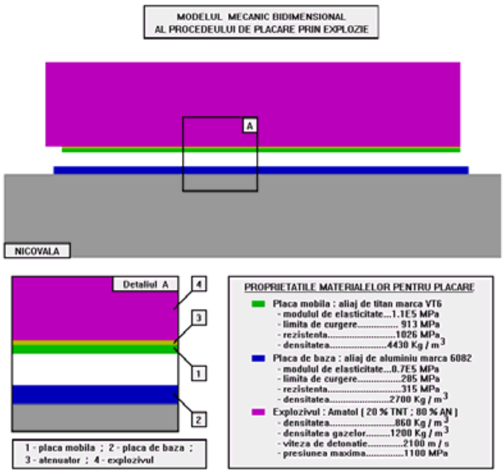
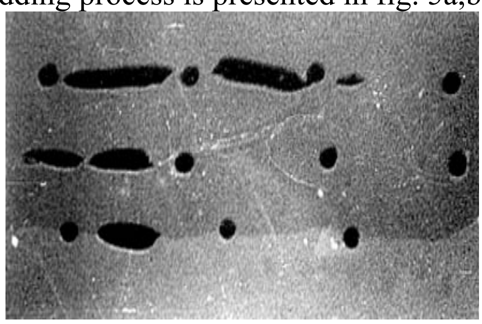


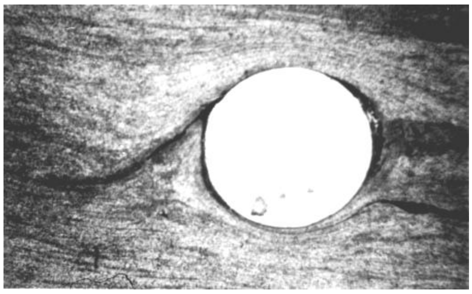
Fig. 4. The bi-dimensional mechanical model from the Explosion Cladding Process

A jet of metal is formed just ahead of the collision front, comprising of the two component surfaces, which is finally ejected from the interface. The surfaces and any surface contaminants are removed in the jet. Behind the collision front, the now clean surfaces bond, under extreme pressure, in the solid state. In cross section, the materials usually bond together in an undulating wave form and the process can weld a parent plate of thickness 0.025mm to over 1m (the maximum flyer plate thickness is one third that of the parent plate). Up to 30m2 can be welded in one explosion.

The stereomicroscopic image of the layered structure obtained by explosion cladding process is presented in fig. 5a,b.



a.



b.

Fig. 5 a,b. The stereomicroscopic images of the structure obtained through the explosion cladding process

The speed's field in the assembly elements can be represented schematically and in principle as in fig.6.

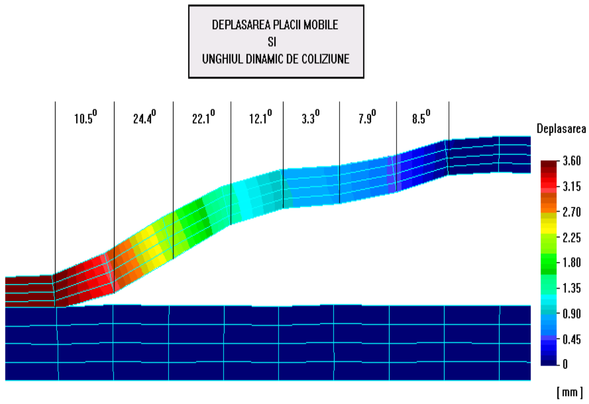


Fig. 6. The mobile plate moving and the dynamic collision angle

Figure 7 presents the graphic of the moving speeds of the nodes in a normal direction the mobile plate. Based on the image obtained throughout the simulation of the explosion plating from the Method Finite Elements process, it can be observed the deformed image of the mobile plate at different moments of time. The types of materials tested, including those obtained by using explosive cladding process, once again underline the fact that the layered materials, can largely meet the requirements.

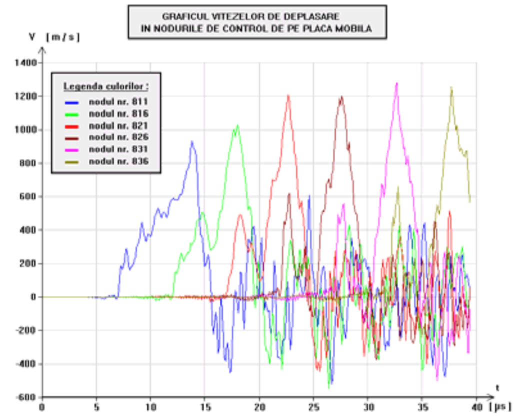


Fig. 7. The moving speeds of the control nodes of the mobile plate.

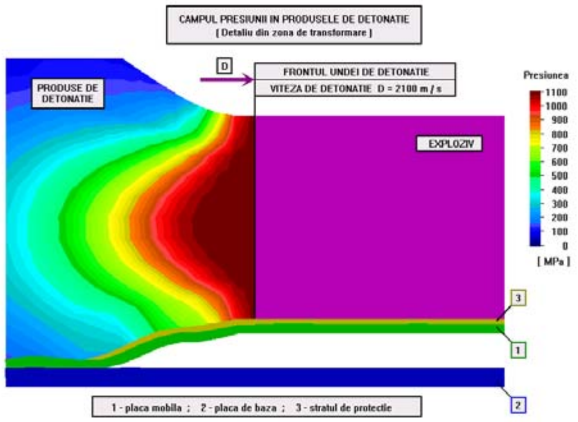


Fig. 8. Presure field in detonation products.

Besides the beneficial effects of explosive cladding technology in fig. 8, some imperfections due to the quality and coated surfaces can be observed.

3. CONCLUSIONS & ACKNOWLEDGEMENT

This paper and the experiments presented conclude that, in order to obtain multilayer structures using a nonconventional explosive welding process, various metallic materials are needed in order to obtain a sandwich of different materials, in particular, thin slabs, which sometimes is impossible by using traditional welding processes.

Explosively welded multi-laminates come very close to achieving ideal composite conditions (sharp transition between layers, physical and mechanical properties which are constant or enhanced throughout individual layer thickness, metallurgical bond between layers). These composites will then be available for a wide variety of industrial and strategic applications. The high integrity of the bond allows design engineers to utilize the specific desirable properties of metals more efficiently.

It can be concluded that the trend in the field of research is to obtain new multi-layer materials with high mechanical properties able to satisfy the most demanding technical requirements imposed by peaking technological development.

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