Investigation of aluminum-steel joint formed by explosion welding

T Kovacs-Coskun*, B Volgyi and I Sikari-Nagl

1,2,3 Obuda University, Banki Donat Faculty of Mechanical and Safety Engineering – Material Science Department – 1081 Budapest – Hungary

kovacs.tunde@bgk.uni-obuda.hu, b.volgyi@freemail.hu, istvan.sikari@gmail.com

Abstract. Explosion welding is a solid state welding process that is used for the metallurgical joining of metals. Explosion cladding can be used to join a wide variety of dissimilar or similar metals [1]. This process uses the controlled detonation of explosives to accelerate one or both of the constituent metals into each other in such a manner as to cause the collision to fuse them together [2]. In this study, bonding ability of aluminum and steel with explosion welding was investigated. Experimental studies, microscopy, microhardness, tensile and bend test showed out that, aluminum and steel could be bonded with a good quality of bonding properties with explosion welding.

1. Introduction

The explosion welding in our century is a traditional technology even that the mechanism of the joining not well understood. Explosive welding was first recognized as a remote possibility in 1957 in the United States, when it was observed that metal sheets being explosively formed occasionally stuck to metal dies [1]. Bond zone wave formation during explosion cladding is analogous to the formation of vortex streets in fluid flow around an obstacle or in the collision of liquid streams. The fluid flow analogy explains the observed transition from a smooth metal-to-metal bond zone to a wavy bond zone above a critical collision velocity [2].

A metallurgical, high quality bond can be formed between similar metals and between dissimilar metals that are incompatible for fusion or diffusion joining. Examples of these systems are like titanium-steel, tantalum-steel, aluminum-steel, titanium-aluminum and copper-aluminum [3]. The explosion bonded composite like aluminum-steel can be useful in case of the chemical industries, some piece of reactors or vehicles [4].

In this work we wanted test unusual cladded sheets. In case of our experiments the flayer plate was aluminum alloy and the base plate was low carbon contain steel. In case of used adjustment we used empirical formulas to get technology parameters. The joints quality was investigated by microscopy, bend test, special tensile test and microhardness testing.

We observed that the evolved joint profile is different than the conventional cladded joints wave line. It knows that the aluminum alloys makes oxide layer very quickly on the surface. This layer is thin but it’s very hard, has a high melting point. During cladding process this layer traverse the conformation of the wave line.
2. Materials and explosive cladding setup

2.1. Used metals

In case of our tests we used steel and aluminum alloy the chemical composition of them is given in Table 1. The base plate material S235JR is a low carbon and alloy contains steel. The flayer plate material AlMgSi1 is an annealed aluminum alloy. The Table 2 shows the basic parameters of the used sheets. The samples size was 50x250 mm.

Table 1. Chemical composition of the used materials (at.%)

| DIN;        | Si  | Fe    | Cu   | Mn    | Mg    | Cr    | Zn | Ti |
|-------------|-----|-------|------|-------|-------|-------|----|----|
| AlMgSi1     | 0.7-1.3 | ≤0.5 | ≤0.1 | 0.40-1.00 | 0.60-1.20 | ≤0.25 | ≤0.2 | ≤0.1 |
| C           |     |       |      |       |       |       |    |    |
| Mn          | ≤0.2 |       | ≤1.4 | ≤0.6 | ≤0.045 | ≤0.045 | ≤0.3 | ≤0.3 |
| Si          |     |       |      |       |       |       |    |    |
| S           |     |       |      |       |       |       |    |    |
| P           |     |       |      |       |       |       |    |    |
| Cu          |     |       |      |       |       |       |    |    |
| Cr          |     |       |      |       |       |       |    |    |
| Ni          |     |       |      |       |       |       |    |    |
| Al          |     |       |      |       |       |       |    |    |

Table 2. Basic performance of the steel and alumina alloy

| Sign by DIN | Thickness | Size       | HV    | Yield stress (MPa) |
|-------------|-----------|------------|-------|--------------------|
| Flayer plate | AlMgSi1 (6082) | 3 mm      | 50x250 mm | 72 HV<sub>0.2</sub> | 92 |
| Base plate  | S235J2    | 5 mm      | 50x270 mm | 120 HV<sub>1.2</sub> | 235 |

2.2. Explosive welding parameters

The used explosive welding technology was a traditional setup. The base plate and the flayer plate are parallel and the explosive find directly on the surface of the flayer plate without buffer see Figure 1. The explosive force brings the plates surfaces together progressively at collision front [5].

Table 3. Setup parameters

| Explosive | PERMON 10T (powder) |
|-----------|---------------------|
| Volume of the gas | 928 dm<sup>3</sup>/kg |
| Detonation rate | 3200 m/s |
| Density | 850 kg/m<sup>3</sup> |
| Distance between the plates | 1.5 mm |
| Thickness of the explosive | 30 mm |
| Weight | 319 g |

The velocity of the collision ($v_c$) must be lower than the speed of the sound ($v_s$) (1), that mean it need to use for this technology a low speed explosive. The interfacial pressure at the collision front also must exceed of the materials yield strength to occur a plastic deformation. This is solid state welding under extreme pressure [6,7].

\[
\frac{v_c}{v_s} < 1
\]  

(1)

Before the explosive welding the contacted surfaces were cleaned by mechanical and chemical cleaning to remove the polluted and oxide layer. The results cladded plates show the Figure 2.

In case of the setup parameters optimization it was used some empirical parameters with the density of explosive, base plate and flayer plate (setup see in Figure 1).

The thickness of the explosive powder was optimized on base of practice. It knows that it needs a minimal amount of explosive, that about 0.017 (g/mm<sup>2</sup>) Permont 10T.
The used parameters in case of the setup posed by (2) when \( l_b \) is the thickness of the flayer plate and \( l_1 \) is the distance (hole) between the base and flayer plate. The collision velocity depends on this distance [4].

\[
0.5 \cdot l_b < l_1 < 1.6 \cdot l_b
\]  

\[ (2) \]

Figure 1. Setup of the cladding

The cross section of the sample shows Figure 3. Usually the materials bond together a wave line form. In case of this procedure the cross section shows also undulating form but it’s not really usually wavy like interface (see Figure 3). Visual and light optical inspection of the joint reveals a structure without visible cracks, pores, or separation of the joined components. Though the surface cleaning on the flayer plate surface renewed a thin oxide layer and traversed the wave line formation and supposedly made some intermetallic island.

3. Experimental procedures and results

3.1. Microscopy

The cross section of the sample shows Figure 3. Usually the materials bond together a wave line form. In case of this procedure the cross section shows also undulating form but it’s not really usually wavy like interface (see Figure 3). Visual and light optical inspection of the joint reveals a structure without visible cracks, pores, or separation of the joined components. Though the surface cleaning on the flayer plate surface renewed a thin oxide layer and traversed the wave line formation and supposedly made some intermetallic island.

3.2. Microhardness testing

The used tester was in case of experiments Zwick 3212 microhardness tester by Vickers indenter. Results are shown by Table 4. Cause of the plastic deformation the hardness increased in case of both materials.

Table 4. Hardness after explosive welding

| Material     | Original hardness | Hardness after cladding |
|--------------|-------------------|-------------------------|
| S235JR       | 120 HV_{1.2}      | 178 HV_{1.2}            |
| AlMgSi1      | 72 HV_{0.2}       | 85 HV_{0.2}             |
3.3. Bending test
The bending tests were performed to evaluate the influence of the cracks on the integrity of the joints and the used plates. The tested specimens were deformed 90° bending angle. It was tested both of side of the cladded plate. It can see (Figure 4) that the alumina side of the cladded plate cracked. The hardness of the alumina increased and the plasticity decreased cause of plastic deformation.

![Figure 4. Crack on the alumina side of the cladded plate was observed](image)

![Figure 5. No cracking and separation of the components was observed](image)

4. Conclusion
Even that it was used a traditional explosion welding technology the results give new information. The low carbon steel platted by alumina is not a very common but very useful composite. In case of explosive cladding the used parameters base some empirical equation what are usually secret. The literature of this process is also poor about the determination of the parameters. To optimize the suitable parameters it was made a many explosive welding tests. The used equations are suitable in case of the technologies parameters calculation.

The results of the tests confirm that the explosion cladding process beside the used parameters is suitable for producing clad plate which will meet or exceed the requirements.

Acknowledgements
The authors would like to acknowledge all members of this project and especially for Andras Szalay S-Metalltech 98 Kft. and Laszlo Lukacs NKE. The project was realized through the assistance of the European Union, with the co-financing of the European Social Fund (TÁMOP-4.2.1. B -11/2/KMR-2011-0001).

References
[1] Proceedings of the Select Conference Hove, 18-19 Sept. 1968, *The welding institute 1969* 1
[2] Cowan C R, Bergman O R, and Holtzman A H 1971 *Metallurgical Transactions* 2 3
[3] Andrew Pocolyko E I 1981 du Pont de Nemours & Company, Inc. Pompton Lokes, N. J. Metallic Coatings (Explosively Clad) 12
[4] Szalay A, Puskás J 1982 Contact component material made by explosion cladding; *Műszaki Könyvkiadó, Budapest* 172
[5] Kovács-Coskun T, Völgyi B, Sikari-Nágl I 2012 Investigation of explosion cladded plates; *Fúrásrobbantástechnika* 2012. Balatonkenese, 149-152
[6] Ettaqi S, Langlois L, Bigot R 2008 *Surface & Coatings Technology* 202 3306
[7] Durgutlu A, Gulenc B, Findik F 2005 Materials and Design 26 497