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THE INFLUENCE OF HEAT TREATMENT ON PROPERTIES OF THREE-METAL EXPLOSION JOINT: AlMg-Al-Steel

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The procedure of welding by explosion is as technical optimal solution of ship-shell parts joining frequently used in shipbuilding industry at transition three-metal joint: AlMg4.5-Al-St.52-3 working out. The investigations of mechanical and metallographic properties of joints, exposed on heat treatment at different temperatures levels, are performed. The results of mechanical and metallographic examinations of transition joints at elevated temperatures, direct on its use below 300 °C.
The additional melting welding working out is in closeness of explosion- welded joint allowed.

Key words: heat treatment, three-metal explosion joint, metallographic and mechanical joints properties

Utjecaj toplinske obradbe na svojstva eksplozijski spojenog trosloja: AlMg-Al-čelik. Postupak spajanja eksplozijom često je u uporabi u brodograđevnoj industriji pri izradbi prijelaznog trosloja: AlMg5-Al-St.52-3 kao tehnički optimalnog rješenja pri spajanju trupa i nadgrađa broda. Provedena su ispitivanja mehaničkih i metalografskih svojstava spojeva izloženih toplinskoj obradbi na različitim temperaturama. Rezultati upućuju na znatnu otpornost spoja pri izlaganju temperaturama do 300 °C, a što dopušta daljnje izvođenje zavarivanja taljenjem u neposrednoj blizini eksplozijskog spoja.

Ključne riječi: toplinska obradba,eksplozijski spojeni trosloj, strukturna i mehanička svojstva

INTRODUCTION

Aluminium and its alloys are commonly used in shipbuilding structures applications as include main strength members such as hulls, deckhouses and other applications as stack enclosures, hatch covers, windows, air ports, accommodation ladders, gangways, bulkheads, deck plates, ventilation equipment, lifesaving equipment, furniture, hardware, fuel tanks and bright trim. Separately interesting is application of aluminum alloy with magnesium (series 5 000). This alloy has good weldability and high mechanical properties at low temperatures as well as high corrosion resistance in seawater. Because of compromise between design requirements regarding on materials properties as well as on ships weight, the ship-carrying part are worked out off structural steel and upper side from aluminium alloy. Explosion welding is, as solid cold joining process, in shipbuilding mostly used at working out of transition Al-Steel joints because of intention to avoid brittle intermetalic compounds by melting welding process. This is a process in which coalescence is effect of high-velocity movement together of the parts which be joined produced by a controlled detonation. Even though the fact that the heat is not applied in making an explosion weld, it appears that the metal at the interface is molten during welding. This heat comes from several sources, from the shock wave associated with impact and from the energy expanded in collision. Heat is also realised by plastic deformation associated with jetting and ripples formation at the interface between the welded parts. When a cladding plate collides with a base plate, a formed jet cleans the surface of plates. Due to unstable plastic flow of metal in the surrounding of the point of incipient flow a wavy interface is formed which is characteristic for the explosive welded metals. It is founded necessity off metal flow plastically in order to provide a quality weld. Analysis of the explosive metal welding phenomenon confirms that welding is directly consequence of the high speed of collision. Experiments confirm that there are critical values for optimum collision. This set of parameters and its interaction makes so-called "the welding window", whereby the critical parameters are:

– collision velocity V_c.
– collision angle required for the appearance of jetting.

Relations between those parameters are graphically present in Figure1 [1]. Curve a - a' in Figure 1 represents the critical collision angle required for the appearance of jetting. Line b - b' represents the upper velocity limit V_c, which is in the range of 1,2 - 1,5 × the sound velocity of clad material. Values of starting angle are, within the range of 3-18°, are represented by lines C - C' and D -

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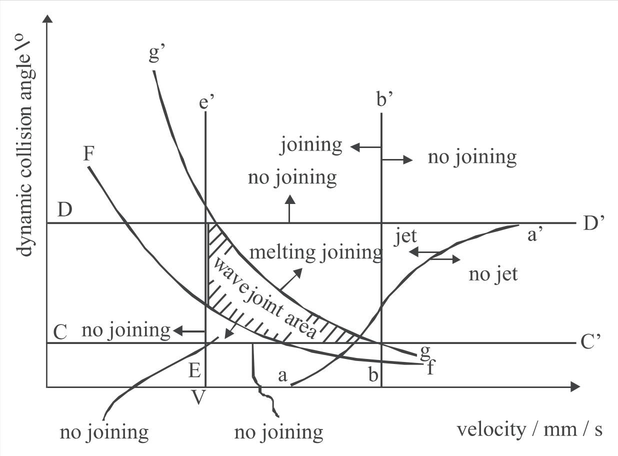

Figure 1 "Joining window" Wittman& Deribas

D'. Curve f - f' represents the lower limit and curve g - g' the upper limit of clad velocity – V_p. Approaching to upper border of V_c, the other parameters selection are inside of "joining window" limited. Dynamical angle ° vary between 2° - 3,1°. Bonding surfaces forming depends on collision angle and clad velocity. The influence of explosion velocity in collision point, on wave configuration (*h, l*) is on Figure 2 shown [2]. The explosives used in explosion welding can vary in form, they range from a flexible plastic sheet or cord to granulate or liquid structure. Different explosives will yield different detonation velocities. The detonation speed is usually ranges from 2 400-3 600 msand is dependent upon the type, thickness and packing density of the explosives.

Some commonly used explosives are:

- RDX (Cyclotrimethylene trinitramine, $C_3H_6N_6O_6$)
- PETN (Pentaerythritol tetranitrate, $C_5H_8N_{12}O_4$))
- TNT (Trinitrotoluene, $C_7H_5N_3O_6$)
- Tetryl (Trinitrophenylmethylinitramine, $C_7H_5O_8N_5$)
- Lead azide (N_6Pb)
- Ammonium nitrate $NH_4\,NO_3$.

A standard commercial blasting cap is used to detonate the explosives. As oxygen atoms bearer almost exclusively at commercial explosives ammonium nitrates is used. Ideally, ammonium nitrates, during explosion process, decompose in acc. with equation:

$$NH_4\,NO_3 \rangle\, N_2 + 0{,}5\,O_2 + 2H_2O + \text{heat} \qquad (1)$$

and the explosion temperature round 1200 °C is produced [3]. In explosive cladding of large plates is necessary to use a commercial explosive with a detonation velocity less than the sonic velocity in the welded metals, which implies a detonation velocity less than 4 km/s or even less for some metals combination [1].

EXPERIMENT AND ANALYSIS OF EXAMINED JOINTS

On Tables 1 and 2 are shown mechanical properties as well as chemical analysis of materials in joint.

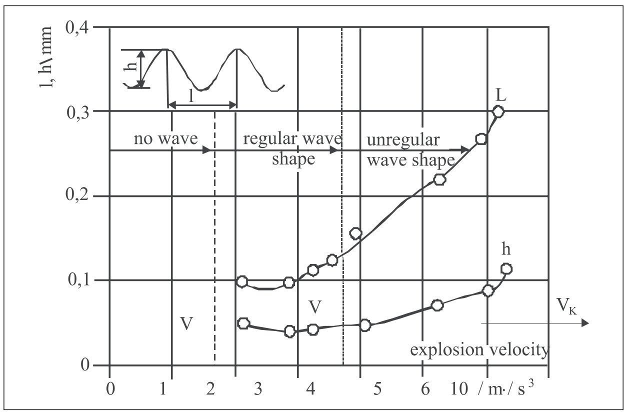

Figure 2 Influence of explosion velocity in collision point on wave altitude *h* and longitude *l*.

Table 1 **Mechanical properties of materials**

Materials (EN 573-3)	Yield Strength / MPa)	Tensile strength / MPa	Elongation / %
Al99	85	137	15
AlMg4,5Mn	125	285	24
St52-3	389	576	23

In Figure 3a is the macro-structure of explosion welded three-metal layer joint with marked measuring places illustrated. The graphical review of joints measured micro hardness HV 0,1 is on Figure 3b shown. The measurements of microhardness performed with intention of hard constituent confirmation as well as cold deformed zones presence on joining interface of different strength levels materials. On Figure 4 structure review of three-metal joint AlMg5-Al- St52-3 is shown, which is used in shipbuilding and naval architecture as transition part between ship hull made of carbon steel and deck of ship made of aluminium alloys. The specimens are etched by HF. Examinations of specimens are performed using optical microscopy at magnification off 50 × and 400 × [4].The intention of performed experiment was to determine elevated temperature resistance of explosion welded Al-Steel joint. The

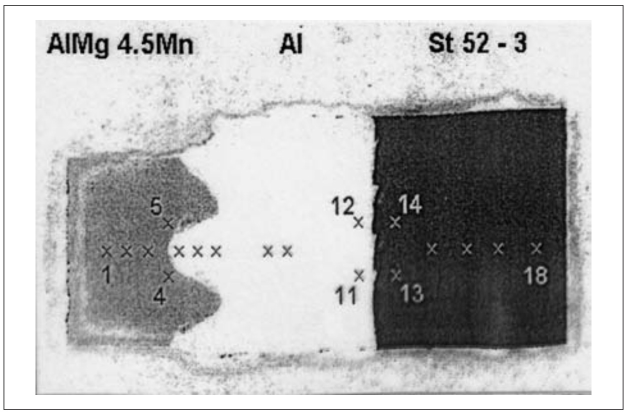

Figure 3a The specimen of steel-Al-AlMgMn alloy joint with marked measuring places

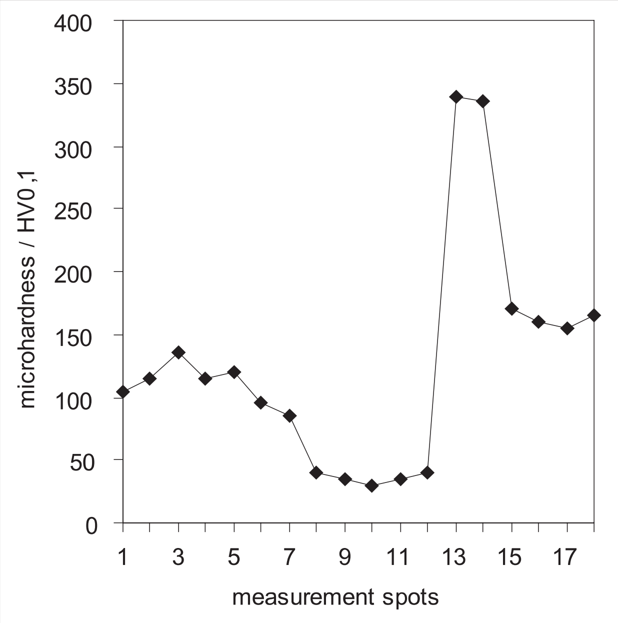

Figure 3b Graphical review of three-metal joints measured micro hardness HV 0,1

temperature levels changed (250 °C, 315 °C and 450 °C) at constant time duration of 6 hours.

Three-metal joints properties on elevated temperatures

The most widely used non-destructive test method for explosion-welded composites is ultrasonic inspection. The acceptable amount of not bonded area depends on application, but min. 95 % of the total area has to be bonded [5-7]. During qualification of explosion welding procedure, the method of bonding quality estimation is the shear strength test (in acc. with ASTM A264) as the destructive method [8-10].

The histogram-graphical review of measured results shear strength tests values is shown on Figure 5. Annealed samples microstructures review are shown on Figures 6-8.The results direct to significant decreasing of joint strength after annealing at 315 °C as well as drastic at 450 °C (Figure 5). At lower annealing temperatures, the new inter-metallic compounds are not registries but at 450 °C it is present as well as tendency to fractures occurrence (Figures 6-8). Formerly homogenous part of interlayer, depending on temperatures rate becomes significantly porous.

Metals with widely different properties and characteristics, such as iron, carbon steels, alloy steel, aluminium, magnesium, show - varying degrees of increase

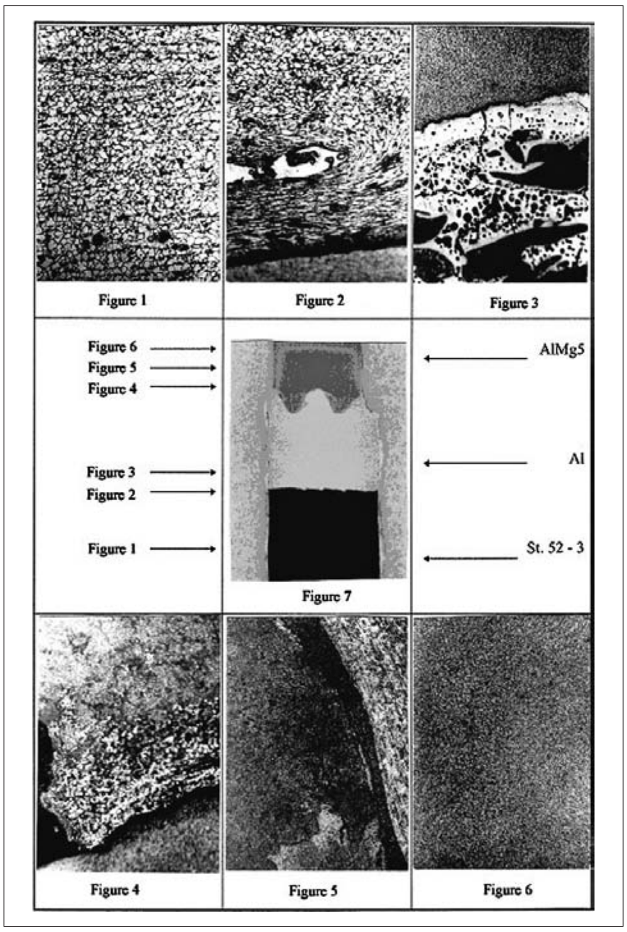

Figure 4 Structural review of three-metal joint AlMg5-Al- St52-3

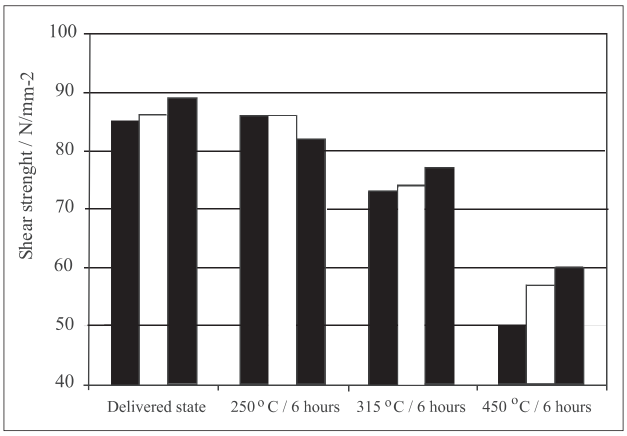

Figure 5 Review of measured results shear strength tests (three specimen for each state)

in hardness and tensile strength as well as reduction in ductility and impact strength when subjected to shock loading. The diffusion across the bond during the process is generally negligible. In welds between metals of

Table 2 **Chemical composition of joining materials**

Chem. comp. of mat. / %	C	Cu	Mg	Fe	Mn	Nb	Ni	Cr	Zn	P+S	Si	Ti	Al	V
Al	-	0,10	-	0,53	-	-	-	-	0,10	-	0,41	0,025	rem.	-
AlMg4,5Mn	-	0,10	4,94	0,40	0,95	-	-	0,17	0,18	-	0,40	0,11	rem.	-
St 52-3	0,17	0,12	-	rem.	1,4	0,03	0,10	-	-	0,05	0,25	-	-	0,10

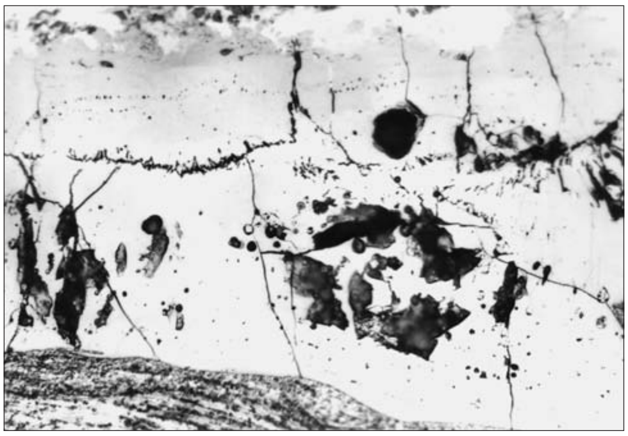

Figure 6 Annealed sample microstructure (250 °C through 6 hours), Magnification 400 ×

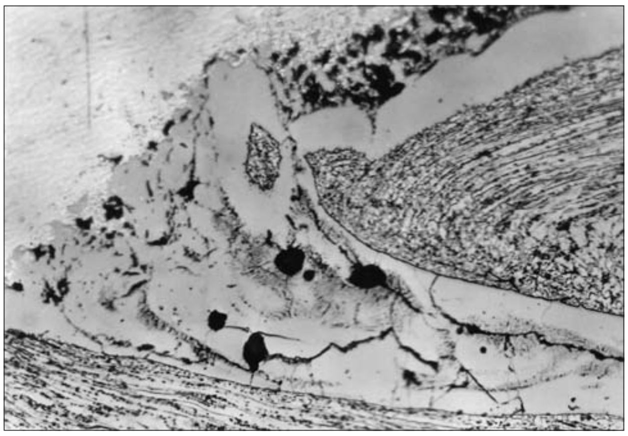

Figure 7 Annealed sample microstructure (315 °C through 6 hours), Magnification 400 ×

very different densities, there is a greater possibility of the formation, which consists of inter-metallic compounds with unfavourable mechanical properties. The vortex zones contain a mixture of the two component metals and due to the kinetic energy of the trapped jet; there is frequently a molten zone at the centre, which frequently contains metastable inter-metallic compounds. The vortices at interface in explosive welds contain a mixture of both component materials.

CONCLUSIONS

At temperatures above 300 °C, in area of joint, as consequences of Al-diffusion, forming of brittle intermetallic compounds is possible. The results are fis-

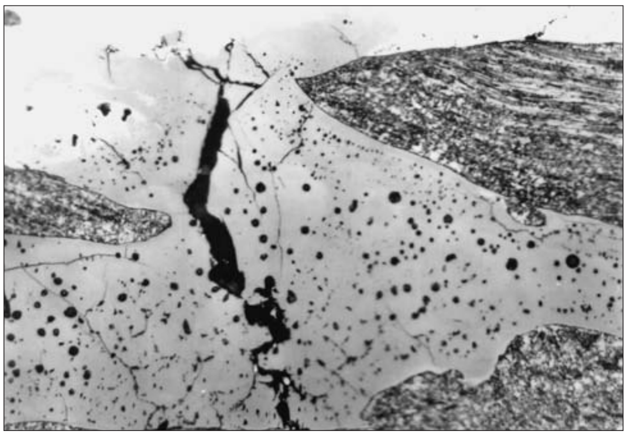

Figure 8 Annealed sample microstructure (450 °C through 6 hours), Magnification 400 ×

sures appearance. This degradation is more structural nature while joints shear strength drop at specimens annealed at 450 °C. The results of mechanical and metallographic examinations of transition joints at elevated temperatures, direct on its use below 300 °C. The additional melting welding working out is in closeness of explosion - welded joint allowed.

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