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Investigation of properties of Cu-Al explosively welded bimetals
Badanie właściwości bimetali Cu-Al zgrzewanych wybuchowo

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Abstract: *Explosion welding of cooper C10200 to AW 5083 aluminium alloy was performed. The C10200 was proposed as a flyer plate. A parallel setup was used during explosive welding.*
Bimetals were characterized by regular wavy interface. The intermetallic compound (IMC) layer was observed at the interface of bimetals after 12 month, however, no annealing was performed. EDX analyses revealed that the interface layer consists of the intermetallic compound CuAl. Microhardness at the interface increased due to the presence of the IMC and work hardening as well.
Streszczenie: *Przedstawiono wyniki zgrzewania wybuchowego miedzi C10200 ze stopem aluminiowym AW 5083. Płytka wykonana z miedzi C10200 była elementem napędzanym. Zgrzewanie wybuchowe prowadzono równolegle na dwóch stanowiskach.*
Otrzymane bimetale charakteryzowały się regularną falistą powierzchnią łączenia. Badania warstwy związku międzymetalicznego, w obszarze połączenia bimetalicznego, przeprowadzono po upływie 12 miesięcy, jednakże bez wyżarzania. Analiza EDX wykazała, że warstwa łącząca składa się z związku międzymetalicznego CuAl. Mikrotwardość w obszarze łączenie wzrasta zarówno w wyniku obecności związku międzymetalicznego, jak i przeprowadzonego zgrzewania.

Keywords: *explosion welding, detonation velocity, copper, aluminium alloy, intermetallic compound*
Słowa kluczowe: *zgrzewanie wybuchowe, prędkość detonacji, miedź, stop aluminiowy, związek międzymetaliczny*

1. Introduction

The possibility of combination of two (three) materials with different properties seems to be an interesting step when preparing new bi- (tri)- metals. Howeve, joining materials with relative different physico-chemical properties (temperature of fusion, speed of sound in metals, chemical composition of metals, *etc.*) and with different crystallographic structure, using common techniques of welding, does not bring convenient results. There are also some new methods (special welding methods) and the most convenient seems to be the one „welding by explosion“. Currently, light materials have got considerable attention for many applications in the automotive, aerospace and ship industries, especially due to the possibility of weight reduction and thus increasing the fuel efficiency and reducing the environmental impacts. Fusion welding of dissimilar materials such as Cu to Al is a great challenge because of important mismatch in physical properties, limited mutual solubility and formation of brittle intermetallic compounds (IMCs) in Cu-Al binary system. Some authors studied this system when annealing the bimetals and found the formation of the IMC, namely $AlCu_3$, Al_2Cu and AlCu. The reason for the utilization of Al/Cu bimetals in armored cables, air-cooling fans, *etc.*, are due to the materials' high thermal and electrical conductivity [1-3].

2. Experimental

2.1. Welded materials and welding setup specification

1-mm-thick Copper C10200 and 10-mm thick AW 5083 aluminium alloy were suggested as experimental materials for explosive welding. Copper was designed as the flyer plate and aluminium alloy was proposed as the base material. The dimensions of the flyer plate were proposed to be larger due to mounting wooden frame for the explosive. The explosive thickness in the case of welding using Semtex S30 equals approximately to flyer sheet multiplying by 10. The distance between this two plates was 2.0 mm (Fig. 1). Semtex S30 loose explosive was applied for joining dissimilar metals. Starline 12 detonating cord with the detonation velocity of 6500 m/s was used to initiate the Semtex S30 explosive. The detonation velocity of the explosive was measured directly during explosion welding process. The value of detonation velocity was 2286 m/s. Experimental set up is given in Figure 1. The welded bimetal after being prepared was put into the desiccator and maintained under ambient temperature (300 K) for a period of one year.

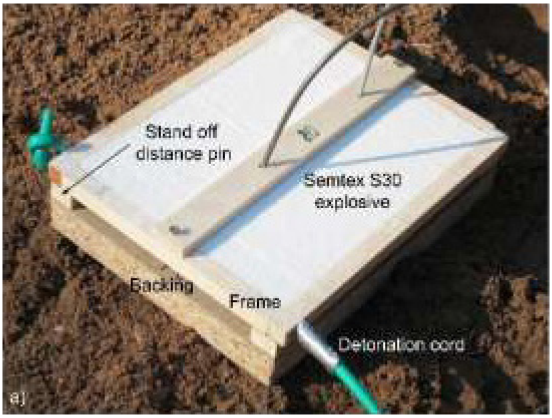

Figure 1. Experimental set-up

2.2. Analytical methods

Analysis of the thickness of IMCs present at the composite interface, elemental linescans and mappings, local chemical composition was carried using HITACHI SU 3500 electron microscope equipped with X-max 50mm2 Oxford Instruments detector for EDS analysis. The microhardness was measured with the Buehler IndentaMet 1100 Series tester. The loading force was 0.25 N. Distance between indents was 50 µm.

3. Results

3.1. Microstructure analysis of bimetals

The interface in (AW 5083 aluminium alloy)/(Copper C10200) system is documented in Figure 2. The interface was regular and wavy confirming the typical feature for explosive welding. No continuous IMC layer was observed at the, as-welded, bimetal interface. In some locations the IMC zones were observed but they had no influence on the mechanical properties of produced bimetals. No IMC layer was observed at the interface immediately after explosion welding. Microscopic observations confirmed good quality of the interface after explosion welding. After 12 month the IMC was observed as can be seen on the Figure 2, however, no annealing process was applied. From the quantitative EDS analysis (Table 1) one can conclude that the IMC formed after 12 month was CuAl. This result should also be confirmed by the XRD analysis, however the tests are not finished yet.

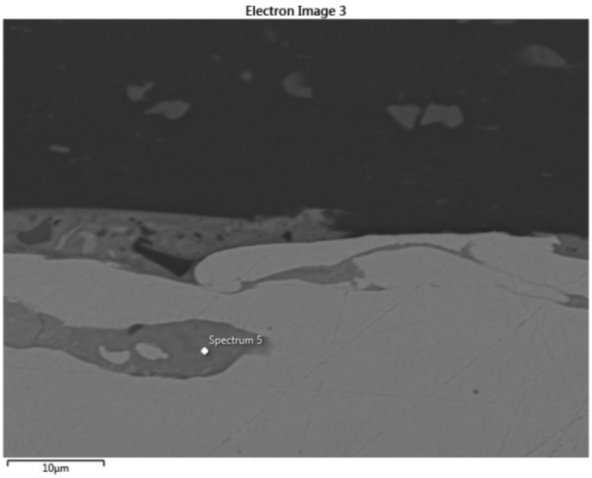

Figure 2. IMC at the bimetal interface

3.2. EDS analysis

Copper and aluminium elemental mapping across (AW 5083 aluminium alloy)/(Copper C10200) bimetal interface in as-welded condition are shown in Figure 3. Aluminium and copper are uniformly distributed at individual materials and IMC as well. EDS point analysis was carried out to characterize the IMC interfacial layers. From the results it arises that in the zone marked as Spectrum 5 (Fig. 2) the concentration of copper reached the value of about 48 wt.%. Furthermore, oxygen, aluminium and magnesium were detected in Spectrum 5. Aluminium content was approximately 20 wt.%.

Table 1. EDS point analysis results

Element	Apparent concentration	K-ratio	Mass ratio [wt.%]	Sigma [wt.%]	Standard
O	–	–	30.84	–	–
Mg	0.60	0.00399	0.95	0.02	MgO
Al	15.17	0.10898	20.44	0.05	Al_2O^3
Cu	32.60	0.32604	47.77	0.08	Cu

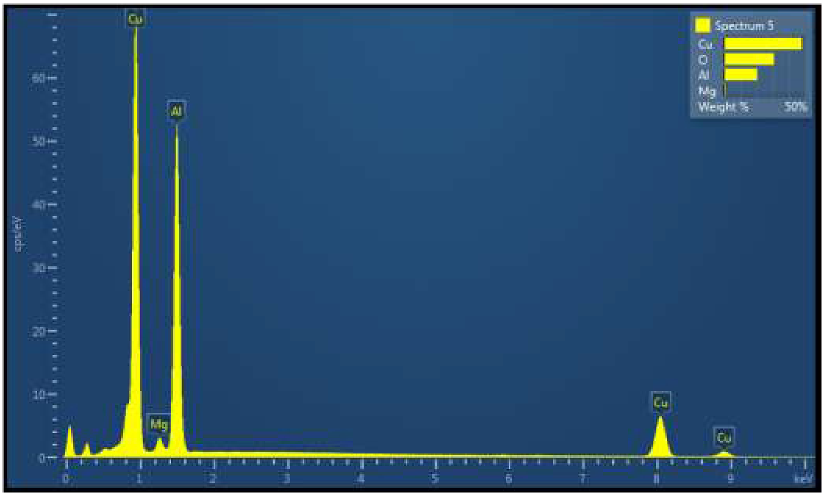

Figure 3. X-ray spectrum

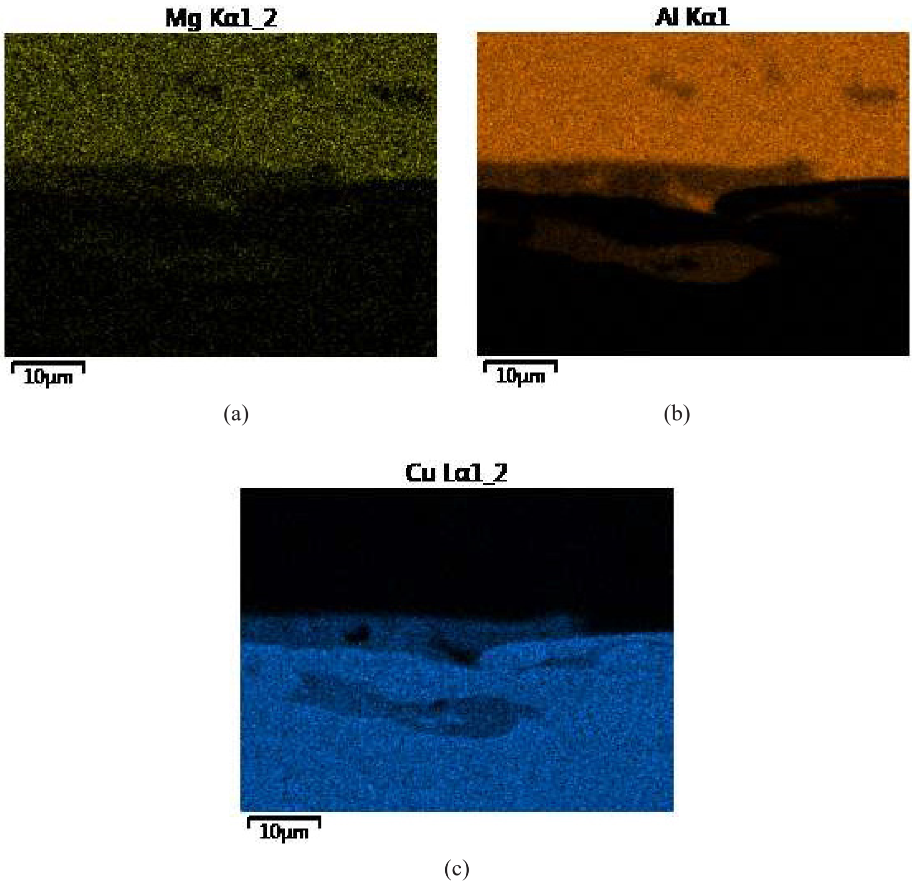

Figure 4. Elemental mapping across bimetal interface

Line EDS analysis was carried out in the next step of analysis of the bimetal interface (Fig. 5). Drop of aluminium content was observed in the direction from AW 5083 alloy towards bimetal interface. Intermixing was observed at the bimetal interface. Slight decrease of aluminium was observed. On the other hand, decrease of copper content was observed in direction from copper side to the interface (Fig. 6). The same effect was observed in the bimetal just after the welding.

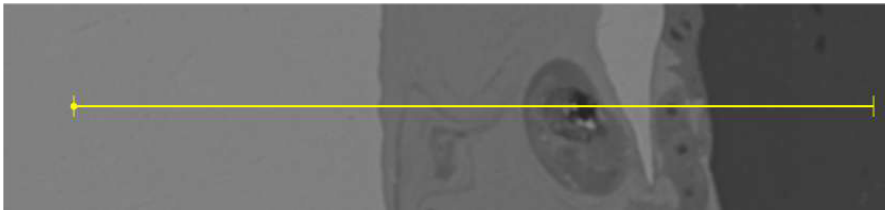

Figure 5. Location of the analysis of local chemical composition of interface

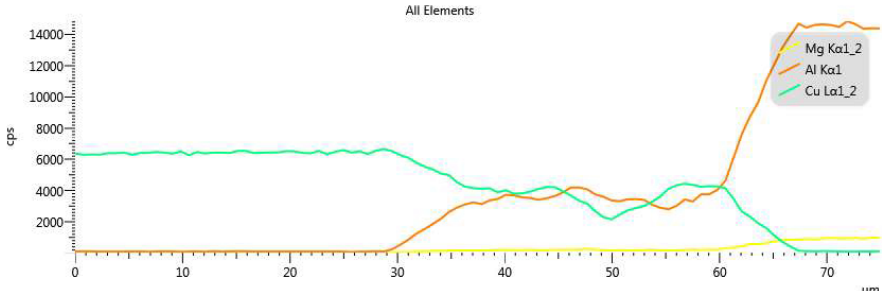

Figure 6. Distribution of Al, Cu and Mg across bimetal interface

3.3. Measurements of microhardness

The course of microhardness across as-welded bimetal interface is shown in Figure 7 and the results are shown in Table 2. The increase of microhardness was observed at the interface. This microhardness increase resulted from the work hardening induced by high velocity impact [8]. Maximum microhardness of about 130 $HV_{0.025}$ was measured at the interface. Similar work hardening behaviour was observed by other authors [9-11]. Work hardening on the copper side was observed at the distance 50 µm from the interface. On the contrary, work hardened region was wider on the aluminium alloy side, up to 250 µm away from the interface. When compared the microhardness with that of the as-welded bimetal a slight increase was observed, *i.e.* the region on the aluminium side was more narrow.

Table 2. Microhardness measurements results

Distance from interface [µm]	Middle	Copper [$HV_{0.025}$]	Aluminium [$HV_{0.025}$]
0	129.8	–	–
50	–	119.5	105.1
100	–	107.2	107.2
150	–	108.2	109.8
200	–	104.1	103.2
250	–	103.6	106.6
300	–	109.2	97.6
350	–	102.2	101.7
400	–	103.6	100.3

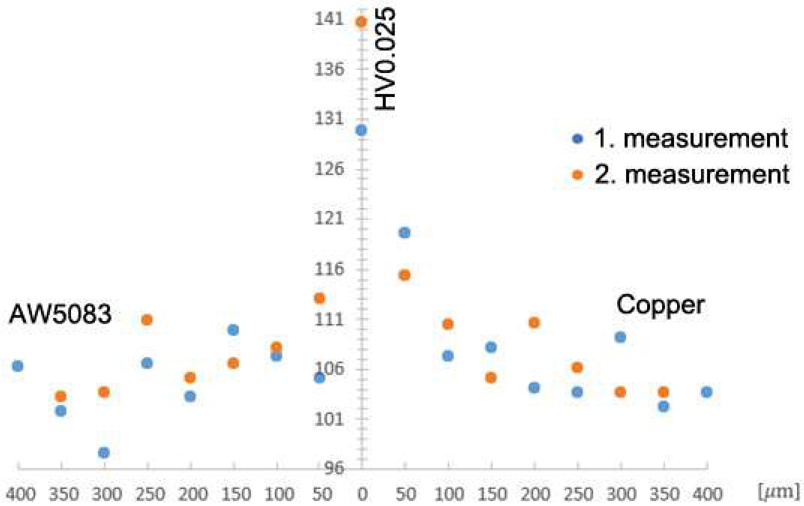

Figure 7. Course of microhardness across interface of as-welded bimetal

4. Conclusion

The following can be concluded according to results obtained after analysis of the microstructure of bimetals:

a) AW 5083 aluminium alloy / Copper C10200 bimetal was characterized by wavy interface confirming the high quality of weld joint.
b) The EDS analysis detected the intermetallic compound CuAl.
c) Decrease in aluminium content from aluminium alloy towards the interface was observed. On the contrary, increase in the copper content was observed.
d) Increasing in the microhardness at the interface of produced bimetals was associated with work hardening. The width of work hardened region was different for both metals.

Acknowledgments

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