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Quality evaluation of some composites materials joining

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Abstract
The composites materials joining must be analyzed in correlation with structural and mechanical characteristics of the components, which generate heterogeneous thermal and stress fields. The mentioned aspects are amplified in case of metallic matrix composites (MMC) and ceramic matrix composites (CMC). The most known procedures to join the composites materials are: electric arc welding, resistance welding, ultrasonic welding, flame brazing. Also, can be used adhesive bonding.
Some aspects of elaboration and joining technologies qualification are presented in this paper.
Keywords: composite, metallic matrix, ceramic matrix, joining technologies

1. Introduction

The metallic matrix composites (MMCs) are very versatile materials and have specific properties, which can be used in many applications. Generally, the components made from this kind of materials are dificult to be joined, in comparison with those made from heterogeneous materials. From this reason, the aim of the researches, made in this field, was to improve the joining processes characteristics. Now, there are information about the specific methods and joining processes, also the useful conditions and limits.

In the case of MMCs and CMCs discontinuously reinforced, there is the possibility to improve the performances and joining quality, using the filler material for stiffening. Because the chemical composition and structure of the stiffening materials can be changed in the melting zone, the mechanical characteristics of the joint can be lower than the same characteristics of the base material. It's very important to obtain a higher ductility in the joining zone than the base material ductility. So, the designer can choose the suitable joint type and the place of joining.

The main features of MMCs and CMCs welding are:

- high difference between the melting temperature of the stiffening elements and the matrix;
- different thermal conductivity and specific heat of the components, which lead to differences between the thermal fields and cristalization conditions;
- tensile strength of MMCs and CMCs, which are depending on kind of fibres and their continuity;
- high differences between the thermal coefficients of expansion corresponding to the matrix and the stiffening elements;
- even the joining process temperature is less than the matrix temperature, the heating time can be high enough to produce the partial lost of the material resistance properties;
- complex problems during the stretching processes on the surface and the matrix softening, in the case of welding of the composites reinforced with fibres; making sure to obtain the established shape and sizes of the welded joint, to avoid the discontinuities;

- involving the diffusion phenomena at the interface fibre-matrix, because of own thermal fields;
- necessity to monitor the heat transfer between the different materials with multidimensional heterogeneous thermal fields and the welding process dynamics; also, for every MMCs and CMCs, it must apply specific welding technologies.

The most MMCs materials contain aluminium. Taking into consideration the great number of aluminium applications, the most used joining processes are:

a. fusion welding,
b. solide state welding, etc.

a. *Fusion welding* is the most used process to join MMCs and CMCs, owing to the large possibility of application and economical aspects. The researches were been focused on the specific technological aspects to avoid the defects and to obtain welded joints of high quality. During the MMCs and CMCs welding processes, there are very important the application and the adhesion on the surface of the filler materials, and their softening. In the case of MMCs and CMCs reinforced with fibres, type SiC, the welding problems becomes very complexes.
Interactions between the matrix and stiffening elements were been observed in the case of Al-SiC, forming „blades" of Al_4C_3 and blocks based on Si.

b. Among the *solide state welding* processes, it can be mentioned: diffusion welding, friction welding, friction stir welding. During the welding of MMCs and CMCs, based on aluminium, at the softening temperature, the materials can be subjected to oxidation. In the friction stir welding, the particles of stiffening elements can use the work tool, because of SiC.

c. Among *others joining processes* for MMCs and CMCs materials, based on Al, it can be considered: brazing, soldering, adhesion bonding.
During the composite materials welding, there are many reactions between the stiffening material and matrix, forming the compound Al-SiC. During the silicon carbide melting, the reaction is:

$$4Al[l] + 3SiC[s] \Rightarrow Al_4C_3\,[s] + 3Si\,[s] \qquad (1)$$

when: [l] –liquid phase; [s] – solide phase.

This reaction is irreversible and produces, at temperatures over 730°C, low Si alloys.

The fusion welding technologies are not recommended for composite materials, type Al/SiC, only if the melting pool temperature is very low. But, it is preferable a minimum 7% Si for the matrix chemical composition.

On the other part, it can be used a reagent metal, for example, titanium. The reaction of titanium carbide is thermodynamic favourable, in comparison with aluminium carbide. In this case, the silicon carbide can be replaced by titanium carbide. So, titanium, in excess, can remain in solution as fine intermetallic phase of Ti_3Al or TiAl following the next reaction:

$$5Ti[Al]j + 3\ Al[i] + SiC\ [s] \Rightarrow TiC[s] + Si[Al]ij + Al[l]+(Ti3Al+TiAl) \qquad (2)$$

In the case of Ti and Si composites welding, it must follow the SiC degradation to the titanium matrix. The conversion SiC => TiC can change the interface microstructure and the reinforcement crystallinity. Also, the „blades” of Al_4C_3 appear into the microstructure. The presence of this compound has unfavourable influence on the welded joint, as follows:

- the microstructure is very fragile;
- the corrosion phenomena can be developed, in the water presence, forming the acetylene;
- the welded joint can de destroyed in few days.

The forming of Al_4C_3 compound is favoure by the high temperature. Some situations were been evinced in the case of electron beam or laser welding. To avoid this compound appearance, it is necessary to choose the right welding conditions and to use the experience of the welder. Also, the hydrogen presence must be avoided, to obtain the welded joints without cracks.

2. Experimental program

The experiments were been made using the composites materials having an Al matrix and the SiC, Al B_2, and Al + 6 % Ti B_2 as stiffening elements, (Table 1).

Table1

No.	Probe mark	Delivery state	Chemical composition	Casting temperature, T (°C)
1 2 3 4 5 6 7	1 2 S1 S2 S3 S4 S5	extruding bar extruding bar cast cast cast cast cast and remelted	Al Al + 20 % SiC Al + 6 % AlB_2 Al + 12 % Al B_2 Al alloy 2014+12 % Al B_2 Al + 6 % Ti B_2 Al + 12 % Ti B_2	 905 840 850 910 920

Mechanical characteristics are presented in table 2.

Table 2

No.	Material	$R_{p\,0.2}$ (MPa)	R_m (MPa)	Z (%)
1 2	Al alloy 2014 Al alloy + 6 % AlB_2	140 65 92	216 114 110	2,8 5,0 3,3

3. Joining experiments

The joining experiments were been made by the next processes:

A. Flame brazing with filler material;
B. Resistance welding;
C. Brazing in oven with filler material;
D. Ultrasonic welding;
E. Laser welding;
F. Friction stir welding.

A. *Flame brazing with filler material* was made in two variants:

A1. In this case, a brazing flux, having the next chemical composition, was been used: 41.4% KCl; 64.2 %NaCl; 6 %LiF.

The filler material was: AlSi alloy, mark A551, wire of Ø 2 mm. This material was melted at 450 °C . The chemical composition was: 11-13.5 %Si; max. 1% Fe, bal. Al. The adherence to the used components was good, beeing observed by visual examination.

A2. In this case, *brazing with neutral flame to carburizing*, based on butan, was been used. Also, the oxygen was been used.

- The probes from S2 and S4 charges were been brazed, after the pickling with ZnCl and HCl. The filler material, $AlSi_3$, as wire, was been melted at approx. 700 °C and spreaded on the contact surfaces. After the brazing, the probes separated, so that this joint is unacceptable.
- The probes from S3 and S5 charges were been brazed, after the pickling with FH20 flux, which adheres on the AG40SN wire. The oven temperature was approx. 700 °C.
  After the brazing, the probes separated, so that this joint is unacceptable.
- The probes from S1 and S2 charges were been brazed with CuP7, phosphorous copper wire. The oven temperature was approx. 700 °C.
  After the brazing, the probes separated, so that this joint is unacceptable.

B. The *resistance welding* experiments were been made using a spot welding machine. Between the components surfaces, was introduced an amorphous material, 50% CuP10 + 50 % Sn. The deoxidant was ½ borax + ½ criolit, forming an water slurry. So, a black thin layer was formed, non-adhesive with the composites materials. This layer was very fragile and it was broken.

C. During the *brazing in oven* at approx. 700 °C, the filler material produced an white layer of zinc oxide, which is not adhesive to base material.

D. *Ultrasonic welding* was been used for all the probes. The welding conditions were:

- welding time 25, and 30 ms,
- amplitude 160 µm,
- press force 10, and 15 kgf.

E. *Laser welding* was been made using the TRUMPF HL 124 P installation, of 2200 W. The welding conditions were:

- welding energie 2.6 J,
- pulse duration 4 ms,
- frequency 30 Hz.

4. Experimental results

4.1. Metallographic examinations

All the visual qualified probes were been examined, to evaluate the joining zones and the microstructures. The magnification was 100x.

a. The structures of the joining zones obtained by flame brazing with filler material are presented in table 3 and figure 1.

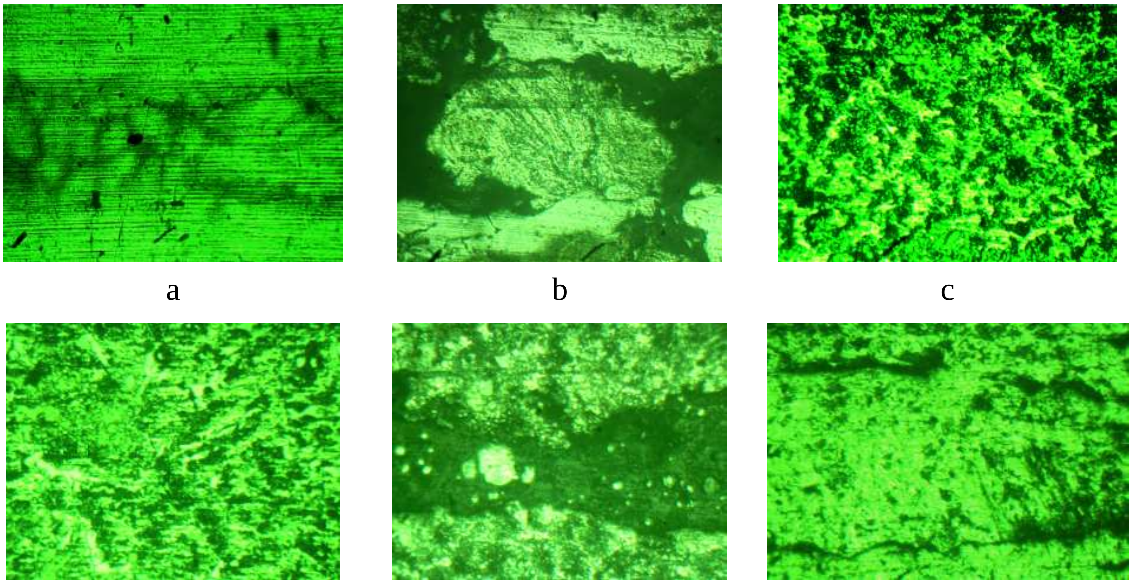
b. The probes obtained by brazing with neutral flame to carburizing are presented în figure 2.
It can be observed the non-adhesiveness of the materials, and mixing between the filler material and the matrix.

c.The probes obtained by ultrasonic welding present an significant adhesiveness, figure 3 a,b,c.

d. The laser welding was been used for many technological variants, applied to the probes S5, (Al + 12 % Ti B_2), (Figure 4).

Table 3

Probe mark	Base metal microstructure	Figure 1	Structure
S1	Aluminium solide solution α with Al B_2 precipitates	c	casting structure
S2	Aluminium solide solution α with Al B_2 precipitates	d	casting structure
S3	Aluminium solide solution α with polyhedral grains, and precipitated intermetallic compounds	f	casting structure
S4	Aluminium solide solution α with Ti B_2 precipitates	g	casting structure
1	Aluminium solide solution α with fine intermetallic inclusions	a	casting structure
2	Aluminium solide solution α with fine and coarse particles of silicon carbide	b	casting structure



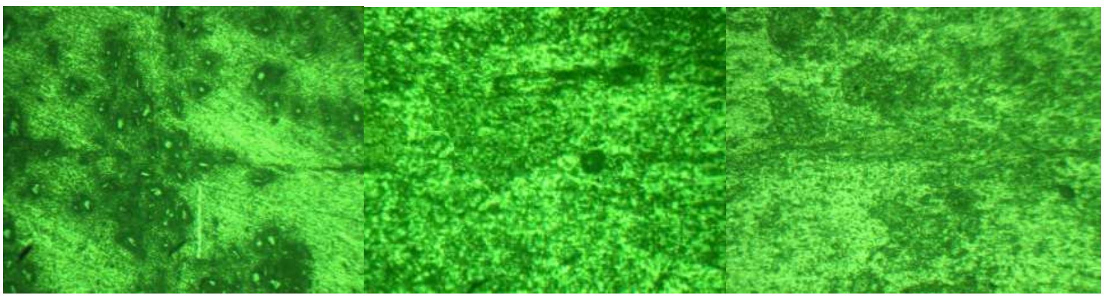
a b c

d e f

Figure 1. Microstructures of of the joining zones obtained by flame brazing with filler material [100X]

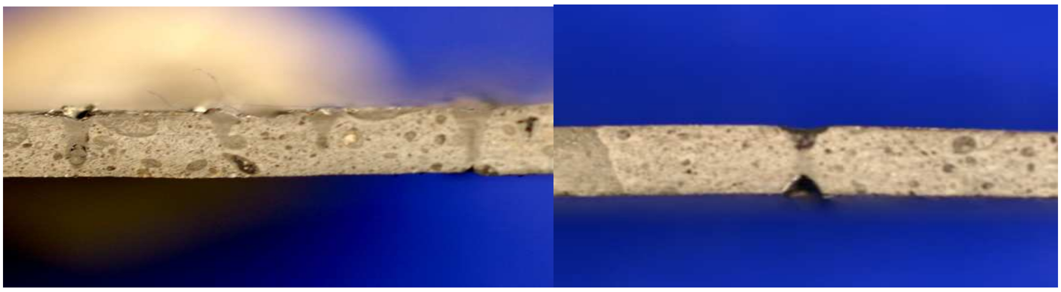
f) e) d) c) b) a)

Figure 2. Probes obtained by brazing with neutral flame to carburizing. The marks are: a - 1, b – S1, c – S2, d – S3, e – S4, f – S5 (according to the table 1)



a) [100 X] b) [100 X] c) [100 X]

Figure 3. Microstructures of the probes having the next marks:
a – 2 (Al + 20 %SiC, extruding bar); b – S2 (Al + 12 % AlB_2 cast);
c – S3 (Al alloy 2014 + 12 %Al B_2, cast)

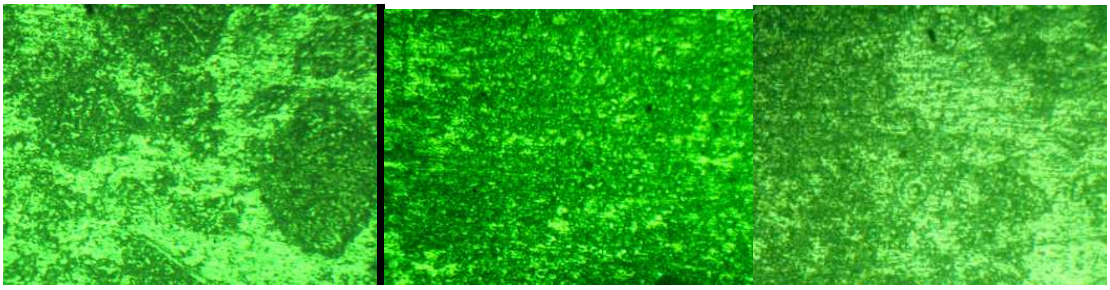


4 3 2 1 X

Figure 4. Probe 5, obtained by laser welding

In figure 5, the microstructures of the S5-X probes (obtained in X welding conditions) are presented.

High melting temperatures and cooling rates characterize the laser welding. It can be observed the intergrowth and good adhesiveness between the welded joints zones. The black points are considered as inclusions.

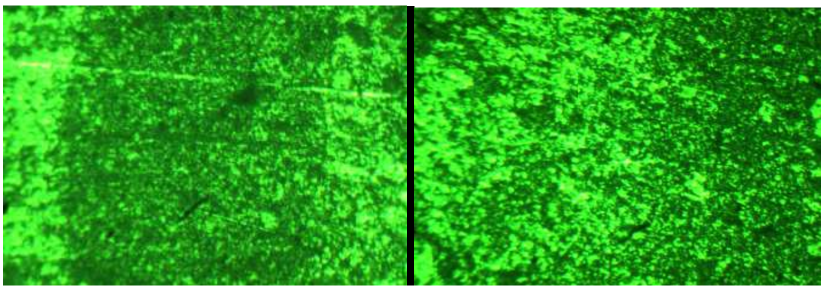


a) b) c)

Figure 5. Microstructures of the probes S5-X:

a – BM, b – WELD, c – HAZ, [100 X]

In the case of welding regime 3, the welding zone (WELD) is limited and contains discontinuities, figure 6. The heat-affected zone (HAZ) has homogeneous structure. Appearance of the black constituents can be a source to initiate the cracking.



a) b)

Figure 6. Microstructures of the probes S5 - 3: a -WELD, b –HAZ.

Laser welding application is influenced by structural non-homogeneities of the processed materials.

4.2. Hardness test

Hardness test, HV1, was made on the probes obtained by laser welding, marked S1 (Al + 6 % AlB_2) and S5 (Al + 12 % Ti B_2). The results are presented in table 4.

Table 4

Mark	Track	BM	WELD 1	WELD 2	WELD 3	WELD 4
S1	1	79.2	81.3	-	-	-
	2	49.3	82.4	-	-	-
	3	88.2	111.0	-	-	-
	average value	72.23	91.56	-	-	-
S5	1	57.2	85.9	85.9	80.3	79.2
	2	83.5	59.2	68.9	90.7	83.5
	3	65.7	60.6	97.4	87.0	68.9
	average value	68.80	68.56	84.06	86.0	77.2

From the table 4, it can be observed low values of the hardness measured in the base metal, in the both the probes, S1 and S5, of max**.** 83HV1.The hardness differences for the charge S1 were been of 38.90 HV1, and 26.3 HV1 for the charge S5, respectively.

It must mentioned, that the hardness, HV1, in the weld zone of the probes S1 was more with approx. 27% than the base metal hardness. For the probes S5, welded with the regime 1, the values of the hardness in the weld zone are almost the same with the base metal hardness values. But, for probes welded with the regime 3, the hardness in the weld zone was more with 25% in comparison with the base metal hardness.

5. Conclusions

5.1. Joining experiments were been made on the charges of aluminium and Al+20%SiC, in extruding state, and five charges of composite materials with aluminium matrix. These composite have different stiffening elements, (Al + 6 % AlB_2, Al + 12 % Al B_2, alloy 2014+12 % Al B_2, Al + 6 % Ti B_2, Al + 12 % Ti B_2), in cast state.

5.2. Flame brazing with filler material can be applied. The metallographic examination evinced specific structures.

5.3. Brazing in oven with filler material not evinced the good results.

5.4. Laser welding without filler material can be considered a good possibility to obtain joined composites materials with Al matrix, MMCs and CMCs. The metallographic examination evinced specific structures and adequate hardness, depending on the material homogeneity.

5.5. Ultrasonic welding can be applied to MMCs şi CMC materials with Al matrix. The obtained welded joints evinced the materials intergrowth. In this case, the microstructure was influenced, correspondely.

5.6. The obtained results put in evidence the possibilities to apply different joining processes. It is necessary to continue the work, to extend it to other joining processes. The aim of these reasearches is to elaborate the adequate technologies for the MMCs and CMCs materials with Al matrix.

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