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FABRICATION METHODS OF DOUBLE COMPOSITES

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Abstract: *This study shows an example for the application of the medium pressure infiltration technique for production of double composite. Prefabricated composite wires were applied as reinforcement in AlSi12 matrix. The reinforcing composite wires contain Nextel 440 ceramic fibres in pure (99,5%) aluminium matrix. These composite wires were produced by continuous infiltration process. I-profiles were fabricated using the composite wires for bending tests. These tests were done on composite wire reinforced and unreinforced pure AlSi12 samples and the results were compared. The interaction between the composite wire and AlSi12 matrix was examined by optical microscopy. The results of the examinations show strong contact between the reinforcement and secondary matrix and all of the reinforced specimens have higher bending strength than the unreinforced ones.*

Keywords: *MMC wire, double composite, pressure infiltration*.

1. INTRODUCTION

The aim of our work was to produce double composite structures by pressure infiltration technique; the examination of the produced double composites especially the influence of the location and quantity of composite wires for the mechanical properties.

The continuous process (Blucher process) uses pressure infiltration of melt into moving fibre bundles, thus making it possible to control production parameters like production speed, fibre versus alloy (matrix) combination and diameter of the composite wire [1]. The continuous infiltration technique prevents fibre degradation and greatly increases yield by virtue of the quick transport of fibres through a molten metal bath under pressure [2]. Blucher et al. described the details of the continuous pressure infiltration technique [3,4,5].

The pressure infiltration technique (batch process) allowed us to make block composites. In case of batch process, it is necessary to place the raw materials of the composite blocks into cans (closed from one side). In this case, raw materials mean aluminium alloy as matrix and composite wires as reinforcement. In the first step the reinforcement get into the bottom of the can. On the top of the reinforcement, an insulator layer was situated. Finally, an aluminium (AlSi12) block was placed on the top. At this time the thermocouples, which ensure controlling of the process, were put in place as well. The prepared and filled container was positioned into the batch unit's chamber. In this chamber one can generate vacuum with a vacuum pump or gas pressure with inert (usually argon) gas. In the next step, the closed chamber is evacuated. The chamber has three heating zones, the furnace becomes heated in vacuum. The melted matrix metal was formed a liquid metal cork, above the fibres - and the vacuum is maintained at the bottom of the chill. Then infiltration pressure is switched on (argon gas) and the pressure forces the aluminium through the insulator layer into the fibres with the help of the vacuum under the metal cork. The reinforced fibres were infiltrated. The pressure depends on the wettability of the materials used. If the wettability is bad, the required pressure is high [6]. After the infiltration step the aluminium solidifies, the furnace was opened and the container is removed from the chamber. By this method also possible to produce carbon fibre reinforced aluminium matrix composite [7, 8].

Metal matrix composite (MMC) wires produced by the Blucher-method open new opportunities for practical application of fibre reinforcements in aluminium structural elements. Apart from using them directly as tension type load carrying elements or combining them into sandwich structures, a major potential application is preferential reinforcement of Al or Mg castings. The two major difficulties encountered during direct fibre reinforcement of cast parts, the required high infiltration pressure and the tendency of the reinforcing fibres to float away from their intended place, are eliminated when the fibres are introduced into the casting in the form of prefabricated MMC wires [9]. The MMC wire reinforced composites are called double composites. Composites, which contain more than one reinforcing or matrix material, are called hybrid composites. [10].

Another method for double composite fabrication is extrusion, which was described by Weidenmann et al. [11]

2. EXPERIMENTAL PROCEDURE

Nextel 440 ceramic fibre [12] reinforced aluminium (Al 99.5) matrix composite wires of 1 mm diameter were fabricated with continuous process. The composite wires contained 3750 filaments. The sizing of the fibre tows was removed at 800°C. The infiltration pressure in the pressure chamber was 1.52 MPa (220 PSI). The production speed was 15 m/min, consequently, the exposure time (the time what the fibres spent in the molten metal) was approximately 0,2 s.

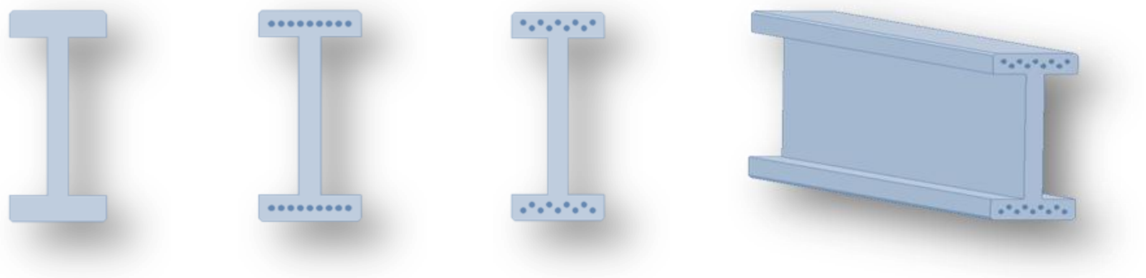

Fig. 1 Structure of the unreinforced and double composite I-profiles

The composite wires were used as reinforcement in the double composite I profile. The outermost fibre of the I profiles contains the reinforcing composite wires. The composite wires are parallel to each other and the longitudinal axis of the profile. Three types of samples were fabricated: composite wire reinforcement in one row; composite wire reinforcement in two rows and without reinforcement (Figure 1).

The first step was the fabricating of the chill. The chill was made from one end closed rectangular cross-section closed profile. Thereunto the 20×40 mm closed profiles were cut for 400 mm long pieces. Flat steel were used to form the "I" cross-section. The two flat steel pieces were inserted and fixed in the closed profile, so the residual chill volume formed an I-profile shape. The edges of the flat steel originally are rounded. These rounded edges had to be eliminated for the sake of easier remove of the product from the chill. The appropriate distance and enough place for the middle section of the I-profile were ensured by welding. The next step was the closing of the chill by welding. Block was cast from the matrix material (AlSi12) into the chill having 20×40 mm cross section. Drilled graphite sheets fixed the composite wires and ensured their parallelism. The graphite sheets were cut for 16×4,5×10 mm pieces and drilled (the used drill diameter was 1 mm). The chills were tested to be gastight.

Thermocouples were placed to the bottom of the chills and into the aluminium blocks for continuous monitoring of temperature. The thermocouples were put in alumina tubes to avoid their damage. The assembled chills were fixed to each other, and placed into the pressure chamber.

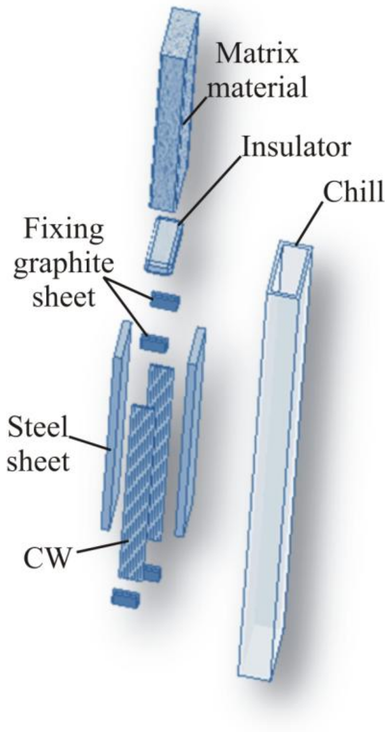

Fig. 2 Experimental assembly

0.34 MPa (50 PSI) infiltration pressure was applied for the fabrication of the samples. This pressure was held until the solidification of the samples. When the pressure dropped in the chamber down to atmospheric value the equipment was opened and the samples were cooled by water. After the pressure infiltration process, the chills were opened and the products were removed. Figure 2 shows the experimental setup.

3. RESULTS AND DISCUSSION

Figure 3 shows the produced samples. The distance between the shoulders was 82 mm during the three point bending tests. The crosshead speed was 5 mm/min. Figure 4 shows the test process. The lengths of the specimens make it possible to do more than one three point bending tests on one specimen. The asymmetrical placement of the specimens in the bending test machine did not cause asymmetrical force distribution.

Fig. 3 Double composite I-profiles

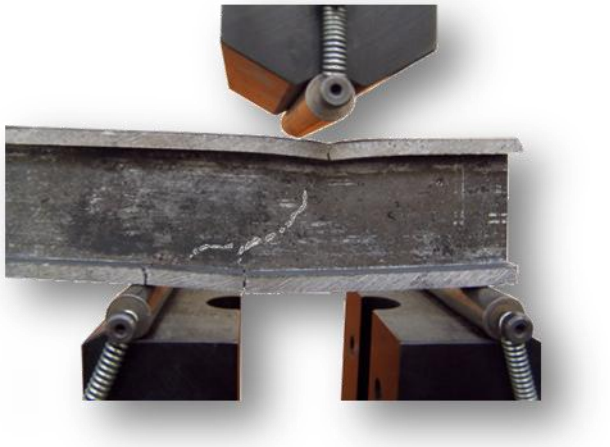

Fig. 4 Bending test of the I-profile

The failure during bending begins by the deflection of the upper rib of I profile which leads to crack initiation. At the same time crack starts at lower rib also, caused by tensile load. This crack propagates forward across the sample until the failure. Due to the porosity, the crack generally propagates parallel with the axis of the specimen, so it has influence on the strength of the component. Subsequently, the results have large deviation.

Figure 5 shows the high deviation but that is clear, double composites have significantly higher bending strength although the volume fraction of the composite wires were only 5,91%. There are two possible reasons of the arising of porosity: temperature gradient was not suitable in the can from the aspect of shrinkage and during the shrinkage of the aluminium matrix the necessary material supply was not provided; bubbles were raised by the high pressure gas in the melted aluminium.

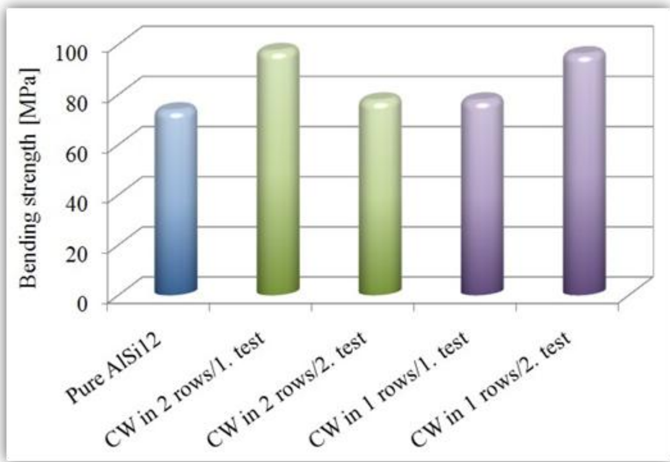

Fig. 5 Results of the TPB tests
(CW – Composite Wire)

Micrographs show that the boundary between the composite wire and the secondary matrix disappeared, so strong connection exists between the secondary matrix and the reinforcement (Figure 6). The strong bonding has high significance because the composite wires covered by alumina skin caused by their aluminium content and there is poor wetting between alumina and liquid aluminium [13, 14]. In the outermost fibres these composite wires stopped the crack opening, hence the crack opened widely in the middle section of the I profile. The diameter of the composite wires did not change, so the heat amount stored in the secondary matrix was not able to change the position of fibres in the composite wires. Composite wires stay in their original position after the process as well. These characteristics prove the more effective application of composite wires compared to the usage of pure fibres.

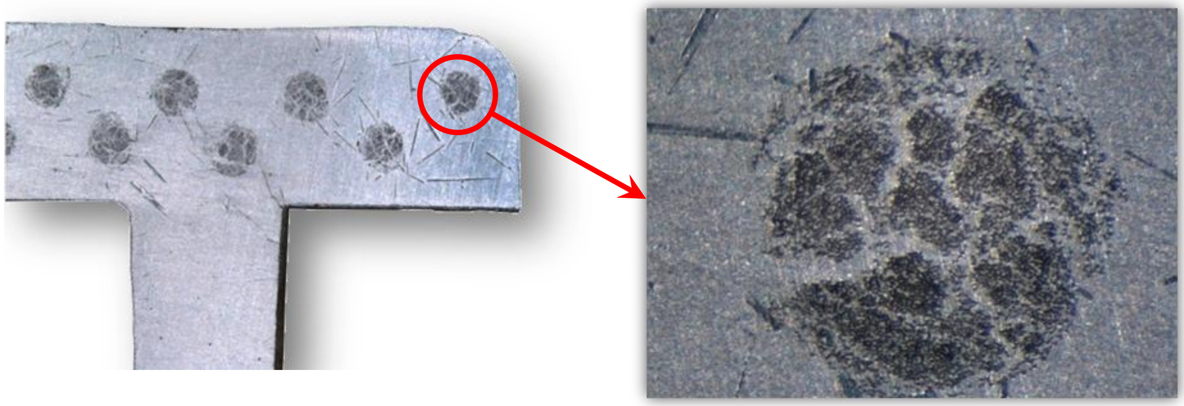

Fig. 6. Cross-section of composite wire reinforced I profile

Small cracks appeared in the micrographs at the corner. It caused by removing the sample from the chill. Other small cracks can arise by thermal shock and heat expansion.

In the micrographs needle-like silicon precipitations are observable in random positions. Dendritic structure was formed during slow cooling which could be seen after etching.

4. CONCLUSIONS

The method developed for fabrication of double composite I-profile makes possible to produce the designed product precisely.

The double composite I-profiles contain 5.9% composite wire reinforcement and it increases the bending strength by 32%.

Thanks to the pressure infiltration (batch process), strong contact was formed between the composite wire and the secondary matrix, without any phase boundary.

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REFERENCES

[1] Blucher JT, Narusawa U, Katsumata M, Nemeth A. Continuous manufacturing of fiber-reinforced metal matrix composite wires-technology and product characteristics. Composites: Part A 32 (2001) 1759-1766.

[2] Williams MG, Isaacs JA, Nadler JH, Sampson SL, Kowalski GJ, Blucher JT. Analytically motivated process improvements in continuous metal–matrix composite wire fabrication. Materials Science and Engineering A266 (1999) 86–92.

[3] Blucher JT, Katsumata M. Method for manufacturing composite materials. Patent No.: US 6524658B2

[4] Blucher JT. Reinforced structural elements incorporating fiber-reinforced metal matrix composite wires and methods of producing the same. Patent No.: US 2003/0029902A1

[5] Blucher JT. Gating system for continuous pressure infiltration process. Northeastern University, US Patent No. 5736199, 1998.

[6] Mizumoto M, Ohgai T, Kagawa A. "Characterization of fiber-reinforced metal matrix composites fabricated by low-pressure infiltration process", Materials Science and Engineering, A 413-414, (2005) 521-526.
[7] Carreno-Morelli E, Cutard T, Schaller R, Bonjour C. "Processing and charac-terization of aluminium-based MMCs produced by gas pressure infiltration," Materi-als Science and Engineering, A251, (1998) 48-57.
[8] Etter T, Papakyriacou M, Schulz P, Uggowitzer PJ. "Physical properties of graphite/aluminium composites produced by a gas pressure infiltration method," Car-bon 41 (2003) 1017–1024.
[9] Blucher JT, Dobranszky J, Narusawa U. Aluminium double composite structures reinforced with composite wires. Materials Science and Engineering A 387–389 (2004) 867–872.
[10] Czigány T. Hibrid szálerősítésű polimer kompozitok. Anyagvizsgálók lapja 2004;2:59-62.
[11] Weidenmann KA, Schomäcker M, Kerscher E, Löhe D, Kleiner M. Composite extrusion of aluminum matrix specimens reinforced with continuous ceramic fibers. Light Metal Age, pp. 6-10 October 2005.
[12] Information on http:// www.energy.ca.gov/ 2004_policy_update /documents/ 2004-06-14-workshop/ public_comments/ 2004-06-28_3M_PART3.PDF (3M: Aluminum Conductor Composite ReinforcedTechnical Notebook).
[13] Kaptay Gy, Bolyán L. Interfacial aspects of producing MMCs. Part II/1. Databank of interfacial energies. BKL Kohászat, 131 (1998:5-6), 179-185.
[14] Kaptay Gy, Bolyán L. Interfacial aspects of producing MMCs. Part II/2. Databank of interfacial energies. BKL Kohászat, 131 (1998:9-10), 305-314