THE PROCESSING AND TESTING OF ALUMINIUM MATRIX COMPOSITE WIRES, DOUBLE COMPOSITES AND COMPOSITE BLOCKS

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ABSTRACT

The Composite Processing and Testing Laboratory operated for about 15 years in USA. After that, in 2004-2005, it moved from Boston to the Budapest University of Technology and Economics One of the main results from research and development projects is that of aluminium matrix composite wires produced via continuous processing. The composite wires have experimental applications for the electrically conductive reinforcement of high voltage electric cables, for example. Ceramic continuous-fibre-reinforced MMC-wires were produced with diameters ranging from 0.1 to 2.5 mm and a fibre volume fraction of up to 60% v/o. Thanks to the high efficiency of the continuous process, interface relations are notably reduced, and this increases mechanical properties.

The other principal result is one pointing to carbon fibre-reinforced block composites processed by a combination of vacuum and high-pressure infiltration. The result of these processes is fibre-reinforced aluminium matrix composite blocks.

Production methods, composite wire reinforced double composites and the results of the material tests of these products are revealed. Various matrixes were made use of in the production of double composites so as to monitor the changes in the interface relations.

Alongside the conventional mechanical testing methods, mechanical properties can be characterized by use of an instrumented impact test, while the solidification structure and interfacial properties can have a SEM-EDS and thermoelectric measurement (Seebeck-coefficient).

1. INTRODUCTION

1.1 Continuous production of composite wires

The composite wires are continuous-fibre-reinforced aluminium matrix composites, which are made by a continuous process. The inventor of this process is J.T. Blucher [1]. Figure 1 shows the principal components of the continuous processing unit. The composite wires are made with this continuous processing unit [2]. The reinforcement fibres are drawn through molten aluminium under high pressure via an on-going process. The liquid metal infiltrates the fibres affected by the high pressure [3] in contempt of incorrect wettability conditions. Thus, the space between fibres is filled up completely. The molten aluminium, operating under high pressure, was made to stay in the chamber via a drawing of the fibres. A continuous drawing of fibres along with a suitable speed is required in the process. The main function of the different orifices is to keep back the molten aluminium [4].

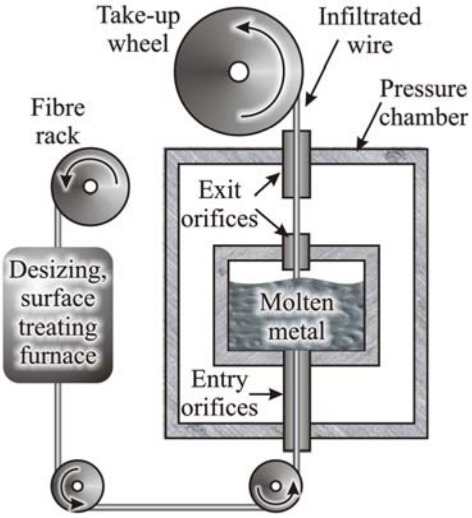

Figure 1 : Schematic diagram of continuous pressure infiltration unit

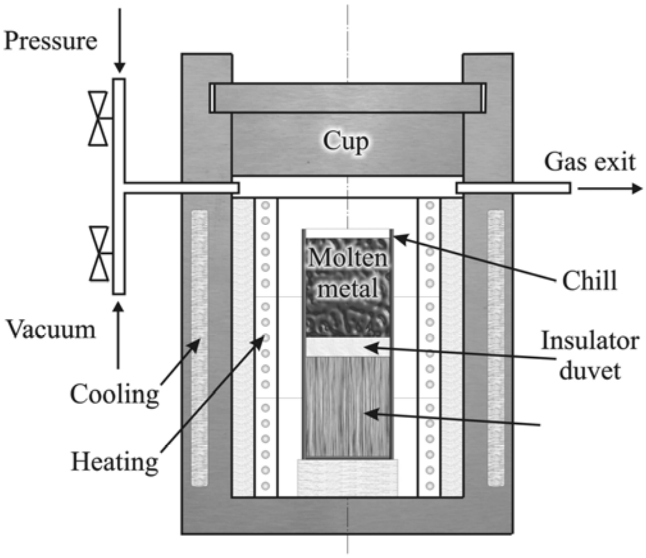

Figure 2 : Schematic diagram of batch pressure infiltration unit

1.2 Medium pressure infiltration technology

In the course of the process a hollow section chill was made and the reinforcement carbon fibres were placed uni-directionally in the chill, to infiltrate the fibres. The reinforced fibres were filled into the chill and a spongy, heat insulator duvet layer together with an aluminium block were placed onto the fibres. At this time the thermocouples, which ensure a controlling of the process, were put in place as well. The prepared and filled chill was positioned into the batch unit. In the batch unit one can generate a vacuum and change it immediately into having medium pressure. The furnace becomes heated in such a vacuum. The melted matrix metal was made into a liquid metal cork, above the fibres - and the vacuum is maintained at the bottom of the chill. Given this, the infiltration pressure is switched on (Argon gas) and it overruns the furnace. With the help of the vacuum under the metal cork, the reinforced fibres were infiltrated. The pressure depends on the material used in the reinforcement. Its role is to increase wettability [5]. After this procedure, the furnace was opened and the chill with the completed composite was taken out and chilled with water. By this method, carbon fibre-reinforced composite blocks were produced with an aluminium matrix [6, 7]. Figure 2 shows a schematic diagram of a batch pressure infiltration unit.

2. EXPERIMENTAL PROCEDURES

2.1 The thermal ageing of composite wires

The composite wires were exposed to durable and high temperature (400°C). These thermal ageing experiments were done so as to see whether a durable high temperature causes any kind of change in reinforcement and in the interfacing of the fibre and matrix. It often happened that the temperature of the power cables reached 200-300°C due to an overloaded electrical grid. Accordingly, being able to handle this phenomenon, it would seem to be reasonable to determine the changes caused by such heat in composite wires. It was observed as well that these effects depend on the temperature and the time duration of the heat treatment. In the experiment a 400°C treating temperature was used for 100, 250, 500, 750 and 1000 hours. After the heat treatment an instrumented impact test was applied to examine the toughness of the composite wires. There was developed a new method, which based on the Charpy impact test. In this test there was no notch on the composite wire specimens. The diameter of the composite wires was approximately 1.6 mm, meaning that the impact energy here is especially low. Consequently the starting angle of the pendulum was 40°. The distance between the two wire holders was 40 mm. Each examined wire had the same length (50 mm), to thus eliminate the effects of composite wire inertia.

2.2 An elaboration of double composite specimens

The tensile and the bending specimens are composite wire-reinforced casts [8, 9]. Various matrix materials were used in the experiments. The composite wires were impregnated by different metals. The matrix of the composite wires is aluminium, so one of the double composite’s matrix metals is aluminium, too. The composite wires also had to serve as reinforcing aluminium casts. So it was also worth trying other metals as matrix materials to see any existing differences in mechanical properties. Utilized metals were chosen with reference to their melting points. This implies that metal with a higher melting point than aluminium cannot be used for a double composite matrix. The other factors needing consideration were the handling properties (castability, fluidity, etc.) of matrix material - and-such handling properties are important when one is to does safety, ease and energy-saving experiments. After these factors had been considered, it was tin that was chosen as the matrix metal, owing to its low melting point (232°C) and good fluidity. Another matrix metal was lead, with a 327°C melting point. Zinc (420°C) and aluminium, with a 660°C melting point, were additionally used as matrix metals. All of the mentioned specimens were prepared via a gravitation casting process.

3. RESULTS AND DISCUSSION

3.1 Impact tests for thermal-aged composite wires

Figure 3 displays impact energy change on the basis of dependence on ageing time for Al_2O_3 and SiC fibres reinforced composite wires. The impact energy of 400°C heat-treated Al-Al_2O_3 composite wires increases with less of an ageing time (about 100 hours). After 100 hours ageing, the impact energy of the Al-Al_2O_3 composite wires decreases. When the ageing time was longer than 250 hours the impact energy did not change. The impact energy of the Al-SiC composite wires was changed at random according to the temperature. Thus, conclusions could not be drawn.

Results of the impact tests show that there was no – or was extremely small – fibre or interfacial damage arising which might harden the composite wires in aluminium-oxide fibre-reinforced composite wires. In spite of what may have been expected [10], there was no notable embrittlement in Al-SiC composite wires. Our expectations were based on the mutual solid-solid phase diffusion of C and Al [11, 12]. Such an examination was carried out via scanning electron microscopy and an EDS-analysis.

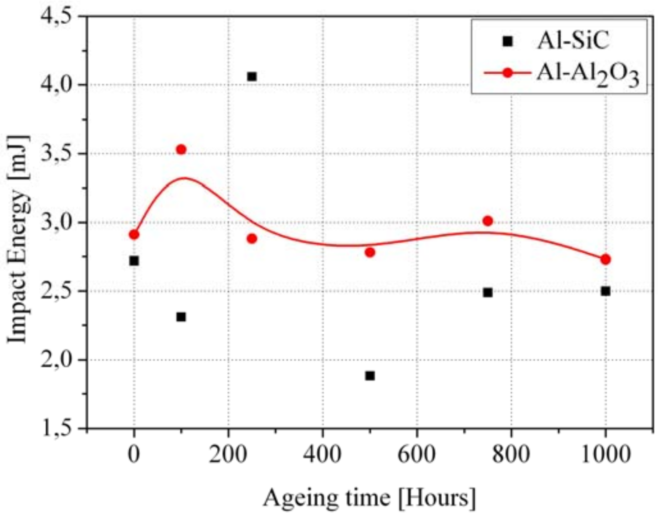

Figure 3 : The impact energy of composite wires depending on an ageing time at 400°C

3.2 Scanning electron microscopy and an EDS-analysis

The composite wires and the interface between the fibre and the matrix were investigated with a scanning electron microscope and EDS-analysis. The changes in components were looked at when on their way through a filament. It is hard to separate the changes of content as regards the diameter of the electron beam and effective changes. The electron beam excites a volume of matrix and the fibre at the same time, therefore decrease measuring precision. Via these results, we can say that there were no reactions between the Al_2O_3 fibre and the aluminium matrix. Infiltration of the composite wire was perfect, as the aluminium filled out all of the space existing between fibres. The looked-at wires were Nextel 440, oval cross-section fibre-reinforced Al 99.99 matrix composites.

3.3 Thermoelectric power measurement

Thermoelectric power (Seebeck-coefficient) shows us how many volts arise between the two ends of the specimen given a 1°C temperature difference. This material parameter displays changes in the material and differences between the materials. 70 mm-long composite wires were used for the test (which is the distance between the equipment's clams). Two types of composite wires were examined (Al_2O_3 and SiC fibre-reinforced). The speed of manufacturing and the infiltration pressure was the difference between the fibres.

On the basis of the thermoelectric power involved, the composite fibres were divided into three groups, as figure 4 shows. Most likely, the connection between manufacturing parameters and the thermoelectric power was the change in the solidification structure of the Al-matrix.

In the second experiment series thermoelectric power alterations were investigated depending on ageing time. In figure 5 the thermoelectric power of Al-Al_2O_3 composite wires with a 100 hour-long ageing time did not change; after this, the thermoelectric power went down linearly so, in this case, the thermoelectric power correlates with the ageing time. The thermoelectric power of the Al-SiC composite wires given a 100-hour ageing time shows an increase, and, afterwards, such thermoelectric power has a mildly decreasing character.

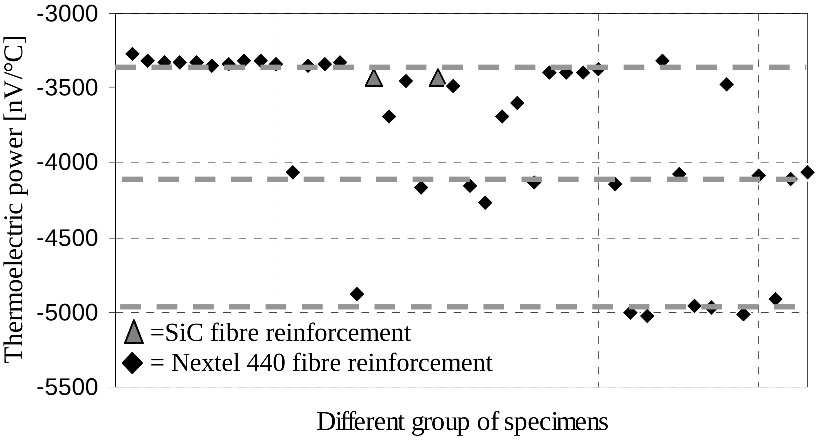

Figure 4 : Thermoelectric power of composite wires grouped by the type of reinforcement

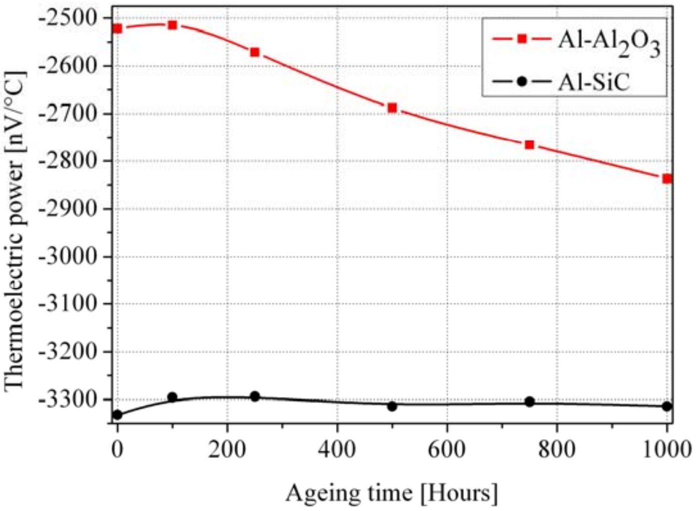

Figure 5 : Thermoelectric power of composite wires depending on an ageing time at 400°C

3.4 Mechanical tests of double composites

The tensile strength of aluminium matrix composites made via continuous process is 674 MPa. This is an average value. Such composite wires were used as reinforcements in the producing of double composites.

The location of reinforcing composite wires and occurring cavities were examined using an X-ray microscope with firmed-up double composite casts. There were no ‘failures’ with most specimens here. The molten metal flow did not alter wires’ original positions. Discovery of the position of composite wires was difficult, though, due to the tiny differences between the aluminium matrix and such composite wires. Most problems arose in connection with aluminium matrix specimens, as its wettability properties are worse than the wettability properties of other metals. Here, many cavities were seen near the wires.

In the tensile tests first, pure matrix metals were tested – and, afterwards, came the composite wire-reinforced variant. The strain of pure tin is greater; and, overall, obvious strain marks appeared. So the complete length of the specimen became greater, until the strain of the composite wire-reinforced specimen was concentrated in a small area (contraction).

Thus, the wire with a higher Young's modulus was loaded and could not affect the other part of the matrix metal until a reinforcing wire failure, with the matrix then carrying the whole load. With lead and zinc there was no great difference between reinforced or pure specimens, however Figure 6 gives us the tensile test results. The composite wire-reinforced specimens carried bigger loads than the pure matrix metal specimens. This tells us that a load transfer occurs between the different matrix materials and composite wires.

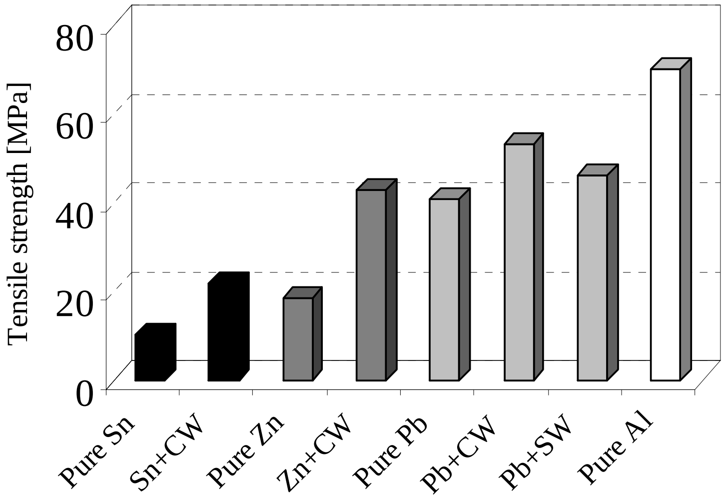

Figure 6 : Tensile strength of specimens
(CW=Composite Wire, SW=Steel Wire)

The results of the bending tests, using different matrix metals, show a similar tendency as that of Fig. 5 concerning tensile tests. With almost all specimens the reinforcing composite wire was able to work together with the matrix. This higher load can be used with the double composites - more than is the case with other specimens (without reinforcement). Exceptions came owing to casting faults.

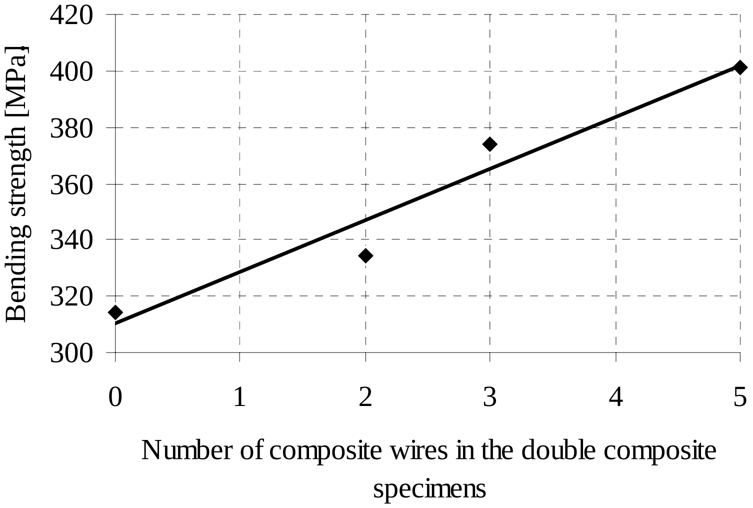

Figure 7 : Bending test for square cross-section aluminium specimens

Figure 7 depicts results coming from square cross-section aluminium matrix double composite bending tests. A regression line related to measured points shows the correlation between the quantity of composite wire and loadability. The strength of the double composite structure is a linear function of the composite wires' quantity.

3.5 Mechanical testing of composite blocks

Owing to the difficulty of machining, the specimens are notched with a radius of 10 mm. The pulling velocity of the tensile test was 0,1 mm/s.

The average tensile strength, as calculated from the tensile tests, was 242 MPa, which is significantly different from theoretical results related to the rule of mixture (926 MPa). The reason for the differences between results was the weakness of the interfacial layer.

As the figure 8 shows, the silicium precipitates was girdled around the carbon fibres. In the interface a brittle layer was formed (probably Al_4C_3), which was not able to assure the right load transfer due to its shear strength being low.

The average strength, calculated from the upset tests, was 849 MPa. The diameter of the specimens was 10 mm and their height was 20 mm. The cross-head velocity of the upset test was 0,1 mm/s. The position of fibres in the specimens was into the direction of the load. The specimens were able to bear a high load according to the results of the tensile tests.

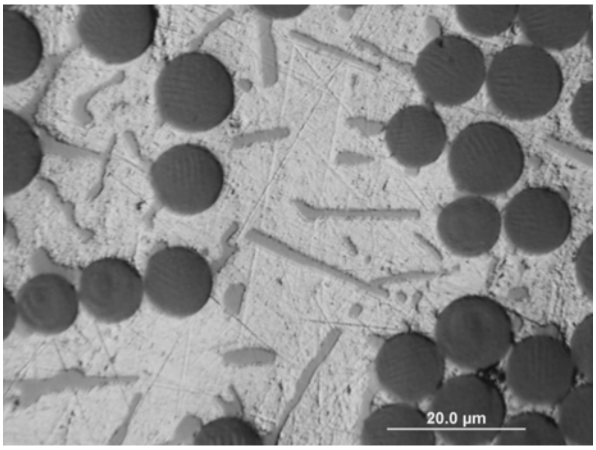

Figure 8 : Microstructure of carbon fibre-reinforced Al-matrix composite

4. CONCLUSIONS

The investigated double composite specimens are reinforced casts with aluminium matrix composite wires (type: Nextel 440 fibre-reinforced wires). Pb, Sn, Zn and Al were used as a secondary matrix material with a casted structure.

The cast from Sn fills the mould in a suitable way – and, after solidification, low imbibitions were noticed, and dendritic crystallites were seen on the surface. The Zn cast had crisp imbibitions and a rough surface. Unfortunately, the Pb chilled too quickly, which resulted in the forming of interfaces. The moulding of Al was most difficult, as it filled the mould and the wires poorly (the molten metal did not successfully fill either the corners or edges of the chill). Imbibitions measurements were smaller with casts that contained composite wires.

An accurate chemical composition of the matrix of composite wires was determined. Long-term ageing experiments show us the effects of the durable heating. In this paper we have shown the thermoelectric power does correlate with ageing time – and this is an important result because in this wise manned time was appreciable by the thermoelectric power measurement.

The double composites were examined via tensile tests and three point bending tests. General conclusions are that composite wire reinforcement improves the mechanical properties of specimens.

Results from tensile tests pertaining to a carbon fibre-reinforced composite and the rate of the fibre/matrix volume show us that the strength of a composite can be reduced by more than 50% when set against theoretical (rule of mixture) results. The reason for this strength lowering is in the formed brittle intermetallic phase.

The reason for the differences in tensile strength results between composite wire and the block composites was that the aluminium matrix composites that are made via continuous process remained at a high temperature for a shorter time in aluminium. With this, the rigid, interfacial phases were not able to evolve themselves.

Nevertheless, the aluminium-oxide fibre-reinforced composite wires are not prone to thermal damage.

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