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Selected mechanical properties of aluminum composite materials reinforced with SiC particles

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Abstract

This work presents the results of research concerning influence of ceramic particles' content of silicon carbide on selected mechanical properties of type AW-AlCu4Mg2Mn - SiC composite materials. Composites produced of SiC particles with pressure infiltration method of porous preform and subject to hot plastic forming in the form of open die forging were investigated. The experimental samples contained from 5% up to 45% of reinforcing SiC particles of 8÷10μm diameter. Studies of strength properties demonstrated that the best results, in case of tensile strength as well as offset yield strength, might be obtained while applying reinforcement in the amount of 20-25% vol. of SiC. Application of higher than 25% vol. contents of reinforcing particles leads to gradual strength loss. The investigated composites were characterized by very high functional properties, such as hardness and abrasive wear resistance, whose values increase strongly with the increase of reinforcement amount. The presented results of the experiments shall allow for a more precise component selection of composite materials at the stage of planning and design of their properties.

Keywords: Cast composites; Silicon carbide; Mechanical properties.

1. Introduction

Composite materials reinforced with ceramic particles belong to a numerous group of materials, whose mechanical properties might be shaped already at the stage of their design. Materials of the planned properties can be produced through selection of proper base material, reinforcement kind, its content and distribution as well as through application of various production techniques. Material reinforcement with ceramic particles results in the increase of its hardness, rigidity and, first of all, abrasive wear resistance [1,3]. However, the experiments demonstrate that plasticity of these materials decreases with quantity increase of ceramic particles, while tensile strength increases to their certain limit amount and then material weakening is observed. There is therefore a necessity to determine suitable proportion of base material in relation to reinforcement amount in order to obtain a material resistant to abrasion wear processes and properly high hardness on one hand, and retaining its high resistance properties on the other hand.

The experimental materials have been produced with infiltration method under pressure of liquid alloy of AW-AlCu4Mg2Mn base material blocks made of SiC particles of 8-10μm diameter and next subject to hot plastic forming consisting in open die forging with 70% deformation. During the last stage the produced materials were subject to heat treatment, including 3 hours of solutioning the temperature of 500°C and artificial ageing at the temperature of 170°C for 12 hours (T6 process – according to ASM), giving the materials their final properties [1].

The experiments have been conducted considering the influence of reinforcing particles on the properties of composite materials. Volumetric participation of the reinforcing particles in the investigated materials was from 5% up to 45%. The samples made of non-reinforced alloy of AW-AlCu4Mg2Mn base material, subject to T6 processing, have also been studied.

Figure 1 presents a structure example of the composite subject to investigation.

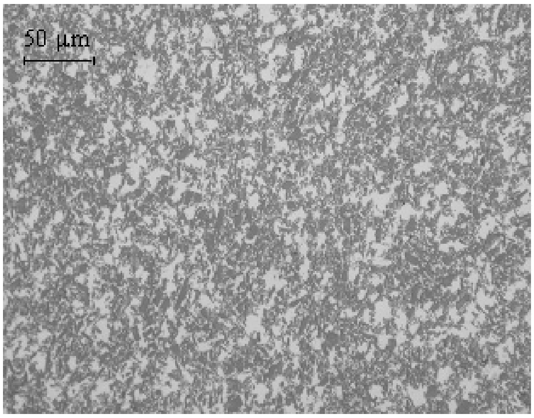

Fig. 1. Composite material AW-AlCu4Mg2Mn - 30% vol. SiC

2. Studies of mechanical properties

2.1. Studies of tensile strength and offset yield strength

Because of specific shape of the produced composite materials obtained as a result of plastic forming consisting in free upset forging, resistance studies have been conducted with the samples of shapes and dimensions presented in figure 2.

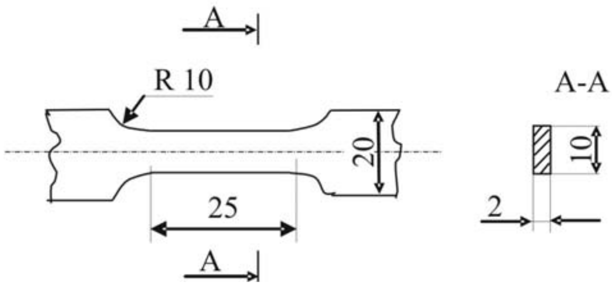

Fig. 2. Shape of the sample for strength studies

Measurements have been conducted with MTS System Corporation, Minneapolis, USA resistance machine, type mark MTS 858 Mini Bionix, at ambient temperature of 20°C

The influence of SiC reinforcing particles quantity on R_m tensile strength and $R_{0,2}$ offset yield strength of composite materials have been presented in figure 3.

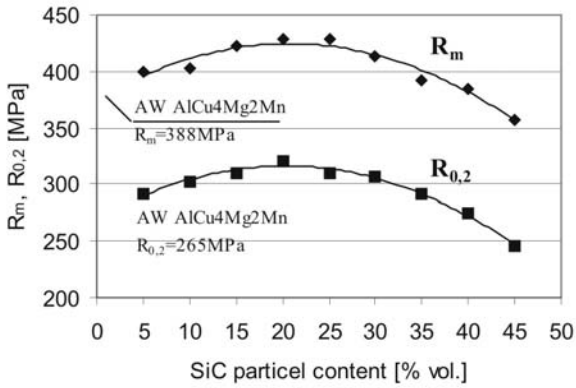

Fig. 3. Tensile strength R_m and offset field strength $R_{0,2}$ of composite materials

Addition of even small amounts of the reinforcing particles to base material positively influences resistance properties of the composites. SiC participation increase within 5% up to about 20÷25% vol. range results in a gradual increase of strength, by about 10MPa on the average (in case of R_m and $R_{0,2}$ as well) per each additional 5% of SiC volume. Curves of tensile strength R_m and $R_{0,2}$ offset yield strength changes reach a maximum at which composites demonstrate their highest resistance with 20÷25% SiC participation. In this case R_m tensile strength reaches even 425MPa (at about 25% vol. SiC).

Increase of the reinforcing particles' participation from 25% to 45%vol. results in a gradual loss of strength, reaching the lowest value of 356MPa at 45% vol. It might be stated, while comparing the obtained values to tensile strength R_m of 388MPa of the non-reinforced AW-AlCu4Mg2Mn alloy, that content increase of the reinforcing particles in composite material to over 30% vol. reduces R_m tensile strength to below that of a non-reinforced alloy strength (388MPa).

In case of change graph course of $R_{0,2}$ offset yield strength a slow increase is initially observed from 292MPa per 5%vol. of SiC particles to 320MPa at 20% vol., similarly as in case of R_m tensile strength. With regard to materials containing over 20% vol. of SiC, $R_{0,2}$ strength begins to decrease gradually reaching the lowest value of 245MPa at 45% vol. of SiC.

Addition of 35% vol. and more of the reinforcing particles to the alloy results in $R_{0,2}$ decrease to below the value obtained for a non-reinforced base material (265MPa). In this case the highest strength properties have been reached by the samples made of material containing 20% vol. SiC reinforcement in AW-AlCu4Mg2Mn alloy.

2.2. Hardness

Hardness measurements of composite materials have been conducted with Brinell hardness tester using steel ball of 2.5mm diameter and P=625 N load. The tests have been conducted with the samples subject to free upset forging and heat treatment consisting in solutioning at the temperature of 500°C and artificial ageing at the temperature of 100°C, 200°C and 300°C for 6 hours. The results of measurements obtained from various areas of the samples have been presented graphically in figure 4 in the form of mean value of five impressions.

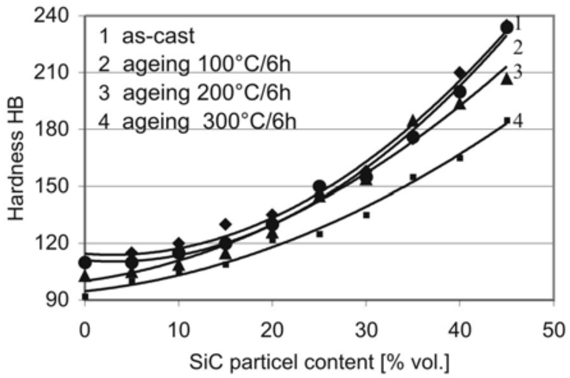

Fig. 4. Hardness of composite materials depending on participation on SiC reinforcing particles after various ageing times

The obtained results allowed for determination of the influence of reinforcing particles' content on base material hardening degree. Reinforcement of base material with SiC particles always leads to hardness increase of composite materials. The highest HB hardness characterized composite material samples containing 45% vol. of SiC particles. Hardness measurement value was 235 HB in this case and it was over two times higher than hardness of a non-reinforced base material of 110 HB. In case of the samples containing 5%, 10%, 15% and 20% of SiC particles this increase is about 6 HB per 5% vol. of the reinforcing particles. For higher volumes of the particles (25 up to 45% vol.) in composite materials their HB hardness increases more intensively, reaching gains of 10÷20 HB per each subsequent 5% vol.

The conducted analysis of heat treatment influence on hardness has not demonstrated significant hardness changes of materials subject to ageing at 100°C/6h in comparison to the materials not treated with heat. However, there are hardness differences of composite materials subject to ageing at the temperature of 200°C and 300°C. Hardness decrease of all the tested materials occurs in these cases. The lowest HB values have been demonstrated by the samples subject to ageing at the temperature of 300°C. In this case the samples of composite materials containing 45% vol. of SiC particles demonstrated only 185 HB, that is over 50 HB units less than the same material prior to ageing.

2.3. Abrasive wear resistance [2]

Tests of abrasive wear resistance have been conducted with the samples of cubicoid shape and 2mmx10mmx40mm dimensions. Butting face (frictional) of the samples has been formed to match the shape of counter-sample surface. Cast iron cylinder of 137 mm diameter and 65HRC hardness, turning with a constant velocity of v=112 rpm, has been used as a counter-sample. The test station has been presented in figure 5.

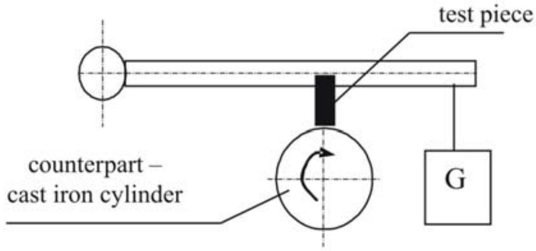

Fig. 5. Layout of the stand for abrasive wear resistance testing

During the tests the sample has been pressed with its butting face to the surface of turning counter-sample with a force resulting in about p=5.5MPa pressure. Friction path was 5800m. Because of possible local overheating the friction face has been cooled with water. This ensured maintenance of constant temperature.

The results of abrasive wear resistance studies have been presented in figure 6. It shows a graph of sample mass changes after the conducted abrasion, depending on SiC particle amount.

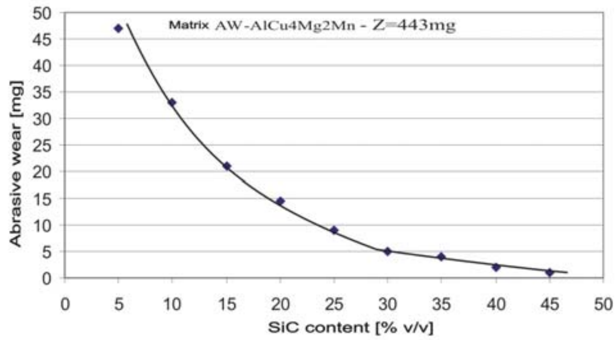

Fig. 6. Abrasive wear resistance of composite materials

Addition of hard particles to a soft base material very positively influenced increase of the material resistance to abrasive wear processes. Sample mass loss was 443 mg in case of non-reinforced AW-AlCu4Mg2Mn alloy. In case of just 5% vol. addition of SiC particles to base material, abrasive wear of the samples was 47mg, which means almost tenfold decrease. Further volume increase of SiC particles leads to even smaller mass loss of the samples and with 15% vol. it is 25 times lower in comparison to a non-reinforced material. On the other hand, the sample containing 45% vol. of SiC is characterized by mass loss of about 1 mg, which proves over 400 times reduction of abrasive wear in comparison to a non-reinforced sample.

3. Conclusions

The studies described in this work constitute evaluation of composite materials produced with foundry method and subject to plastic forming with regard to influence of reinforcing particles on their properties.

The studies demonstrated that resistance properties of composite materials depend strongly on the amount of reinforcing particles. Increase of their participation in base material from 5÷25 vol. of SiC results in R_m and $R_{0,2}$ strength increase by about 10MPa per each additional 5% vol. The highest strength characterizes composites reinforced with 20÷25 vol. of SiC, reaching R_m strength of 425MPa at 25% vol. and 320MPa at 20% vol. of SiC. Content increase of ceramic particles over 30% vol. in these materials results in decrease of tensile strength to below 388MPa, characteristic for a non-reinforced alloy. At 45% vol. of SiC the produced composite material is characterized by about 350MPa strength, that is 13% lower than a non-reinforced AW-AlCu4Mg2Mn alloy.

Reduction of tensile strength at higher SiC contents should be explained by decrease of the active, stress transferring surface of base material alloy, worse connections at the boundaries of base material / SiC ceramic phase as well as overlapping of reinforcement zones c [2].

While analyzing the influence of SiC particle content on plasticity, a decrease of $R_{0,2}$ value is observed in composites containing over 25% vol. of ceramic particles, which might be explained by similar factors.

The produced composite materials are characterized by hardness reaching even about 235 HB (45% vol.), which should be considered as a very significant increase in comparison to base material of 110 HB hardness. The influence of heat treatment is most distinctly visible in case of materials subject to ageing at the temperature of 300°C for 6 hours. In this case, composites containing 45% vol. of SiC particles are characterized by hardness of 185 HB, that is 50 HB units lower than in case of material not subject to ageing.

Addition of silicon carbide particles to AW-AlCu4Mg2Mn alloy results in the increase of abrasive wear resistance of the material. In case of composite materials containing only 5% vol. of SiC, abrasive wear resistance is about tenfold lower than of a non-reinforced base material alloy. Further increase of SiC particle content results in a successive increase of this resistance and in case of material containing 45% vol. of this addition, the sample mass loss is about 400 times lower than of a non-reinforced material. Studies of abrasive wear resistance kinetics demonstrated that, regardless of silicon carbide volume in the composite material, its abrasive wear is most intensive during the initial stage, decreasing only after a certain time, and it is then approximately proportional to friction path.

The obtained research results confirm that proper selection of ceramic particles might help to produce composite materials of high functional properties, such as hardness and abrasive wear resistance, which makes them especially predisposed for many practical applications.

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