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Thermal analysis of matrix composite reinforced with Al_2O_3 particles

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ABSTRACT

Purpose: The aim of this paper is to present a modern manufacturing method of production and compare the thermal, mechanical, properties of composite materials with aluminium alloy matrix reinforced by Al_2O_3 particles.

Design/methodology/approach: The material for investigation was manufactured by the method of powder metallurgy (consolidation, pressing, hot concurrent extrusion of powder mixtures of aluminium EN AW-AlCu4Mg1 (A) and ceramic particles Al_2O_3). The amount of the added powder was in the range of 5 mass.%, 10 mass.% and 15 mass.%.

Findings: The received results concerning the enhancement of hardness, which show the possibility of obtaining the MMC composite materials with required microstructure, influencing the properties of the new elaborated composite materials components. Concerning the thermal properties, especially the linear thermal expansion coefficient was measured, as well as the dilatometric change of the sample length was analysed.

Practical implications: Concerning practical implications it can be stated that the tested composite materials can be applied among others in the transportation industry, but it requires additional research.

Originality/value: The received results show the possibility of obtaining new composite materials with controlled and required microstructure with possible practical implications.

Keywords: Matrix composite, Differential Scanning Calorimetry, Plastometric tests, Abrasion resistance

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PROPERTIES

1. Introduction

The physical, mechanical and machining properties as well as attractive thermal and electrical characteristics that can be obtained with metal matrix composites have made them attractive candidate materials for a large variety of applications in various engineering areas (in the aircraft industry, automotive-, and armaments ones, as well as in electrical engineering and electronics, etc.). These materials MMC have been endless of applications because of their behaviour, compared to other conventional monolithic materials since it has demonstrated less density and significantly higher resistance. A wide array of metals, especially low-density metals or alloys, are generally selected as the matrix material for the composite. MMC with a wide range of matrix materials (including aluminium, copper, nickel, etc.) and second-phase particles (including borides, carbides, nitrides, oxides and their mixtures) have been produced. More recently, ceramics particulate reinforced MMC that have many benefits have attracted considerable attention because of their characteristic isotropic properties and relatively low costs. Reinforcement in the metal matrix composite can be in the shape of particles, dispersoids or fibres [1-6].

Aluminium matrix composites reinforced with ceramic particles (Ti(C,N), Al_2O_3, SiC) are gradually being implemented into production in electronic, military, aero-space, automotive or aircraft industries, first and foremost due to high resistance to friction wear [1,4,5, 7-9, 10].

Powder metallurgy (PM) is thought to be the most common production technique for MMC's. One of the advantages of PM compared to casting is having better control on the microstructure, where the better distribution of the reinforcement is possible in PM compacts. An important advantage of this method is its low processing temperature compared to melting techniques. Therefore, the interaction between the matrix and the reinforcement phases is prevented. On the other hand, good distribution of the reinforcing particles can be achieved [4, 11-15].

The factor determining the mechanical properties of composite materials produced is the structure of the interfacial composite. A significant group of phase separation boundaries are the boundaries that are formed between the metal material and ceramic material [11,12,14,16].

2. Experimental procedure

The investigations were made of the metal matrix composites obtained with the powder metallurgy methods and by hot extrusion of the EN AW-AlCu4Mg1(A) aluminum alloy (0.20% Si, 0.30% Fe, 3.8-4.9% Cu, 0.30-0.9% Mn, 1.2-1.8% Mg, 0.10% Cr, 0.25% Zn, 0.15% Ti, Al rest) reinforced with the Al_2O_3 phases ceramics particles with the mass portions of 5, 10, and 15%. The size of the matrix material powder particles is smaller than 75 µm, of the reinforcement powder is smaller than 0.5 µm.

In the laboratory, vibratory ball mill starting materials were wet mixed to obtain in the matrix the uniform distribution of the reinforcement particles. Next, mixed powders were dried in the air. The components compacted at cold state in a die with the diameter of ∅ 26 mm in the laboratory vertical unidirectional press–with a capacity of 350 kN [7,11].

The obtained PM compacts were heated to a temperature of 480-500°C and finally extruded – with the extrusion pressure of 500 kN. Bars with a diameter of 8 mm were obtained as the end product.

Obtained composite materials, at the temperature of 495°C, were hyperquenched for 0.5h with the subsequent water cooling, and next were quench aged for 6 h at 200°C. Such prepared samples were etched in 5% HF.

Hardness tests of the fabricated composite materials were made on HAUSER hardness tester with the Vickers method at 10 N load, according to the Polish Standard PN-EN ISO 6507-1 [17]. Hardness measurements were made on the transverse section diameter for specimens, both for the fabricated composite materials reinforced with the ceramics particles and for the EN AW-Al Cu4Mg1(A) aluminium alloy, to determine their average hardness.

The device designed at the Faculty of Mechanical Engineering of the Silesian University of Technology was used for the abrasion resistance wear tests. To obtain four flat and even surfaces 30 mm long test pieces were ground with the 1200 grit abrasive papers. Tests were carried out on prepared surfaces, using as the counter-specimens: the steel balls with 8.7 mm diameter, at various loads: 4, 5, 6, 7, and 8 N and with the constant number of cycles of 5000 (120 m). To clean test pieces, they were rinsed in the ultrasonic washer and next to check the mass loss they were weighed with the accuracy of 0.0001 g using the analytical balance [7,18,19].

Differential scanning calorimetry (DSC) measurements was performed using DSC 822e apparatus (Mettler-Toledo, Switzerland). Two calorimetric traces were taken for each sample at heating and cooling rates of 5°C/min. Samples of approximately 47±1 mg were introduced into crimped aluminium pans. The first calorimetric trace (first heating run) was taken from 0°C to 600°C. All experiments were performed under a nitrogen atmosphere (flow= 60 ml/min).

3. Results and discussion

Hardness tests of the fabricated PM composite materials revealed its diversification depending on the weight ratios of the ceramics particles Al_2O_3 (5, 10 and 15%) in the aluminium matrix.

Mean hardness values of the aluminium alloy EN AW-AlCu4Mg1(A) and metals matrix composites MMC shown in Table 1.

Table 1.
The hardness of the matrix from the EN AW-Al Cu4Mg1(A) aluminium alloy and composite materials (A-before the heat treatment, B-after the heat treatment)

Material	Hardness HV1	
	A	B
EN AW-Al Cu4Mg1(A)	89.3	97.7
EN AW-Al Cu4Mg1(A)/5% Al_2O_3	91.9	99.3
EN AW-Al Cu4Mg1(A)/10% Al_2O_3	106.6	110
EN AW-Al Cu4Mg1(A)/15% Al_2O_3	123.3	130

Wear of the investigated aluminium metals matrix composites versus load change at the constant distance has a linear character. The composite materials' mass loss after the wear tests may be affected by many factors: hardness of the made composite materials, dimensions and shape of the Al_2O_3 particles, and also values of load between the counter-specimen and the test piece [11,19].

Reinforcement of the soft aluminium matrix by hard Al_2O_3 particles influence of the hardness growth the wear resistance of composite materials.

The hardness of the fabricated PM composite materials grows along with the increasing portion of the reinforcing material in the EN AW- Al Cu4Mg1(A) aluminium metal matrix. Additional hardness increase of the investigated metal matrix composites was caused by precipitation hardening.

Addition of the reinforcing particles Al_2O_3 in the soft matrix from the aluminium alloy causes also increase of the abrasion wear resistance. The wear rate is proportional to the applied load and inversely proportional to the contents of the reinforcing particle. The precipitation hardening process caused wear resistance growth of the fabricated material (Fig. 1) [7].

Reinforcement of the soft aluminium matrix by hard Al_2O_3 particles influence of the linear thermal expansion coefficient decreasing with reinforcement amount growth (Fig. 2).

The hard Al_2O_3 particles as reinforcement of soft matrix from the aluminium alloy causes changes in length under heating. Change in length of composite materials was reduced with the increasing portion of the reinforcing material in the metal matrix. The most noticeable reduction of change in length is observed between 5% and 10% of Al_2O_3 particles. 10% of used reinforcement reduced the extension of the tested composites in consequence of reduced mobility of soft matrix. Hard reinforcement blocks the linear expansion of composites. This behaviour is caused that under heating composites with the Al_2O_3 particles, in matrix function compressive stress. From the other side, used reinforcement also causes additional hardness increase of the investigated materials.

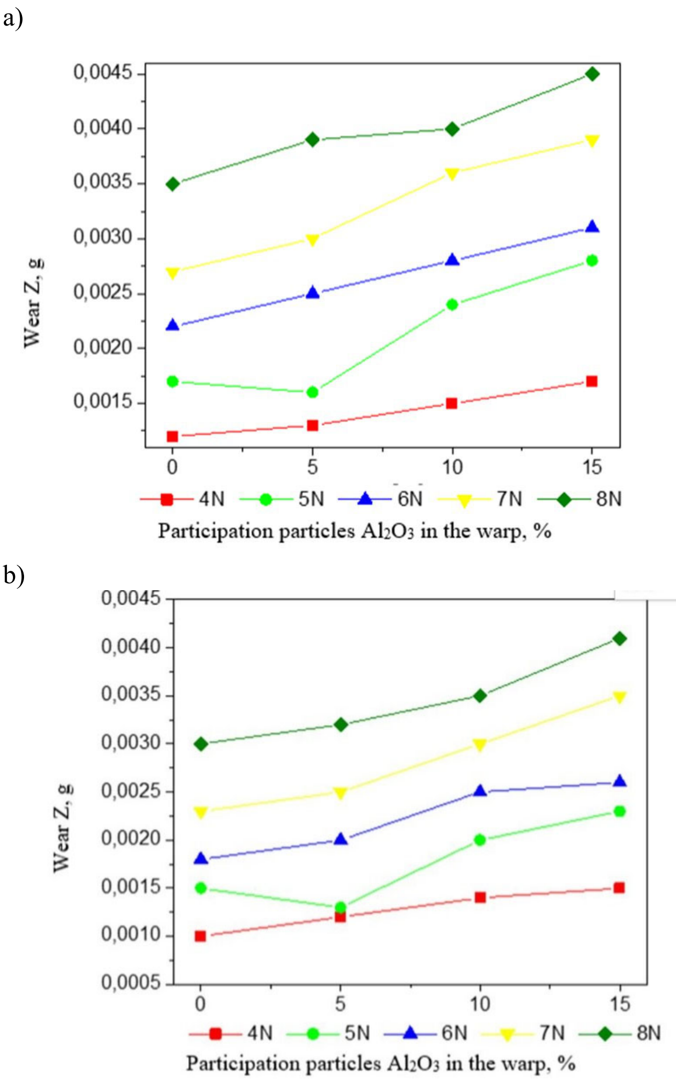

Fig. 1. Wear of the aluminium alloy and composite materials in the following states: a) before the heat treatment, b) in the precipitation hardened state, at various load values, N

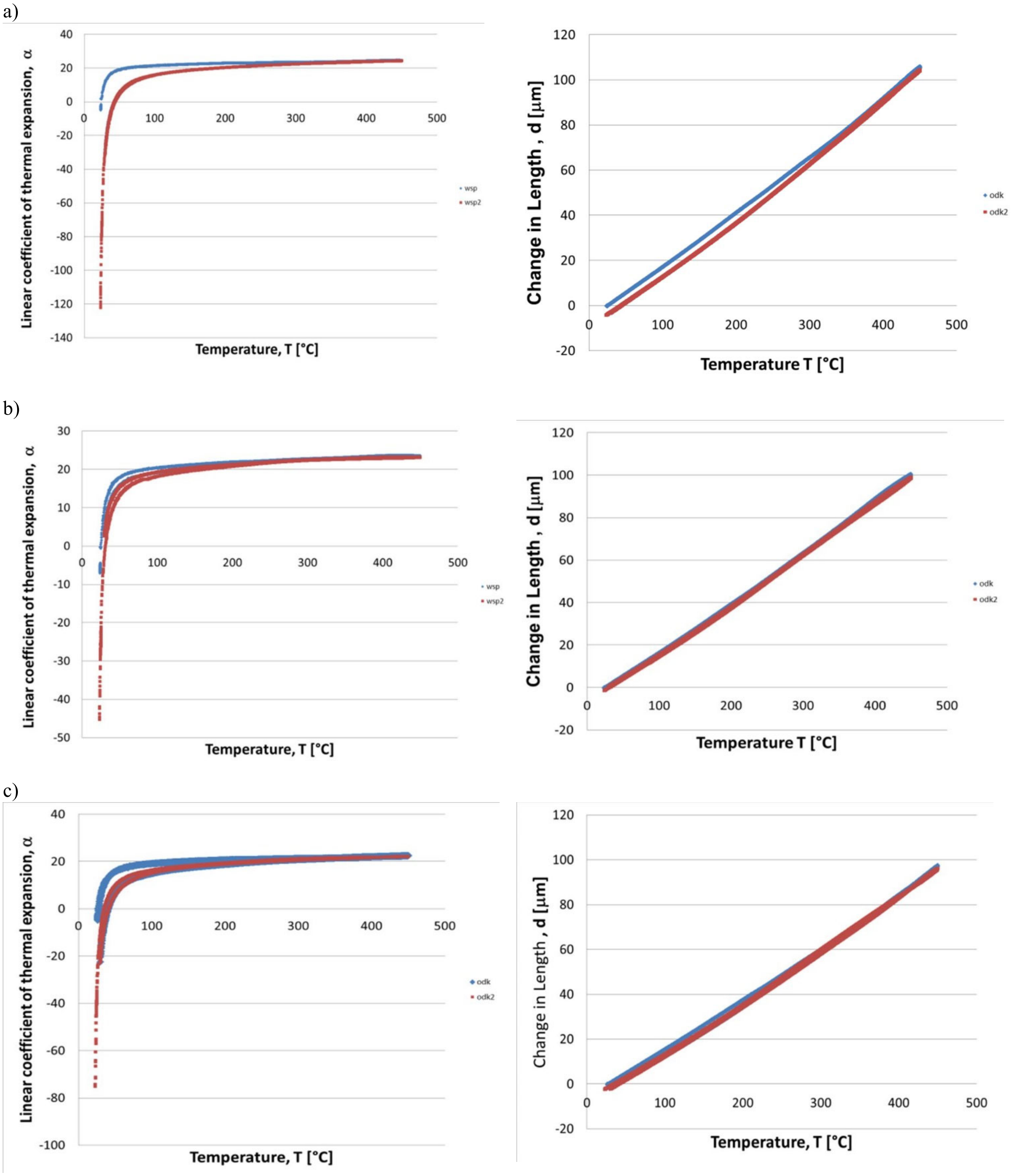

Fig. 2. Influence of the linear thermal expansion coefficient decreasing EN AW-Al Cu4Mg1(A): a) 5% Al_2O_3, b) 10% Al_2O_3, c) 15% Al_2O_3

Addition of the Al_2O_3 reinforcing particles in the soft matrix from the aluminium alloy also not causes irregularity under changes global stability of described properties, i.e. hardness, abrasion wear resistance. Changes in mentioned properties are consistent with reinforcing particles amount in composites.

Obtained composites were also examined by differential scanning calorimetry (DSC) method. The tests were performed with heating and cooling rate of 5°C min^{-1}. The differences between tested composites, introducing the hard Al_2O_3 particles, were lead on curves from heating and cooling run.

At DSC traces from I^{st} heating run the endothermic peaks are observed (Fig. 3). The first peak value at 215°C, 214°C and 218°C for composites with 5%, 10% and 15% Al_2O_3 respectively was determined. The endothermic peak for Al_2O_3 powders is connected with vaporisation of physically bound absorbed water. In some cases, under stoichiometric

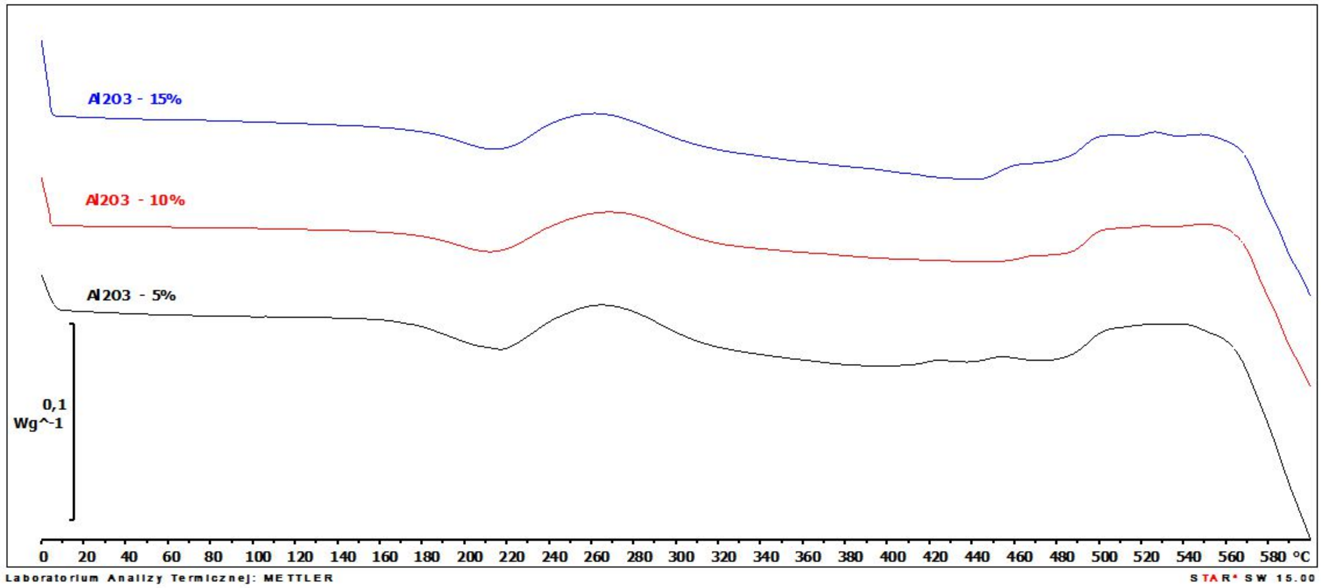

Fig. 3. DSC traces of EN AW-Al Cu4Mg1(A) + Al_2O_3 composites form I^{st} heating run

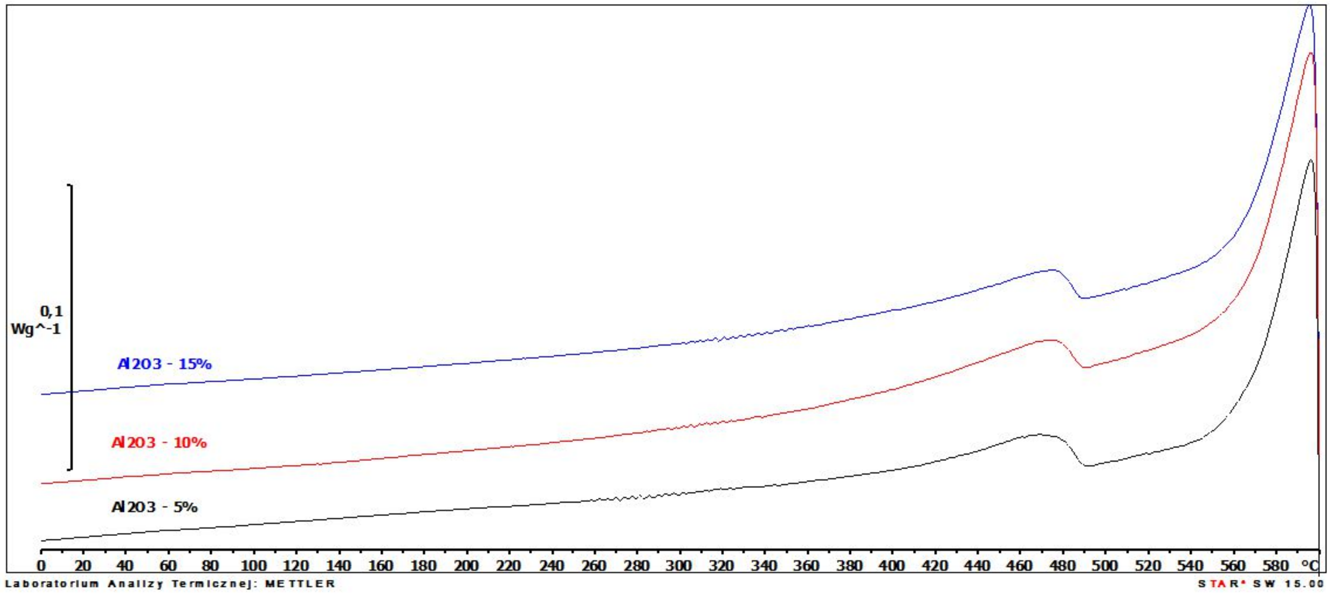

Fig. 4. DSC traces of EN AW-Al Cu4Mg1(A) + Al_2O_3 composites form cooling run

conditions, the combustion temperature remains approximately 260°C with an increase of γ phase of Al_2O_3 powders. Al-Cu-Mg alloy showed peaks of endothermic transition at 437°C, 432°C and 436°C and also at 472°C, 473°C and 482°C for composites with 5%, 10% and 15% Al_2O_3.

Changes under determined thermal properties from I^st^ heating run are in interrelation with linear thermal expansion coefficient where is observed changes in length with temperature growth.

The slice differences are observable under cooling run (Fig. 4) when the amount of order fraction crystallise. There is a slight difference at onset temperature form 492°C, 490°C to 488°C for 5%, 10% and 15% of Al_2O_3 correspondingly. There is also a negligible change in crystallisation peak maximum value 469°C, 472°C to 471°C for 5%, 10% and 15% of Al_2O_3 adequately. The enthalpy of exothermic transition was a similar value. The amount of Al_2O_3 particles was with no effect on determined enthalpy values.

4. Conclusions

Introducing the hard Al_2O_3 particles into the soft matrix from the EN AW- Al Cu4Mg1(A) aluminium alloy causes hardness increase of the fabricated matrix composites. Increasing the proportion of reinforcing material in the metal matrix results in a simultaneous increase in the HV1 hardness of the tested composite materials. Additional hardness increase of the investigated of the fabricated materials is caused by precipitation hardening.

Addition of the particles in the matrix from the aluminium alloy causes also increase of the abrasion wear resistance. The precipitation hardening process caused wear resistance growth of the fabricated MMC.

Addition of Al_2O_3 particles has influences on thermal properties of composites. Linear thermal expansion coefficient decreasing with reinforcement amount growth. Also the values of determined characteristic transition are negligible change, nevertheless, the influence of Al_2O_3 particles of thermal properties are observed.

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