

# Bending Strength of Composite Materials with EN AC-44200 Matrix Reinforced with $Al_2O_3$ Particles

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## Abstract

There are presented results of a research on bending strength of aluminum alloy EN AC-44200 based composite materials reinforced with aluminum oxide particles. The composite materials were manufactured by squeeze casting with the liquid EN AC-44200 Al alloy of porous ceramic preforms under pressure of 100 MPa. For reinforcing of the EN AC-44200 matrix alloy, preforms made of  $Al_2O_3$  particles with porosity 60, 70, 80 and 90% were applied. In relation to unreinforced EN AC-44200 base Al alloy, bending strength of composite materials increased about 10% per each 10 vol.% increase of  $Al_2O_3$  particles in the matrix. The highest bending strength of over 400 MPa was reached by the materials reinforced with 30 and 40 vol.% of  $Al_2O_3$  particles. Microscopic observations of fracture surfaces confirm that the particles intensively restrict plastic deformation of the alloy, which contributes to creation of a typically brittle fracture. The particles present on the crack propagation path inhibit development of microcracks initiated during bend tests. Most often, the fracture runs through interfacial matrix-particle boundaries, which is caused by brittle bridges of silica binder, present on these boundaries.

**Keywords:** Composite materials, Aluminium oxide particles, Bending strength

## 1. Introduction

Metal Matrix Composites (MMC) with aluminum matrices are commonly used in automotive and aircraft industries, as materials with satisfactory specific strength understood as the ratio of their mechanical properties to specific gravity. Usually, these materials are characterised by good mechanical properties, high stiffness and good abrasion resistance with reasonable manufacturing costs [1-4]. Among many casting technologies, the squeeze casting method makes possible to manufacture composite castings locally reinforced in the areas of high stresses concentration. Composite castings as pressure castings show

limited porosity and fine-grained structure. In this method, an reinforcing element can be a porous preform made of ceramic fibers or particles [6-9].

It is relatively often that composite elements work in the conditions of complex stresses and they are often subjected to bending stresses. For this reason, behaviour of these materials during three-point bend testing was analysed within this research. Due to a significant volume content of reinforcing particles, the examined composite materials are characterized by high hardness and stiffness, and thus by low ability for plastic deformations [3, 10]. So, there is a interest to determine, how the reinforcing particles affect deformation process of a composite material and to know the reached values of the maximum bending stresses.

## 2. Experimental methods

The materials for investigations were prepared by squeeze casting of preforms with open porosity [1, 5-9]. The preforms were made of a mixture of Al<sub>2</sub>O<sub>3</sub> particles, porophor and aqueous solution of a silica binder. The mixture was placed in a mould and subjected to pressing and further heating in order to get the assumed porosity of the preforms. Next, the preforms were thermally stabilized by firing at the temperature of 960 °C [5-7]. Specification of the applied ceramic particles is given in Table 1.

The composite castings were based on the EN AC-44200 Al alloy, typically used in heavily loaded machine parts and devices. Chemical composition of the alloy is given in Table 2. The castings were manufactured under squeeze pressure of 100 MPa.

Table 1.  
Specification of Al<sub>2</sub>O<sub>3</sub> particles

Composition [wt.%]	Diameter [μm]	Density [g/cm <sup>3</sup> ]
Al <sub>2</sub> O <sub>3</sub> content: 99.7%	3 to 6	3.95
Residue: Na <sub>2</sub> O, SiO <sub>2</sub> , Fe <sub>2</sub> O <sub>3</sub> , CaO, TiO <sub>2</sub> , K <sub>2</sub> O		

Table 2.  
Chemical composition of base material EN AC-44200

Weight fraction [%]	Si	Fe	Cu	Mn	Zn	Ti
EN AC-44200	10.5-13.0	0.55	0.05	0.35	0.10	0.15
Al – remainder						



Fig. 1. Microstructure of composite material EN AC-44200 containing 20 vol.% of Al<sub>2</sub>O<sub>3</sub> particles

An exemplary microstructure of the composite material containing 20 vol.% of Al<sub>2</sub>O<sub>3</sub> particles is shown in Fig. 1.

Bending tests were carried-out at 20 °C applying the testing machine Tinius Olsen H25KT. The test samples were prepared as cuboids of 60 × 10 × 4 mm. There were tested samples from the

composite materials containing 10, 20, 30 and 40 vol.% of reinforcing particles. For comparative reasons, the tests were also carried-out applying the unreinforced reference materials.

## 3. Results and discussion

### 3.1. Bending strength

The examinations showed a dependence of the bending strength  $R_b$  on volume fraction of Al<sub>2</sub>O<sub>3</sub> particles reinforcing the composite materials similar as in [8]. Figure 2 shows the relationship between fraction of the reinforcing phase in the composite material bending and strength.

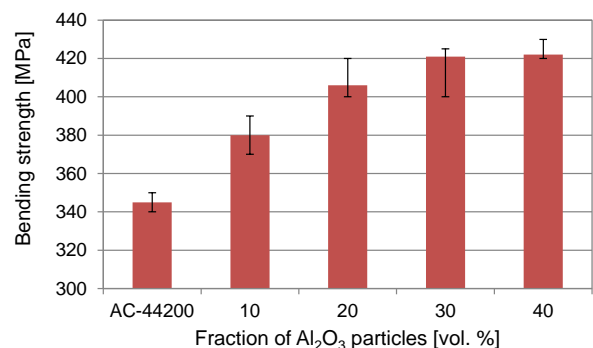


Fig. 2. Bending strength of composite materials based on EN AC-44200 alloy reinforced with ceramic Al<sub>2</sub>O<sub>3</sub> particles

The lowest  $R_b$  value of ca. 345 MPa was shown by the specimens made of the reference material, unreinforced squeeze-cast AC-44200 alloy. Bending strength of the samples containing 10 vol.% of Al<sub>2</sub>O<sub>3</sub> particles is ca. 30 MPa higher in comparison to the unreinforced alloy. A further 30 MPa increase of  $R_b$  value is observed for the composite containing 20 vol.% of the particles. The highest  $R_b$  value of 425 MPa is shown by the specimens containing 40 vol.% of the reinforcing particles.

### 3.2. Microstructure

Scanning electron microscope examinations of fracture surfaces and of microstructure under the surfaces of the fracture were carried-out in order to analyse creation and development of cracks during static bend testing. Observations of fracture surfaces of unreinforced EN AC-44200 alloy showed that cracks most often develop by tearing and separating alpha phase from Si crystallites. Si crystallites, often with sharp edges, act as notches, see Fig. 3a.

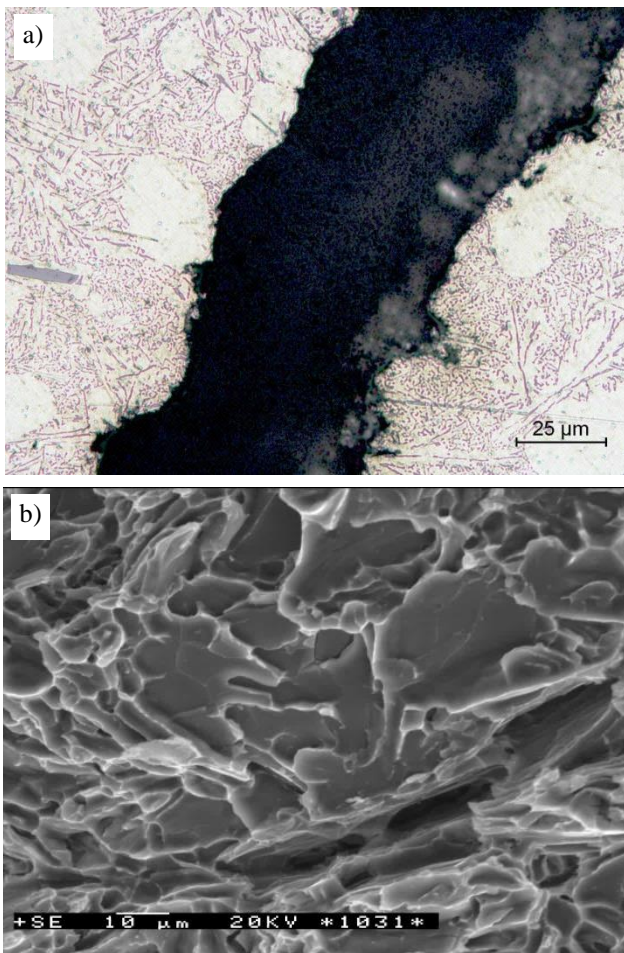


Fig. 3. Microstructure of AC-44200 alloy after bend test: a) crack, b) fracture surface

Microscopic examinations of fracture surfaces most often showed scaly areas left by Si crystallites, as well as sparse elongated, jagged structures of destroyed dendrites, see Fig. 3b.

On the other hand, in the composite materials reinforced with ceramic preforms, fractures are of brittle nature [6, 8, 11]. Cracks propagate most often through interface boundaries between matrix alloy ceramic particles. In the areas with larger volume of the matrix and smaller content of reinforcing particles cracks propagate most often through boundaries of these areas, see Fig. 4a and 4b.

Observations performed in vicinity of the main crack showed deformations of matrix material and sparse small microcracks. In particular, these deformations are visible in the specimens with 10 vol.% and 20 vol.% of  $Al_2O_3$  particles, bringing sometimes to breaking and fragmentation of reinforcing particles, see Fig. 4b. Privileged places of crack propagation become also agglomerates of  $Al_2O_3$  particles, occurring more often in the composite materials with 30 and 40 vol.% of the strengthening particles. Observations in these agglomerates confirm also more frequently occurring residual porosity and tearing-off the particles from metallic matrix.

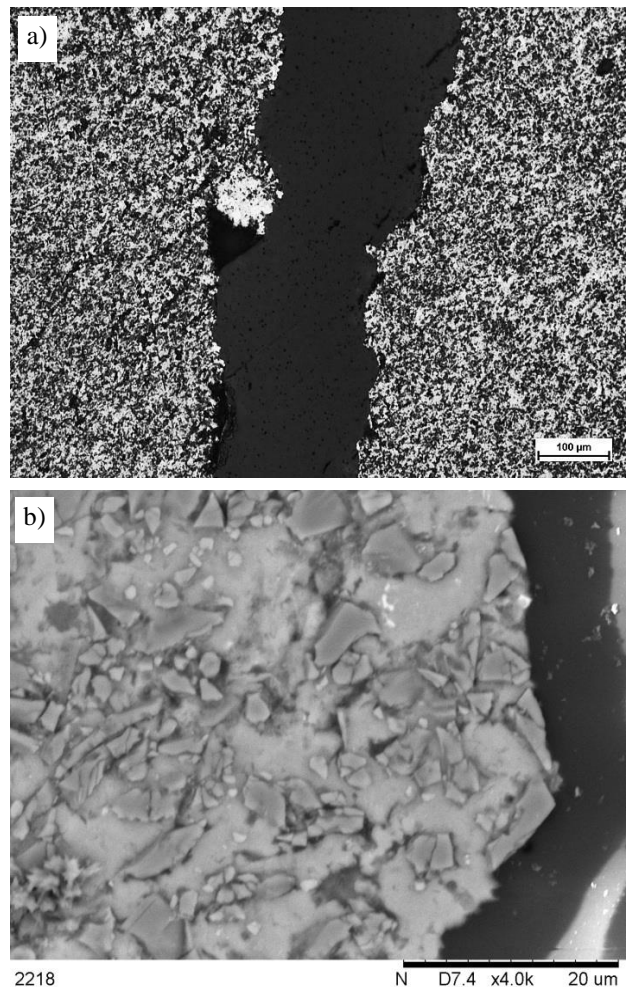


Fig. 4. Microstructure of composite material containing 20 vol.% of  $Al_2O_3$  particles after test: a) crack, b) vicinity of cracks

Taking into account the specific process of ceramic preforms manufacturing based on joining of alumina particles with sodium water-glass according to the reaction (1), in the vicinity of ceramic particles the higher sodium and silicon content is observed (spectrum1):

$Na_2O \cdot nSiO_2 + mH_2O + CO_2 \rightarrow nSiO_2 \cdot pH_2O + Na_2CO_3 \cdot gH_2O + (m-p-g)$   
 During hardening of sodium water glass with the carbon dioxide the hydrated sodium carbonate ( $Na_2CO_3 \cdot gH_2O$ ) and silica are formed, which further can be decomposed thus forming of alumina  $Al_2O_3$  and increasing the vicinity regions in silicon. This is the explanation for the increased content of Si (about 17%) and oxygen (about 10%) in the vicinity of ceramic particles (Fig.5).

Spectrum 1

Element	Weight%	Atomic%
Al K	71.30	66.85
O K	9.56	15.76
Si K	18.45	16.64
Na K	0.69	0.75
Totals	100.00	

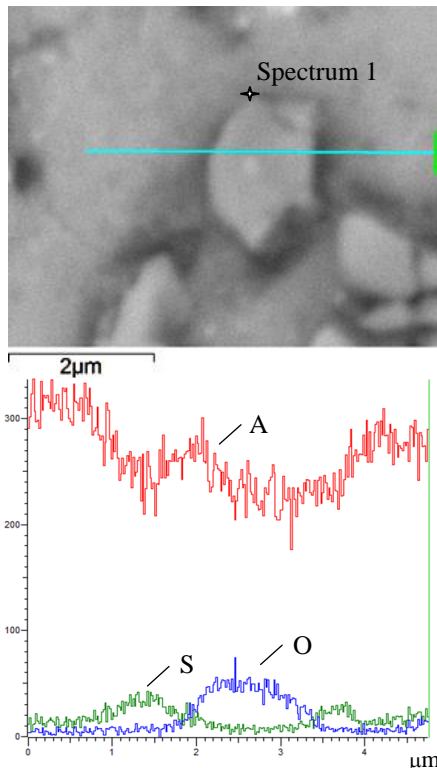


Fig. 5. Microstructure and EDS analysis of composite material containing 10 vol.% of  $\text{Al}_2\text{O}_3$  particles

## 4. Summary and conclusions

1. Increased volume content of ceramic  $\text{Al}_2\text{O}_3$  particles in EN AC-44200 matrix alloy effects on the strengthening of the matrix and results in higher bending strength of composite material. Introduction of 10 vol.% and 20 vol.% of the ceramic alumina particles increases the bending strength value, in average, by 30 MPa per each 10 vol.% of reinforcing ceramic particles. The materials containing 30 and 40 vol.% of  $\text{Al}_2\text{O}_3$  particles are characterized by the highest bending strengths of 410 to 420 MPa.
2. The fractures of composite materials reinforced with  $\text{Al}_2\text{O}_3$  particles investigated in the bending tests show the typical brittle character.
3. In the composite materials the main cracks propagate through the interface between matrix and the ceramic particles surface and sometimes cause the partition of ceramic particles.
4. In the vicinity of the main crack, the matrix material is slightly deformed, which contributes to tearing-off the

strengthening particles from the matrix and also to their breaking (fragmentation) and displacement.

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