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SOME NEW DIRECTIONS IN ALUMINUM-BASED PM MATERIALS FOR AUTOMOTIVE APPLICATIONS

NEKATERE NOVE SMERI PRI ALUMINIJEVIH ZLITINAH PM ZA AVTOMOBILSKO INDUSTRIJO

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The growth of aluminum PM structural parts in the automotive market is creating opportunities for lightweight alloys in cost-effective applications. The successful implementation of the aluminum-based PM approach, using conventional processes like the press-sinter-repress process, makes it possible to develop a number of potentially high-impact commercial opportunities in the automotive industry. This paper highlights some new developments in PM materials that can influence the more widespread use of PM parts, up to now, restricted by the cost of producing the final components.

Key words: metal-matrix composite, powder metallurgy route, reinforcement

Rast porabe PM-aluminijevih izdelkov na avtomobilskem trgu ustvarja možnosti za racionalno uporabo lahkih zlitin. Uspešna uveljavitev aluminijevih PM-zlitin, izdelanih npr. po postopku stiskanja - sintranja - ponovnega sintranja omogoča razvoj in pomembno uporabo v avtomobilski industriji. V tem članku je predstavljen razvoj PM-zlitin, ki bi lahko razširil uporabo PM-delov v primerih, ko je bila uporaba omejena zaradi previsoke cene.

Ključne besede: kovinski kompoziti, metalurgija prahu, ojačitev

1 INTRODUCTION

One of the attractions of powder metallurgy (PM), as a fabrication approach, lies in its potential to fabricate precise, low-cost parts, which are applied in specific areas where the net-shaping capabilities can be combined with good properties. However, the applications of aluminum PM parts application are limited because of their inadequate elastic modulus, wear resistance or elevated temperature properties. These are the reasons why there is a need for some alternatives to conventional aluminum alloys.

This paper will highlight some other advanced processing options that might, or already have found, applications in the automotive industry.

From among the various possibilities, two topics will be addressed. In both of them the aim is to lower the cost of the products to the levels required for automotive use.

The first of the topics is the possibility of creating alloys with higher performance by using prealloyed aluminum powders. The second is the possibility of processing aluminum-based composite materials, together with ways of identifying their improvements in properties.

2 POWDER PREALLOYING AND SLURRY PRODUCTION

The simplest example of prealloying in (PM) is the conventional *press and sinter* approach in which metal powders are mixed with powders of alloying elements and subsequently liquid-phase sintered to produce an alloy. The main improvement in properties derives from the ability to incorporate alloying elements at higher levels than would be possible in conventional processes. This is mainly because of the rapid solidification process that results in the extended solubility of some alloying elements in aluminum-based alloys. Rapid solidification increases the solubility of Si, Fe, Mn etc.

One powder- mixing approach is the unconventional method of producing a globular metallic slurry, which is very different from the conventional idea of introducing mechanical shear stresses during solidification, usually by means of some form of rotary motion[1]. A method has been developed for fabricating of metallic slurries based on the premixing and compaction of different powders. In recent reports the technique has been termed *Consolidation of powders as synthetic slurry (COMPAS)*[1]. After premixing the powders (the basic powder and the alloying powder), the material is heated to below the melting point of powder of higher melting point and then compacted under pressure to eliminate the porosity. The powder with the lower melting point melts, so the surface-tension forces drive the liquid to fill much of the space among the globules of solid material. The melting of the solute-rich material is rapidly followed by surface liquation of the remaining globules where there is a contact with the liquid. There is complete freedom to specify the size and the volume fraction of the globules and the composition of the globular and surrounding materials.

One of the most promising areas of application for this method is in pressure die-casting[2]. In this process the charge is injected at high velocity to inhibit premature solidification, forcing this material to enter the die in a turbulent manner and causing internal porosity. Replacing the liquid charge with a semi-solid slurry can result in the controlled filling of the die with reduced thermal shock[1]. One of the areas that offers such an opportunity is the Al-Si-X hypereutectic system which has good wear resistance, thermostability and castability; the properties depend on the percentage of silicon. Automotive interest in the application of wear-resistant Al-Si alloys that have improved properties over conventional cast alloys is great[3].

The alloys with an average silicon content ranging from 10 wt.% - 17 wt.%, which are obtained by conventional casting methods, have coarse primary silicon crystals, growing during solidification. On the other hand, a higher silicon content increases the wear resistance and the thermostability. The semi-solid slurry method offers the possibility to choose the volume fraction and the size of the silicon particles, because it is the silicon particles that remain in solution as a solid. This "refinement" possibility of the silicon particles gives improved properties such as workability, wear resistance and thermal expansion coefficient. Specimens obtained by the semi-solid slurry method present some microstructural changes typical of the rapid solidification processes[4]: the primary silicon crystals are homogeneously dispersed and have a smaller size (**Figure 1**).

Many of the alloying elements that are slowly diffusing into the aluminum matrix are retained in solid solution or precipitated on a fine scale as intermetallic phases during rapid solidification.

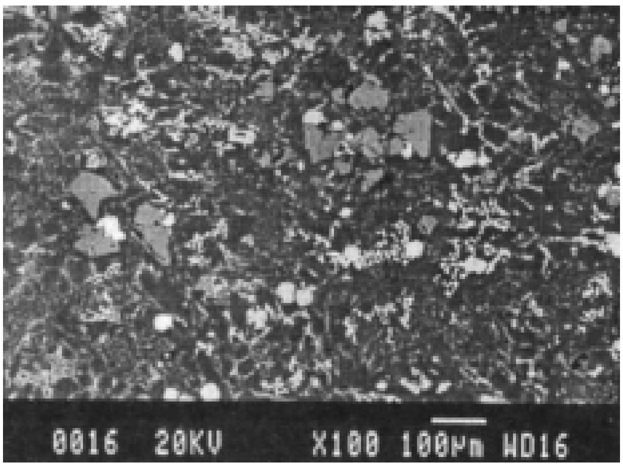

Figure 1: Homogeneously dispersed primary silicon crystals in powdered Al-Si-X alloy
Slika 1: Homogeno dispergirana primarna zrna silicija v PM-zlitini Al-Si-X

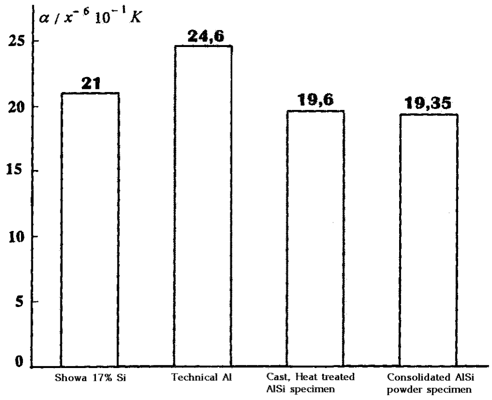

Figure 2: Some CTE values in temperature interval of 20-300 °C
Slika 2: Nekatere CTE-vrednosti v razponu temperature od 20 do 300 °C

The dispersed phases produce dispersion strengthening in the alloy and adequate mechanical properties.

The thermal expansion coefficient (CTE) for the same alloy produced in the previously described manner reaches values that are 30% lower than the corresponding values for technical aluminum (**Figure 2**).

There are many applications, especially engine-related, where a lightweight material with sufficient strength retention at higher operating temperatures could be very beneficial.

3 ALUMINUM-BASED METAL-MATRIX COMPOSITES

Metal-matrix composites (MMCs) are now recognized as important structural materials. The incorporation of anisotropic ceramic, carbon, boron or metal particles as fibres or whiskers into metal matrices can enhance the elastic modulus, the yield stress and the rate of work-hardening.

The discontinuous reinforcement of light weight aluminum alloys with short fibres, platelets or particles of ceramic, such as alumina or silicon carbide results in composites with a high specific strength and stiffness, which are suitable for advanced engineering applications in the automotive industry. There are several routes by which the reinforcement may be introduced into the matrix, so the composite properties will depend on the production method, the type and the quantity of ceramic[5,6].

Discontinuously reinforced composites are considered low-cost materials and have applications in those areas where the best properties may not be required and where their presence could be cost effective. For example, cost-weight-stiffness components, such as engine static structures[7] do not require the level of properties available with continuously (fibers) reinforced composites.

Table 1: Mechanical compressive characteristics of Al-Si-X alloy
Tabela 1: Tlačne mehanske lastnosti zlitin Al-Si-X

Compressive yield stress MPa	302.92
Compressive strength, MPa	627.90
Reduction (%)	23.25

The fabrication process for a low-cost reinforcement-low-cost composite usually includes direct- casting and hot-moulding processes[8], as well as spray casting and squeeze casting[9]. A PM route[10,11,12] offers good flexibility in terms of alloy chemistry, particle type, size and volume fraction. Producing the composites with a molten metal mixing process was until now, more common than the PM processes because of the lower cost. But the products obtained with the metal mixing process do not show the same degree of improvement as those produced with PM processing.

Key factors in producing a uniform distribution of reinforcement in the aluminum matrix relate to the relative particle size of the reinforcement and the matrix alloy powders and the control of specific aspects of the blending process[13].

Extensive reviews of the deformation mechanisms that occur during the incorporation of fibres, particles or whiskers into the metal matrix have been presented in literature. The studies cover the use of short fibres, preform infiltration, extrusion, squeeze casting and spray casting[6,14,15,16].

The use of an alternative technique, the so-called "coated reinforcement method"[11,17], has been used to make copper-matrix, silver-matrix as well as aluminum-matrix composites. Classical methods of conventional PM that use reinforcement and metal-matrix powder have been restricted to a low filler contact with an increasing reinforcement volume fraction. Excessive reinforcement-reinforcement contacts during the sintering processes lead to a composite with inferior properties due to ineffective reinforcement-reinforcement sintering at the relatively low processing temperatures. It was found that the composites with aluminum-film-coated SiC particles as the reinforcement, were superior (compressive strength, hardness, electrical conductivity) to the corresponding composites made with a noncoated reinforcement, processed with a simple admixture method. Composites were prepared by mixing Al-Si alloy powder with aluminum-coated SiC particles which were then cold pressed, semi-solid heated and hot pressed (**Table 1**). A scanning electron micrograph of a composite after hot pressing is shown in **figure 3a,b**. The dark parts with irregular shapes are the pores that are located among the SiC particles. During the pressure action the SiC

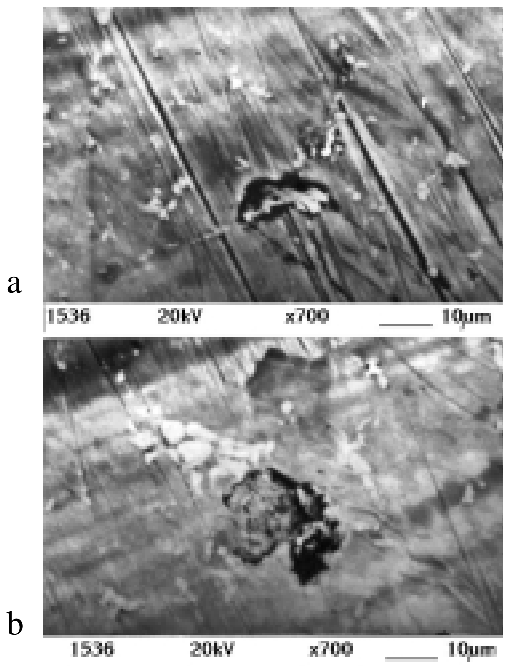

Figure 3: SEM of 15v/oSiC 2014 aluminum alloy matrix composite after hot pressing - a) coated reinforcement compact, b) noncoated reinforcement compact
Slika 3: SEM-posnetka 15v/o SiC-kompozita iz matične aluminijeve zlitine 2014 po vročem stiskanju: a) prekrita ojačitev, b) neprekrita ojačitev

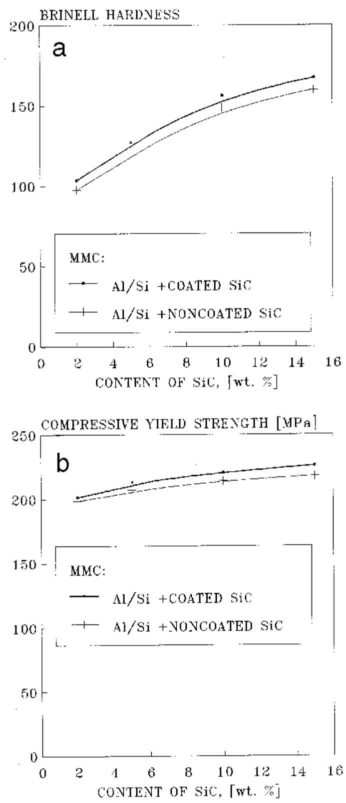

Figure 4: Influence of SiC content on hardness and compressive yield strength values for 2014 aluminum alloy matrix composite - a) Influence of SiC content on hardness, b) Influence of SiC content on compressive yield strength
Slika 4: Vpliv vsebnosti SiC na trdoto in tlačno mejo plastičnosti za kompozite z matico iz aluminijeve zlitine 2014 - a) vpliv SiC na trdoto, b) vpliv SiC na tlačno mejo plastičnosti

Table 2: Some properties of 2014 aluminum alloy matrix composites
Tabela 2: Nekatere lastnosti kompozitov z matico iz zlitine 2014

Composite	Al/SiC_p 2% wt. of SiC_p		Al/SiC_p 2% wt. of SiC_p		Al/SiC_p 2% wt. of SiC_p		Al/SiC_p 2% wt. of SiC_p	
Property	Admix	Coated	Admix	Coated	Admix	Coated	Admix	Coated
Porosity vol. %	0.18	0.18	0.21	0.20	0.27	0.22	0.42	0.37
El. Cond. MS/m	21.2	21.2	17.8	18.5	16.32	17.9	14.98	15.21

particles cracked easily. **Figure 3a** reveals the porosity around the aluminum-coated SiC particle. The porosity situation is more complex in the case of a noncoated filler (**Figure 3b**) obtained with a simple admixture method. In the former case the SiC particles peel off easily during the deformation process. This peeling of the particles is due to the weak interfacial bonding between the noncoated SiC particles and the matrix.

Coated reinforcement compacts show better properties than noncoated ones, especially in terms of porosity (**Table 2**), with various weight fractions of SiC particles; the hardness and the yield strength show the same tendency (**Figure 4**)

The coating process does not increase the composite price much, relative to the improvement in properties, because the process of reinforcement coating is relatively cheap when compared to its contribution.

The other type of PM processing of aluminum composites may require the combination of the aluminum alloy powder, either as a mixture of elemental and master alloy powders or in prealloyed form, with the reinforcement in a blending process. In one of the commercial processes[11] SiC particles of diameter 1-100um are blended together with argon-atomized 2014 aluminum alloy powder; this is followed by cold pressing and subsequent hot pressing at 200 °C. The preforms are sintered at 500 °C, then extruded at 455 °C with an extrusion ratio in the range 9:1-20:1. In order to obtain a stable structure and to avoid dynamic precipitation during hot workability tests, the T6 temper (solutionizing at 530 °C for 3 hours then aging for 24 hours at different temperatures) is used. The microhardness and electrical conductivity values of the composite solutionized and aged for 24 hours at 200, 300 and 380 °C are shown in **Figure 5**.

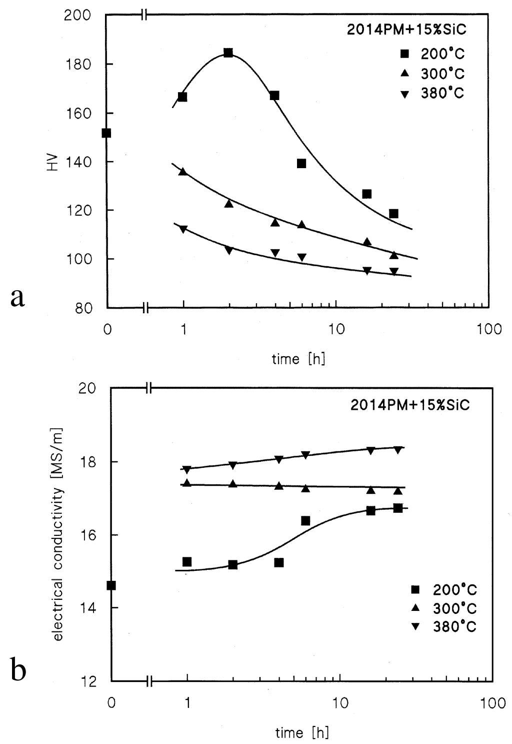

Figure 5: Microhardness (a) and electrical conductivity (b) value of the composite after T6 temper
Slika 5: Mikrotrdota (a) in električna prevodnost (b) kompozita po žarjenju T6

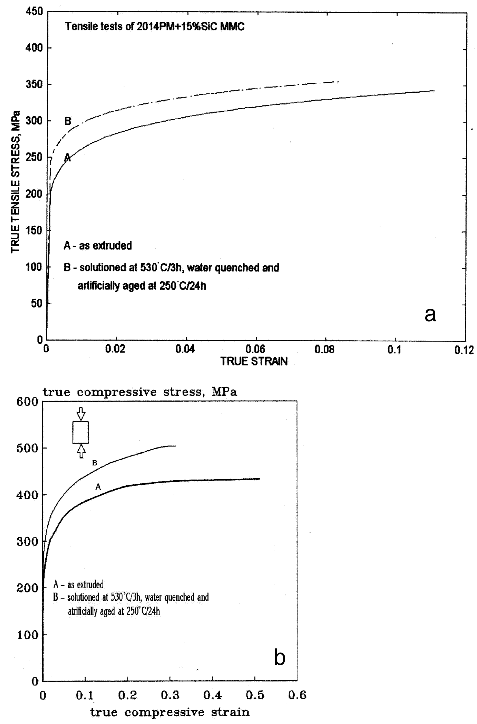

Figure 6: True stress-strain curve for a) tensile b) compressive test for heat treated and non treated 2014 aluminum alloy matrix composite
Slika 6: Prava odvisnost napetost-deformacija za a) raztržni in b) tlačni preizkus za toplotno obdelan in neobdelan kompozit z matično zlitino 2014

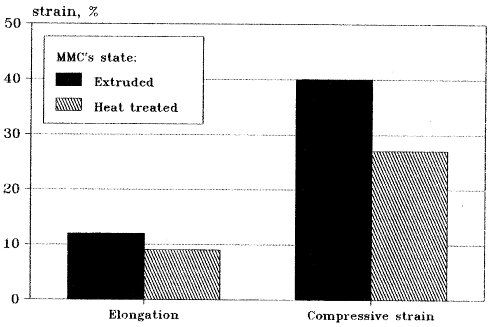

Figure 7: Mutual relation between elongation and reduction for heat treated and non treated 2014 aluminum alloy matrix composite
Slika 7: Odvisnost med raztezkom in redukcijo za toplotno obdelan in neobdelan kompozit z matično zlitino 2014

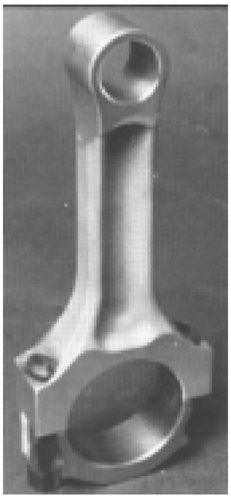

Figure 8: Prototype aluminum-based MMC connecting rod[19]
Slika 8: Prototipna aluminijeva MMC-ojnica[19]

The testing of mechanical properties was carried out with tensile and compressive tests on specimens solutionized at 530 °C for 3 hours and stabilized at the extruding temperature for 24 hours as well as an as-received (extruded) composite without heat treatment (**Figure 6**).

The relation between elongation and reduction for heat-treated and non-treated 2014 aluminum matrix composites is shown in **Figure 7**.

Better mechanical properties that lead to improved high-cycle fatigue resistance, especially at moderately elevated temperatures compared to the conventional aluminum alloys[18,19] are one of the primary performance benefits for aluminum-based PM MMCs in automotive applications.

Figure 8 shows an automotive engine connecting rod, a primary target for aluminum-based PM MMCs because of the combined requirements of lightweight and good high-cycle fatigue performance.

There are several candidate materials for the connecting-rod application, among them 2024/SiC/15p and 2080/SiC/15p show the best combination of specific modulus and specific fatigue strength[19].

4 CONCLUSION

The challenge of commercial applications for PM aluminum-based PM MMCs in high -volume automotive areas always lies in achieving the desired properties at a sufficiently low cost. In these terms, the mentioned directions together with net-shape processing hold the key to success.

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