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Influence of cooling condition on properties of extruded aluminum alloy matrix composites

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ABSTRACT

This paper discusses the influence of applying water cooling after extrusion on the stability of mechanical properties on the AA6061-7.5 vol. % SiC composite rods cross section. The materials were prepared via powder metallurgy processing using extrusion with a reversibly rotating die at the last technological stage. The mechanical properties, texture and microstructure of composites were analyzed following the experiment. In both deformed samples the XRD measurements indicated that the <111> was the predominant orientation, which, however, was weaker towards the edge of the specimen. Moreover, some differences in microhardness between the center and the edge of water cooled rod were observed.

1. Introduction

Extrusion is a widespread method used as the last step while manufacturing aluminum matrix composites (AMC) [1–3]. The common use of this method is caused by its high productivity, the ability to manufacture parts of complex shapes, high dimensional accuracy and good surface quality of manufactured components. Moreover, the possibility of improving density, strength properties and homogeneity of composites microstructure (both matrix material and reinforcement particles distribution) [2,4–6] is of great significance. Despite many advantages of extrusion processes, a strict control of its parameters is required to achieve products of a good quality. The extrusion conditions can affect the surface quality (fir-tree cracks formation), as well as the mechanical properties of composites (inhomogeneous mechanical properties along the length and cross section of the extruded profile) [7–10]. Additionally, materials subjected to plastic deformation create a strong crystalline texture, which leads to a high anisotropy of plastic and elastic properties [11,12]. The crystallographic texture is an important material feature which influences the formability of aluminum alloy products. This study analyzes the homogeneity of mechanical properties throughout the cross section of the extruded profile.

The differences in mechanical properties between the center and surface of extruded sample may be caused by the non-uniform temperature distribution on the cross section of the product. The temperature increase may activate the processes responsible for the transformation of the microstructure, i.e. recovery, recrystallization and growth of grains and, consequently, decrease strength properties of the material. In direct extrusion, the temperature distribution depends on the tribological, mechanical and thermodynamical aspects of extrusion [13]. Possible temperature profiles are shown in Fig. 1(b) and (c). Heat generation on the extrudate surface may be caused by the friction on the billet-die interface and is more intense for higher the bearing length. Also, the extrusion speed has a significant influence on the uniform temperature distribution on the extrusion cross-section. The increase of extrusion speed leads to increasing surface temperature as the amount of time to transfer the heat from the surface to the center of the extruded product is limited. Non-uniform mechanical properties throughout the extrudate cross-section are often linked with the strain gradient inherent in the extrusion process. The higher strain is observed at the extrudate surface, and therefore, this region is more prone to recovery processes [14]. The strain gradient along the extruded product cross-section is higher in the case of direct extrusion with a reversibly rotating die method (Kobo method),

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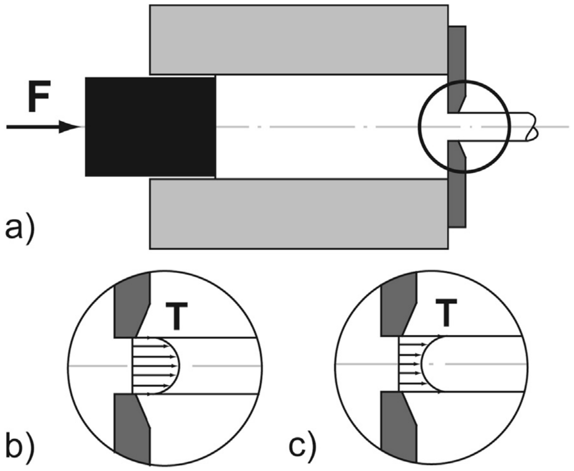

Fig. 1. Temperature distribution during direct extrusion.

compared to conventional extrusion processes. The Kobo technique is carried out by superimposing an additional cyclically reversed action of the shaping tool upon the unidirectional operational forces of the punch. The die movement is transmitted onto the treated material by rows made on its front face [15,16]. The additional die movement increases the deformation degree which the extruded material is subjected to. However, when the die hole is arranged in the axis of forming tool, the central part of the material is not subjected to torsion and consequently, this region is deformed to a lesser degree than the extrusion surface. More information on the KoBo method is given elsewhere [15–18].

2. Experimental procedure

In this study AA6061-7.5 vol. % SiC composites were fabricated via powder metallurgy technique. β-SiC_p and AA6061 powders with the average particle size of 0.42 μm and 10.6 μm, respectively, were used as substrates. The alloy composition of matrix material is shown in Table 1. After blending the AA6061/SiC mixtures were cold isostatic pressed (CIP) to achieve compacts with the diameter of 40 mm and the length of 50 mm. The compacts prepared were then preheated at extrusion temperature and consolidated by direct extrusion with a reversibly rotating die (the KoBo method). The parameters of the extrusion process were as follows: temperature: 350 °C, ram speed: 0.25 mm/s, frequency of the die oscillation was changed within the range of 5–8 Hz, oscillation angle: 4 deg, extrusion ratio: 25. Additionally, the materials were extruded with and without applying water cooling directly behind the die.

Obtained rods with the diameter of 8 mm and the length of 1 m were cut perpendicularly to the extrusion axis and subjected to further measurements. The specimens were mechanically polished down to the grit size of 0.2 μm. The microstructures of as-extruded specimens were studied with the use of a light microscope (LM) Nikon Eclipse MA200 and transmission electron microscope (TEM) Jeol 1200 with accelerating voltage of 120 kV. Based on LM observations, the homogeneity of SiC particles in the center and on the edge of composite rods was examined. The SiC distribution was analyzed by using skeleton by influence zone (SKIZ).

In this method, the influence zones of microstructure elements are determined. Based on the coefficient of variation of zones area (CV(A)), it is possible to compare homogeneous distribution of tested materials. Moreover, the mean grain sizes (d_2 - defined as the diameter of a circle which has the surface area equal to the surface area of a given grain) were determined by TEM for at least 100 randomly selected grains. Also, the dislocation density (ρ) was calculated based on the TEM images. This measurement was carried out by applying an equal number of straight lines on the images and counting the number of dislocation cuts along these lines. The value was then divided by the surface of the analyzed area. In order to o determine the uniformity of the composite properties, microhardness route contours were performed on the perpendicular cross section to the rod axis with the use of Matsuzawa Microhardness Tester MMTX7B. Texture measurements were performed on Bruker D8 Discover diffractometer with vanadium – filtered chromium radiation ($\lambda = 0.229$ nm). The texture was analyzed qualitatively and quantitatively (orientation distribution functions - ODFs) based on the incomplete pole figures (111), (200) and (220) determined by the Schultz reflection method [19].

3. Results

3.1. Microstructure observations

The microhardness route contours were made along the diameter of the specimens (distance between each indentation 1 mm). The results are presented in Fig. 2. Despite relatively minor differences in microhardness between cooled and not cooled composites, variations in the contour shape were visible. Water cooled specimens were characterized by higher microhardness on the rod edge than on the center. In the case of not cooled composites, almost the same values of microhardness were noted along the specimen diameter. The extrusion parameters for both series of composites were the same, hence it is possible to conclude that the influence of SiC distribution on microhardness inhomogeneity is not significant.

These assumptions have been confirmed by the results of homogeneity for the cooled composite. Almost identical values of CV(A) for the edges (1.00) and the center (1.01) were obtained.

The TEM observations of cooled and not cooled composites in the central and near edge areas of rods are presented in Fig. 3. In the case of all specimens it can be seen that the grains are almost free of dislocations which may indicate that the dynamic recovery process occurred during the process of extrusion [20]. It may suggest that water cooling applied even directly after die is not effective enough to prevent the extruded composite against dynamic recovery. Based on the TEM images, the dislocations density and mean grain size were calculated. For not cooled composite, the ρ values of the center and the edge differed significantly. The dislocation density reached the level of $1{,}72 \times 10^6$ and $1{,}73 \times 10^6\ m^{-2}$ for the edge and center, respectively.

A similar tendency was observed for the grain size. On the edge of the rod the average grain size equaled 0.84 ± 0.03 μm and was almost the same as in the central part of the sample (0.87 ± 0.05 μm). Substantial variations were noticed for the cooled composite. The density of dislocations was higher on the edge of the rod ($2.11 \times 10^6\ m^{-2}$) than in the central part ($1.6 \times 10^6\ m^{-2}$).

Table 1
Chemical composition of AA6061 alloy (wt. %).

AA6061	0.272	0.011	1.04	0.111	0.634	0.001	0.179	0.006	0.006	Balance
Alloy	Cu	Mn	Mg	Fe	Si	Zn	Cr	Ni	Ti	Al