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AN EXPERIMENTAL STUDY OF ALUMINUM ALLOY MATRIX COMPOSITE REINFORCED SiC MADE BY HOT PRESSING METHOD

BADANIA KOMPOZYTU NA OSNOWIE STOPU ALUMINIUM WZMACNIANEGO SiC OTRZYMANEGO METODĄ PRASOWANIA NA GORĄCO

The present work investigates the possibility of using powder metallurgy processing for producing a metal matrix composite. Materials were prepared from AlSi5Cu2 chips with reinforcement of 10, 15, 20 wt. % silicon carbide. Aluminum alloy chips were milled with SiC powder in a high-energy ball mill by 40 hours. Mechanical alloying process lead to obtain an uniform distribution of hard SiC particles in the metallic matrix and refine the grain size. The consolidation of composite powders was performed by vacuum hot pressing at 450°C, under pressure of 600 MPa by 10 min. The results shows that the addition of SiC particles has a substantial influence on the microstructure and mechanical properties of composite powder as well as consolidated material. Hot pressing is an effective consolidation method which leads to obtain dense AlSi5Cu2/SiC composite with homogeneous structure and advanced mechanical properties.

Keywords: Al/SiC composites, powder metallurgy, mechanical alloying, hot pressing

1. Introduction

The interest in recycled materials subject is continuously rising. In accordance with the rules of the European Union, all materials deriving from waste products or forming part should be made with the aim to be required. Aluminum chips are very difficult to be recycled due to a low density and large surface area which is covered with oxides and oil emulsion. The wastes are used in industry, mainly in foundry operations, which allow high tolerances when selecting the chemical composition. However, that forming technique causes high environmental pollution and forms other scraps in the final stage of processing generated elements. Also, going through the liquid phase, it reduces the resultant properties of the alloy, causes high energy consumption and allows to obtain aluminum dross which is very difficult to be recycled. For those reasons researchers are actually trying to develop recycled materials which can be produced differently than through remelting processes and will have some particularly properties. There are several examples where powder metallurgy process has been used to reuse aluminum chips [1-5].

Composite materials are one of the most common materials in the industry. Increased production began in the 40's, when the increase of the demand for the production of lightweight and durable material that can replace steel and other metals took place. The possibility of connecting components with different properties is dependent on the technology of preparation and consolidation. The use of PM processes allows to obtain a material of homogeneous structure and good properties. Powder metallurgy provides relatively low processing temperatures avoiding strong interfacial reaction and minimizing the undesired reaction between matrix and the reinforcement. The process starts with mixing or mechanical alloying of aluminum (or aluminum alloy) powder with ceramic particles followed by compaction and hot pressing, sintering or hot extrusion. Addition of ceramics particles has a positive influence on grain refinement during the milling process and increases the hardness of sintered samples [6-11].

There are also some scientific publications where researchers use aluminum alloy chips as a matrix to produce composite material. Authors obtain final product with low porosity, high tensile strength and stiffness for composite material with less than 10% of ceramic fiber [12]. Some promising results were obtained in [13], where composite material is characterized by a lack of segregation segregation of the reinforcement phase and good properties.

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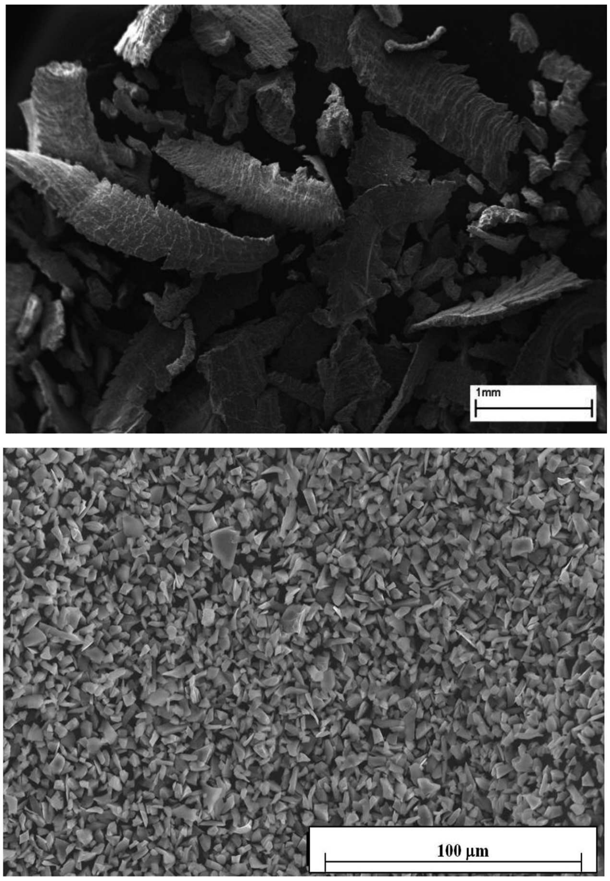
2. Experimental procedure

AlSi5Cu2 aluminum alloy chips and silicon carbide (SiC) powder particles were used as a starting material. Figure 1 shows the morphology of as-received AlSi5Cu2 and SiC particles. As it can be seen in Figure 1a, aluminum chips had a very irregular shape; this is a direct result of the production procedure (machining and turning processes), their average particle size being about 250 μm. The morphology of the SiC particles is angular with sharp edges as a result of crushing and grinding of SiC lumps that occur during the fabrication methods (Fig. 1b). The average particle size of as-received SiC particles was about 2μm.

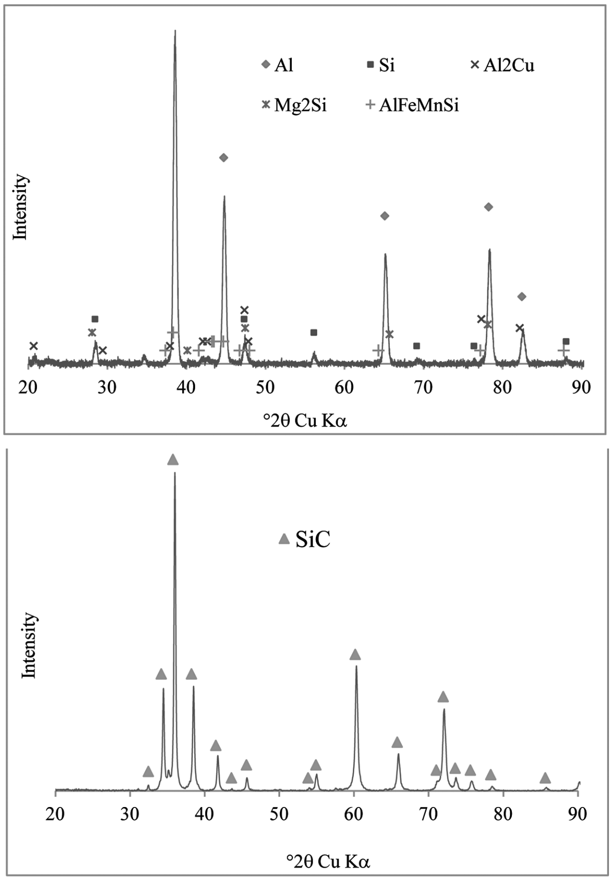


(a)
(b)

Fig. 1. Morphology of as-received AlSi5Cu2 chips (a) and SiC powder particles (b)

To confirm the participation phases of the starting materials the X-ray diffraction was performed. Figure 2 a show the XRD pattern where all characteristic phase of AlSi5Cu2 alloy was identified. XRD pattern of silicon carbide shown that 6H-SiC powder with hexagonal unit cell was used as reinforcement for.

AlSi5Cu2 aluminum alloy chips were used as a matrix and reinforced with 10, 15 and 20 wt. % SiC particles. 1 wt. % of stearic acid as a process control agent was added to the powder mixture to prevent agglomeration of the powder particles. The powders were mechanical alloyed in a Fritsch Pulverisette 5/4 high-energy ball mill using stainless steel balls with diameter 10 mm. The weight ratio of ball to powders was about 10:1. Rotation speed was 200 rpm Handling and milling steps were performed under a high purity argon atmosphere in a glove box. To minimize the extreme cold welding and prevent high temperature, the process was stopped periodically (45min) after each 15 min of milling. Detailed results of the composite powder preparation and properties have been reported in [14-16].



(a)
(b)

Fig. 2. XRD pattern of AlSi5Cu2 chips (a) and SiC particle powder (b)

The prepared and identified powder mixtures were finally densified by the hot pressing method in a specially constructed chamber. The powders were embedded in a copper cubs and hot pressed at 450°C, under 600 MPa in vacuum for 10 min to obtain disc shape compact with diameter of about 20 mm and a thickness of 4-5 mm.

The microstructure of compacted powders was examined by transmission electron microscopy (TEM), scanning electron microscopy (SEM) and light optical microscopy (LEICA MF4M A/M). The Vickers hardness (HV_5) tests were performed using Innovatest hardness testing instrument. Density of AlSi5Cu2/SiC samples for different weight fraction of SiC particles were measured using Archimedes method. The CWIK testing machine was used for compression tests.

3. Results and Discussion

Fig. 3 show the evaluation of particle size during mechanical alloying. The irregular shape of as-received AlSi5Cu2 chips has changed to flat after 1 hour of milling, what is typical of the beginning of the mechanical alloying process. Predominance of deformation and welding had taken a place. After

10 hours of milling, the process reach a moment in which welding and fracturing start to be in balance. Morphology of composite particles is near to granular. From this stage, particles produced by mechanical alloying are composite. Longer time of high-energy milling reach to obtain smaller particles with reduced porosity [16]. Particle size decrease from 250 μm to 3 μm after 40 hours of high-energy milling. After mechanical alloying composite powder displaying a fine, homogeneous distribution of the reinforcement within the particle (Fig. 4) what was in detail demonstrated in previous work [15-16].

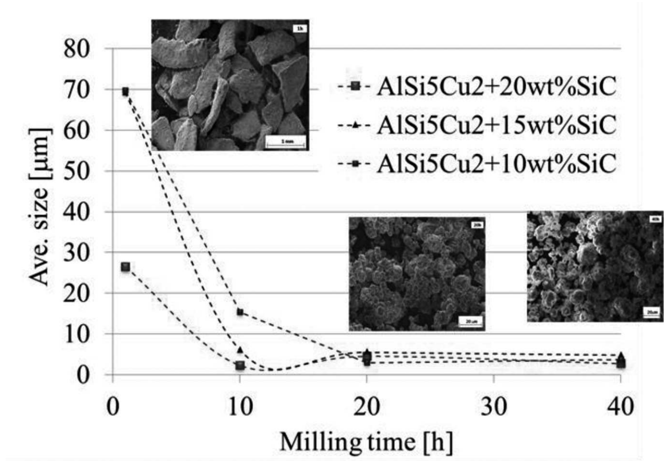


Fig. 3. Particle size vs. milling time; morphology of 10 wt. % SiC reinforced composite powder after 1, 20, 40 hours of high-energy milling

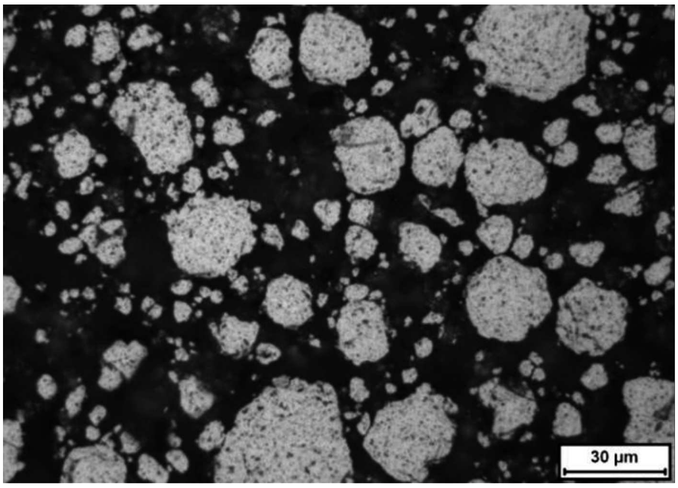


Fig. 4. Microstructure of composite particles of AlSi5Cu2 reinforced with 10 wt. % SiC after 40 hours of mechanical alloying [17]

Applied parameters of mechanical alloying of AlSi5Cu2 chips and SiC leads to obtain composite powder where the SiC particles are apparently occluded by Al (Fig. 5). The rings belonging to the α (Al rich solid solution) in the corresponding SAED pattern from the composite powder, indicated the nanoscale level of both material components.

After hot pressing at 450°C, under 600 MPa the porosity [%] of the AlSi5Cu2/SiC was investigated using optical micrographs from cross-section of a polished surface. As shown in Figure 7, homogenous structure with very small amount of pores or voids can be observed. This indicates that the consolidated compact was fully densified under applied conditions.

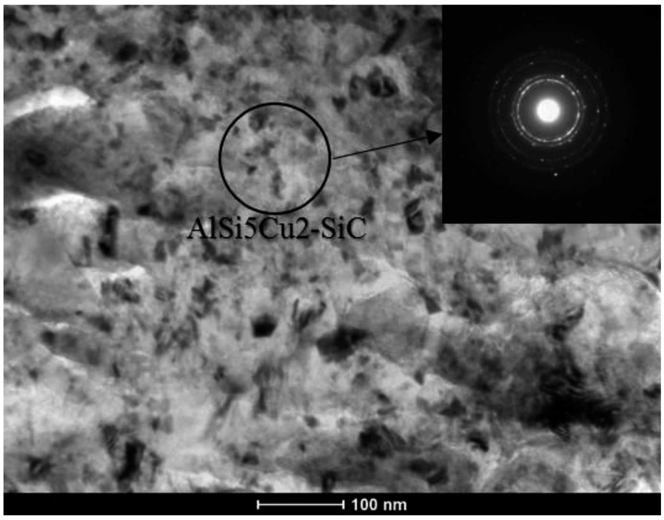


Fig. 5. TEM bright – field images of high-energy milled AlSi5Cu2/SiC powder (20 wt. % SiC) and as insert corresponding diffraction pattern, in which – reflection of α-(Al rich solid solution)

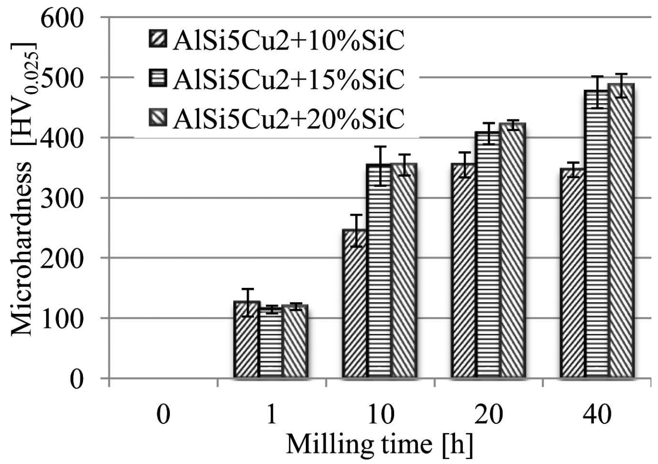


Fig. 6. Microhardness of composite powders as function of milling time

Figure 8 reveals that relative densities of AlSi5Cu2/SiC composites slightly decrease from 99,5% to 95% with increasing of SiC amount. That small decrease can be due to the fact, that hard small particles can block diffusion between Al particles. Higher content of reinforcement can lead to formation of cracks or microvoids at the interfaces between the particles and matrix during hot pressing at 600MPa.

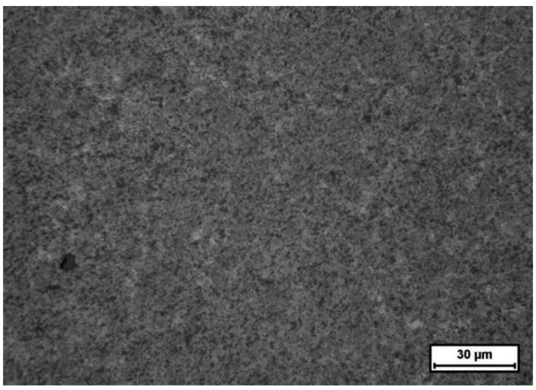


Fig. 7. Microstructure of polished surface of AlSi5Cu2+20wt%SiC hot pressed samples

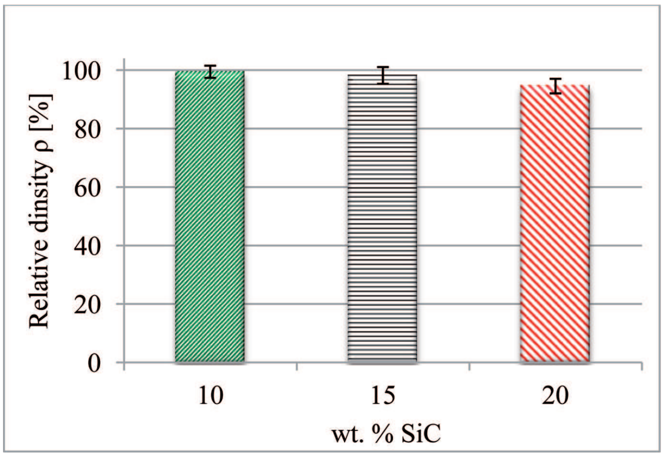


Fig. 8. Relative density (%) vs. wt. % of SiC, (d) microhardness ($HV_{0.1}$) vs. wt. % of SiC

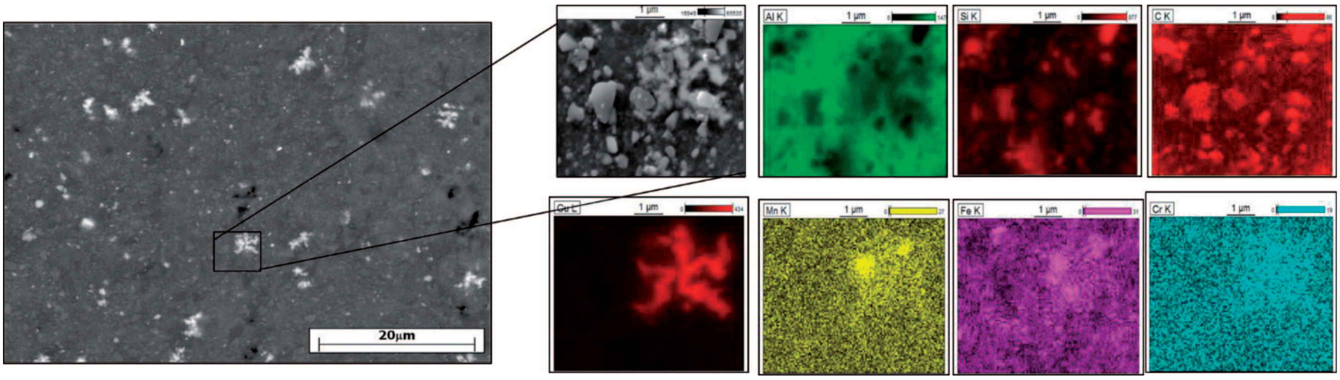


Fig. 9. SEM/EDX analysis of composite samples AlSi5Cu2 +20 wt. % SiC after hot pressing process

Samples were studied using by EDS mapping analysis (Fig. 9). White precipitate phase (in the form of snowflakes) is distributed homogeneously in all samples. That intermetallic phase have chemical composition similar to α-AlFeSi phase reach in Cu.

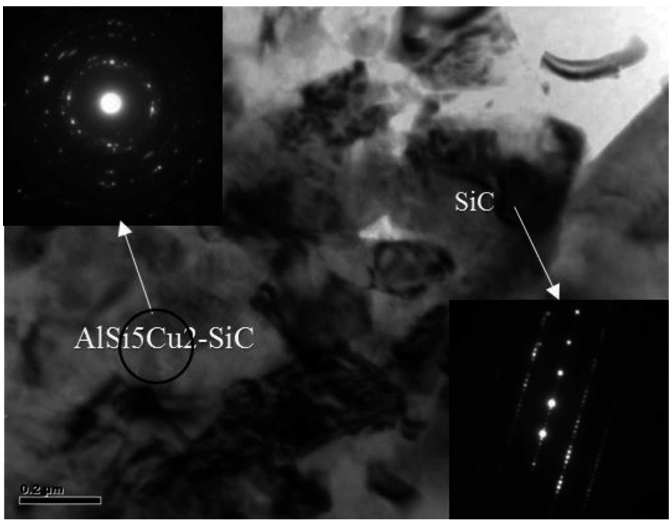


Fig. 10. TEM bright-field image ball milled and hot pressed AlSi5Cu2 +20 wt. % SiC composite

The TEM bright-field image of sample with 20 wt. % of SiC presented in Fig. 10 shows randomly distributed, regular grains less than 200 nm. The mechanical alloying powders before consolidation as well as hot pressing process caused refinement of the microstructure of obtained samples. The SiC particles are in intimate contact with Al matrix. The absence of discontinuities and voids at the Al/SiC samples reveals the strong bonding between the reinforcement and the matrix.

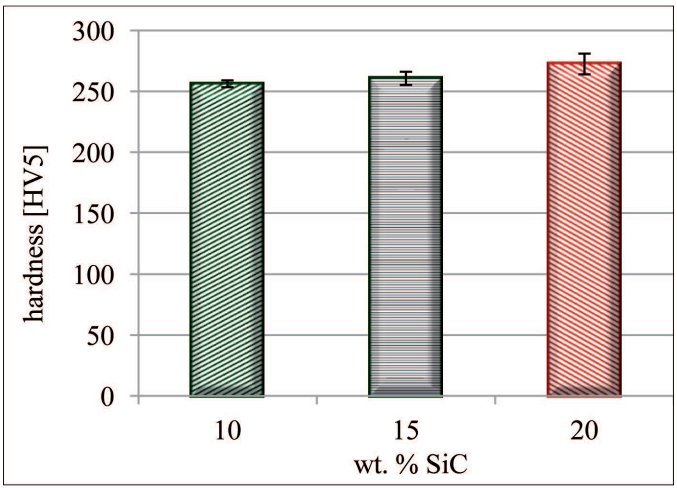


Fig. 11. Hardness (HV5) of composite samples vs. wt. % of SiC. Hardness is a property related to the material resistance against plastic deformation which was confirmed by compression test. It can be seen on the compression curves in Fig. 12 that higher content of SiC addition allows to increase true stress but ductility of composite samples is still very low

Figure 11 shows the hardness of AlSi5Cu2/SiC composite produced by hot pressing of 40 h mechanical alloyed powders. The addition of SiC particles lead to increase in the material hardness. Good bounding between matrix and reinforcement particles as well as homogeneous distribution of SiC without clustering relevant to obtain high properties of hardness.

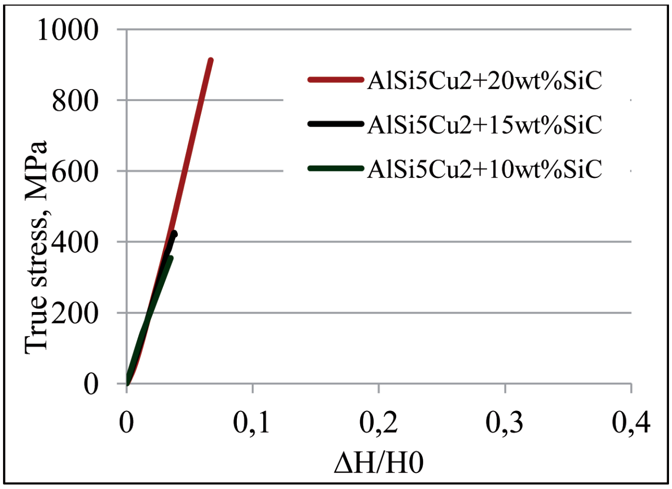


Fig. 12. Effect of deformation on a flow stress characteristics for AlSi5Cu2/SiC composite

4. Conclusions

1. Mechanical alloying can produce AlSi5Cu2/SiC composite powder with homogeneous distribution of SiC throughout the particles.
2. Hot pressing of AlSi5Cu2/SiC composite powder allow to obtain components with homogeneous structure and density above 95%.
3. In the AlSi5Cu2/SiC composites, by increasing of SiC indicate higher hardness and stress values, whereas the ductility of composite samples is very low.

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REFERENCES

[1] J. Gronostajski, H. Marciniak, A. Matuszak, Journal of Materials Processing Technology **106**, 34-39 (2010).
[2] M. Samuel, Journal of Materials Processing Technology **135**, 117-124 (2003).
[3] V. Güley, N. Ben Khalifa, A.E. Tekkaya, International Journal of Material Forming **3**, 853-856 (2010).
[4] Z. Sherafat, M.H. Paydar, R. Ebrahimi, Journal of Alloys and Compounds **487**, 395-399 (2009).
[5] A. Tekkaya, M. Schikorra, D. Becker, D. Biermann, N. Hammer, K. Pantke, Journal of materials processing technology **209**, 3343-3350 (2009).
[6] L. Blaz, A. Kula, J. Kaneko, M. Sugamata, G. Wloch, K. Sobota, Journal of Microscopy **237**, 416-420 (2010).
[7] P. Kurtyka, N. Ryłko, Archives of Metallurgy and Materials **58**, 357-360 (2013).
[8] J. Torralba, C. da Costa, F. Velasco, Journal of Materials Processing Technology **133**, 203-206 (2003).
[9] D. Garbiec, M. Jurczyk, Composites Theory and Practice **13**, 255-259 (2013).
[10] B. Leszczyńska-Madej, Archives of Metallurgy and Materials **58**, 43-48 (2013).
[11] K.L. Meena, A. Manna, S.S. Banwait, American Journal of Mechanical Engineering **1**, 14-19 (2013).
[12] M. Samuel, Journal of Materials Processing Technology **142**, 295-306 (2003).
[13] J. Fogagnolo, E. Ruiz-Navas, M. Simón, M. Martinez, Journal of Materials Processing Technology **143-144**, 792-795 (2003).
[14] M. Suśniak, J. Karwan-Baczewska, J. Dutkiewicz, M.A. Grande, Inżynieria Materiałowa **186**, 86-89 (2012).
[15] M. Suśniak, J. Karwan-Baczewska, J. Dutkiewicz, M.A. Grande, M. Rosso, Archives of Metallurgy **58**, 437-441 (2013).
[16] M. Suśniak, D. Kołacz, M. Lis, J. Karwan-Baczewska, T. Skrzekut, Rudy i Metale Nieżelazne **58**, 447-453 (2013).
[17] M. Suśniak, J. Karwan-Baczewska, J. Sulima, Key Engineering Materials 641, 30-38 (2015).

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