THE MANUFACTURING PROCESS AND TRIBOLOGICAL PROPERTIES OF ALUMINUM BASED COMPOSITE REINFORCED WITH ALUMINUM OXIDE PARTICLES AND GLASSY CARBON ADDITIONS

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ABSTRACT
Influence of temperature on tribological properties research was performed for the aluminum based composite reinforced with aluminum oxide with a glassy carbon addition. Investigated material was manufactured using powder metallurgy technology. Pressing and sintering of a composite powder was conducted with prior high energy milling in a planetary mill. Structure investigation at Scanning Electron Microscope and phase analysis at X-ray diffractometer were performed for obtained material. As a main part of presented results a comparison of tribological properties in friction in air conditions at room (25°C) and high (350°C and 450°C) temperatures was made. During examinations a stability of friction coefficient as a distance function and the level of wear were taken into account. Conducted tests clearly revealed that glassy carbon additions are desirable additions for friction materials, especially for composite working at elevated temperatures.

INTRODUCTION
This paper presents manufacturing process and tribological analysis of aluminum based composite, reinforced with aluminum oxide particles with glassy carbon addition. Alumina was used as a reinforcing component because of its high hardness and high wear resistance. The ceramic particles reinforcement in metal matrix composites (MMC) is well-known trend in tribological materials manufacturing. Reinforcement with Al2O3 and SiC particles should be included to the most popular solutions. Those particles are often used because of their physical properties and economical reasons. Due to a wide range of known production methods manufacturing of MMC is a convenience. Between the most attractive methods are casting (gravity casting, stir carting and centrifugal casting), powder metallurgy (pressing, sintering) and coatings (HVOF, plasma etc.). All methods of MMC production with ceramic reinforcement ensure increase of friction coefficient, wear reduction and ipso facto a life lime elongation in tribological materials [1,2].

An amorphous carbon phase – glassy carbon (GC) exhibit high hardness and low share resistance, what makes these addition an excellent material solutions for tribological applications. Those specific properties lead to changing the predominant wear mechanism [3, 4]. It resulted in stabilisation of tribological properties and
reduction of friction coefficient value up to a desirable level. Glassy carbon application should also provide stabilisation of properties at high temperature due to its high thermal capacity and thermal conductivity.

A common action of both types of reinforcement is to give an opportunity to production innovative composite material for high work temperature friction points. The aluminum oxide particles ensure protection against progressive wear, while GC particles makes thin tribological film on the surface of material. Those thin layers work as a solid lubricant between friction surfaces, what led to decrease of friction coefficient and wear limitation. Moreover, glassy carbon particles should protect against a higher temperature increase as a secure point (at elevated temperatures tests) due to thermal energy accommodation. This thesis in a main point of the performed research.

EXPERIMENTAL
Manufacturing process of presented material was based on powder metallurgy method. Initially, all components were milled at Planetary Micro Mill PULVERISETTE 7 premium line. High energy of milling was ensured by velocity 1000 rmp. Milling process was conducted in gas atmosphere – nitrogen, on time 1 hours, realized in 12 cycles. Next obtained composite powder was hot pressed. The powder was heated up to 640°C and held during 15 minutes in this temperature. Sintered operation was conducted under 10 MPa of press in vacuum 10⁻³ Torr.

As a first step of conducted research an analyses of microstructure was performed by Scanning Electron Microscope HITACHI SU-70. Applied accelerating voltage during observation was on the level of 15 kV. Then phases analysis was made on X-ray diffractometer D8 Discover. The measurement was carried out in the range of angle between 10 ° to 90° with a step of 0.015° per 30 seconds. The evaluation of tribological properties was a main part of the experiment. Friction tests were performed on CSM high temperature tribometer tester at room temperature (25 °C), elevated temperature (350 °C) and at working point equivalent to the state of emergency (overheating of the material: 450 °C). All tests were made in friction in air conditions, on distance of 200 m, with 0.1 m/s velocity and 10 N of load. As a counterpart a bearing steel 100Cr6 pin was used. The resultant friction wear track was analysed on Scanning Electron Microscope with analogous parameters as during microstructure observation. Additionally, wear products obtained during friction were analysed.

RESULTS AND DISCUSSION
A proper alumina particles homogeneity, without agglomerates was observed using a scanning electron microscope with low magnification, what was a basic description of material microstructure (Fig. 1a). However, a detailed analysis of structure revealed pure aluminium areas without reinforcing particles (Fig. 1b). Those structure inhomogeneities can result in undesirable properties in the macro-scale composite properties. Moreover, there was only a partial carbon particles breaking, what is an effect of the incorrect milling process. The glassy carbon particles were in a wide range of size, between 1 and 100µm.
A phases analysis was made using X-ray diffraction method in order to check the quality of sintering process. As a main result of conducted research an aluminum carbide phase was detected. A predominant places to $\text{Al}_4\text{C}_3$ phase formation are grains boundary between metal (Al) and ceramic (SiC, GC) particles. This phenomenon can lead to decreasing final properties and delamination in internal part of material in the extreme case. The elevated temperature during both milling and sintering processes is a proper conditions to start $\text{Al}_4\text{C}_3$ phase formation. Moreover, X-ray diffraction confirmed presence of pure aluminum areas, created as a result of incorrect sintering or milling processes.

An analysis of influence of elevated temperature on tribological properties was a main part of conducted research. Previous detailed literature data analysis and our own experiences [5, 6] determined maximum work temperature for Al based composite near 400°C. Presented works included tests at room (25°C), elevated (350°C) and extreme (450°C) temperatures over the expected one. The highest temperature point corresponds to the emergency states of system. An evaluation of an average friction coefficient showed significant increase of those values at elevated temperatures. At room temperature friction coefficient was 0.54, while at elevated
temperature it increased up to 0.7. Moreover, at room temperature a high stability of friction coefficient without any significant disruptions was noted. The higher friction temperature resulted in decrease of friction properties. The fluctuations in the value occurring at 350°C ranged between 0.58 and 0.78. The friction properties at temperature 450°C did not decrease in comparison to test at elevated temperature. The friction coefficient values ranged between 0.6 and 0.82 with only a slight increase of an average friction coefficient (Fig. 3). Based on the presented results, a thesis that increasing of work temperature did not have a strong influence on tribological behaviour of material with glassy carbon was confirmed.

The obtained mass loss as a results of wear tests showed strong correlation between work temperature and mass loss. For a test at 350°C, a wear was eight times higher if compared to the test at 25°C. However, friction at 450°C did not result in significant wear increasing. Only slight increase of mass loss was detected in comparison to test the at 350°C, what showed a possibility of using this material up to 450°C.

Fig. 3 A tribological behaviour of Al-Al₂O₃-GC composite at different temperatures.

Fig. 4 Mass loss of Al-Al₂O₃-GC composite after the wear test conducted at different temperatures.
SUMMARY
The presented research revealed that aluminum based composite, reinforced with aluminum oxide particles with glassy carbon addition meets special requirements for friction materials. The main advantage of using glassy carbon particles is protection against a progressive wear, especially at elevated temperature, as a result of unique properties (high hardness, low shear resistance, high thermal conductivity and high thermal capability). However, manufacturing process needs detailed analysis in order to eliminate undesirable effects of pure aluminum areas presence and aluminum carbide formation. An elimination of those effects might cause increase of physical and tribological properties of analysed material.

For better understanding of manufactured material the future research is planned. Both, physic (eg. density, hardness) and subsequent wear result (eg. analysis of wear track) will be performed.

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LITERATURE