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Tribological properties of composite working under dry technically friction condition

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Materials

ABSTRACT

Purpose: The article presents the research results on tribological properties (friction coefficient, wear) of the frictional couple cast iron-composite. The subject of that research was aluminium heterophase composites containing two carbide phases: chromium (Cr_3C_2) and titanium carbides (TiC).

Design/methodology/approach: The friction process was conducted on a tribological pin-on-disc tester (T-01M) under technically dry friction conditions.

Findings: The results of friction and wear coefficients' investigation allowed the determination of how the volume fraction of $NiCr/Cr_3C_2+TiC$ composite powder can influence on the course and degree of cast iron and composite wear.

Practical implications: An increase in the reinforcing phase fraction allowed the elimination of the phenomena connected with adhesion wear. The 10% fraction of a carbide reinforcing phase ensures a uniform wear mechanism and has a beneficial influence on the operation of the tribological couple: cast iron – heterophase composite, during which no negative effects of increased wear of the cooperating material are observed.

Originality/value: The application of heterophase reinforcement is a solution which to a large extent enables the broadening of the possibilities to design and diversify the tribological properties of friction couples.

Keywords: Composites; Wear resistance; Image analysis; Casting; Powder metallurgy

1. Introduction

As results from the to-date research, the application of heterophase reinforcement is a solution which to a large extent enables the broadening of the possibilities to design and diversify the tribological properties of friction couples [1-4]. The appropriate choice of components, such as the matrix and reinforcing phases, allows a reduction in wear of friction couple elements and gaining a stable value of the friction coefficient. In the literature data, there is only some information signalling the tribological properties of aluminium composites with carbide phases different than silicon carbide, aluminium carbide or titanium carbide [5-9]. As results from the review of the literature made, there is no information there about the production and tribological properties of composites containing two carbide phases used for hybrid reinforcement of aluminium alloys In their own investigations conducted at the Silesian University of Technology, Department of Composites and Powders Metallurgy, the authors of this paper have assumed that chromium and titanium carbides, first of all due to their physicochemical properties, can form effective reinforcement in composite aluminium alloys, in particular in those intended for centrifugal casting and tribological cooperating [4,10-12].

2. Objective and scope of the research

The aim of the research conducted was to examine the tribological properties, i.e. the friction coefficient and wear, of heterophase composites containing chromium and titanium carbides, shaped in the process of centrifugal casting, as well as to assess the wear of the element cooperating with it. The scope of the research encompassed:

- the production of a composite with an aluminium matrix and carbides,
- the use of a composite suspension in centrifugal casting and production of a sleeve with layered arrangement of reinforcing phases,
- examination of the tribological properties, friction coefficient and wear of the friction couple: cast iron-composite,
- examination of hardness.

3. Materials, research methodology and structure of the composites produced

As a carrier of reinforcement, a composite powder was applied containing chromium and titanium carbides and a phase of solid solution NiCr. A composite powder obtained in a self-propagating high-temperature synthesis (SHS) [13,14]. The phase composition and morphology of the powder used for the matrix alloy modification are discussed in detail in papers [10-12]. The composite powder, 20-40µm in size, was introduced into mechanically stirred liquid aluminium in a range of temperatures from 720^0C to 740^0C [10]. The so obtained composite suspension was stirred for 10 minutes and cast into a graphite mould. Two volume fractions of the composite powder were applied: 5% and 10%. The composite ingots produced were remelted and cast into a rotating mould in order to obtain centrifugal casts [10,11]. From the so formed sleeves rings were cut out which were then subjected to tribological examination. The friction process was conducted on a tribological pin-on-disc tester (T-01M) manufactured by the Institute of Technology and Operation in Radom [4]. A counter-specimen in the form of a cast iron pin, 3mm in diameter, was pressed in a vertical position with 5 MPa to a composite disc rotating at a speed of 0,7 m/s. The measuring diameter was so selected that the cooperation between frictional elements would take place in the area of the composite layer. The friction process took place under technically dry friction conditions.

4. Results and analysis of tribological investigations

The investigations of tribological properties encompassed the determination of the values of friction coefficient and mass decrement of the cast iron – composite layer couple elements cooperating under technically dry friction conditions. In addition, a microscopic analysis was performed of wear-out traces to enable the identification of the mechanisms of wear in the investigated friction couples.

Figure 1 shows a diagram of the friction coefficient changes as a function of distance for the tribological couple: cast iron - AlMg+10%NiCr/Cr_3C_2+TiC composite. For the analyzed friction couple: cast iron – composite, at the initial stage of friction, the friction coefficient amounted to a little more than µ=0.2, after which it rapidly increased up to µ=0.5. After a friction distance of ca. 400 meters, the friction coefficient value stabilized at µ=0.4 and, with insignificant fluctuations, did not change until the end of the test.

Figure 2 presents photographs of the cooperating surfaces of the cast iron - AlMg+10%NiCr/Cr_3C_2+TiC friction couple. On the composite disc surface, a uniform trace is visible left by the cast iron pin of a diameter equal 3 mm. This trace is relatively shallow. On the working surface of the cast iron pin, scratches can be observed as well as small grooves, the direction of which corresponds to the direction of movement of the cooperating friction couple. During the test, an small amount of wear products was obtained in the form of fine black powder uniformly distributed all over the surface.

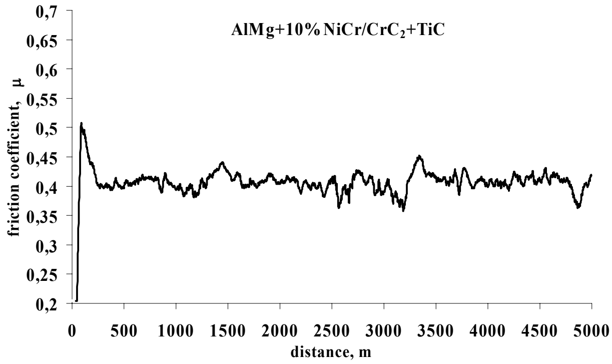

Fig. 1. The diagram of friction coefficient shifts in track function for AlMg+10% NiCr/Cr_3C_2+TiC composite

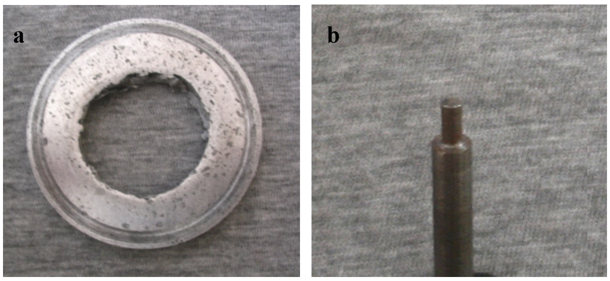

Fig. 2. View of the frictional coupe cast iron- AlMg+10% NiCr/Cr_3C_2+TiC composite: a) composite ring, b) cast iron pin

Figure 3 shows the results of the investigations of the friction coefficient changes as a function of distance for the cast iron - AlMg+10%NiCr /Cr_3C_2+TiC composite couple.

A distinct grinding-in period can be observed from the course of the friction coefficient changes at a distance of ca. 500m. At the initial stage of the cooperation, the friction coefficient value amounted µ=0.7, after which it began to fall rapidly to µ=0.5.

Next, the decrease of the friction coefficient was not so dynamic as before, however, it still fell systematically and after ca. 500m its value stabilized at µ=0.4, such value being recorded till end of the measuring process, with some slight deviations.

Figure 4 shows some views of the AlMg+5%Ni Cr/Cr_3C_2+TiC composite disc and the cast iron pin. As can be seen, the traces of wear of the cooperating elements have rather irregular shapes. The products of wear formed as a result of friction had a form of fine brown powder and silvery chips, the formation of which was not recorded in the previous test. The wear-out trace formed on the composite disc surface was distinctly deeper compared to the previous test.

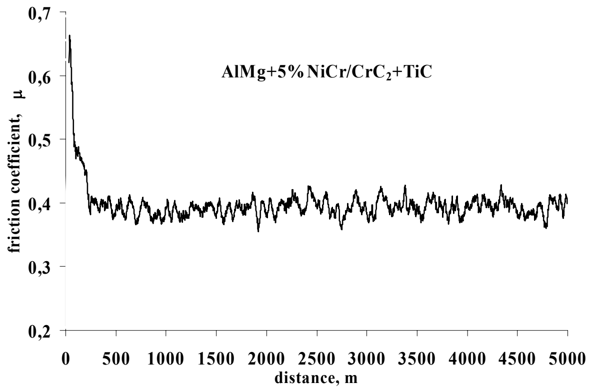

Fig. 3. The diagram of friction coefficient shifts in track function for AlMg+5% $NiCr/Cr_3C_2$ + TiC composite

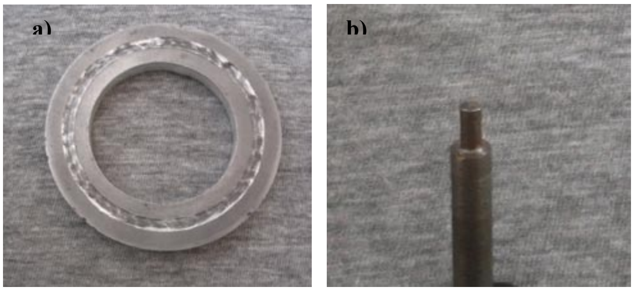

Fig. 4. View of the frictional coupe cast iron- AlMg+5% $NiCr/Cr_3C_2$+TiC composite: a) composite ring, b) cast iron pin

After tribological investigations, the wear-out trace formed on the cooperating surfaces was subjected to a microscopic analysis. The analysis was conducted using a Nikon stereoscopic microscope, SMZ 1000, equipped with an ED Plan 2*WD 32.5 objective, which cooperated with a digital camera of the same make. During the investigations, the Lucia Net program was applied for image analysis. In order to characterize the type and nature of tribological wear, a number of images from several different places of the wear-out trace were recorded for each of the specimens. Owing to the functions of a stereographic microscope, the depth of the trace could be analyzed. For a full analysis of the phenomena responsible for wear of the investigated tribological couples, mass decrement examinations were performed (Fig. 5) for the cooperating elements as well as measurement of the composite layers' hardness (Fig. 6).

Figure 7 presents the image of the wear-out trace formed on the AlMg+10%$NiCr/Cr_3C_2$+TiC specimen. The uniform ridging formed throughout the friction surface testifies to an abrasive mechanism of wear. The trace of wear-out is uniform and not too deep, which was confirmed by the microscopic and mass decrement examinations. In this case, permanent deformation took place in the place of wear-out, followed by pushing out of the excess material outside the furrow formed, as well as its partial abrasion. The reinforcement region is large enough to encompass the entire space of cooperation between the pin and the disc.

Figure 8. shows the wear-out trace on the AlMg+5%$NiCr/Cr_3C_2$+TiC composite. In this case, the observed wear-out trace testifies to a combination of abrasion wear and adhesion wear. It is particularly visible on edges of the wear-out trace, where plastic deformation occurred.

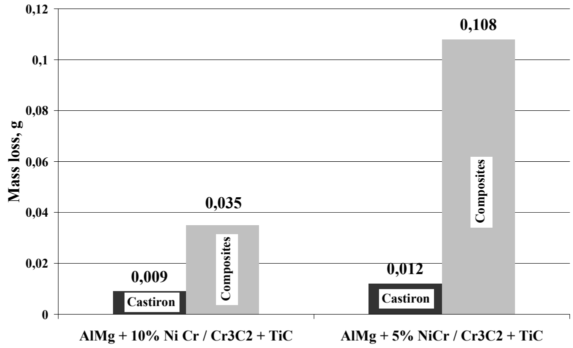

Fig. 5. The loss of cast iron counter sample mass after collaboration in dry sliding conditions at the 5000m distance

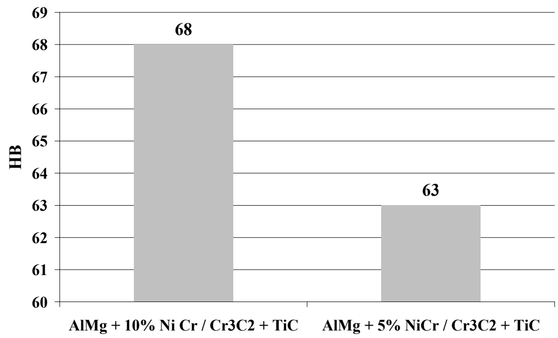

Fig. 6. The hardness of HB Composites layers under the process of wear

Fig. 7. Erosion rack on the AlMg+10%$NiCr/Cr_3C_2$+TiC composite layer, mag. 50x

The plastic deformation observed on the wear-out trace edges may have resulted from the too small width of the composite layer in relation to the cast iron pin diameter. The trace left by the cast iron pin is deeper compared to the trace formed on the AlMg+10%$NiCr/Cr_3C_2$+TiC composite surface and the composite disc mass decrement was almost three times as big (Fig. 5). The direction of ridging corresponds to the direction of movement, however, it is very irregular and the edges of the wear-out trace are uneven and jagged.

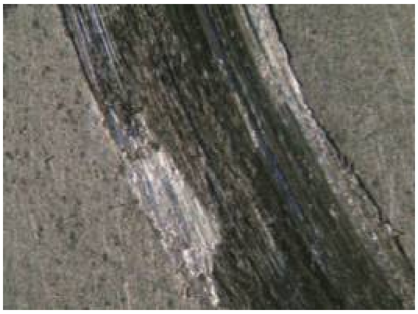

Fig. 8. Erosion rack on the AlMg+5% NiCr/Cr_3C_2+TiC composite layer, mag. 50x

5. Summary

Comparing the results of the tribological investigations of couples such as the cast iron – composite with reinforcement of a heterophase nature, a significant influence has been observed of the volume fraction of the composite powder applied for the reinforcement on the course and degree of wear. When using a 5% fraction of the NiC/Cr_3C_3-TiC powder mixture, a higher degree of wear was observed in the composite than in the case of a composite where a 10% fraction of powder mixture was applied.

The decreased wear of the composite with a lower fraction of reinforcing phases in the friction region results from the fact of occurrence, during its work, of two mechanisms of wear: adhesive and abrasive. The combination of these mechanisms clearly intensifies the degree of wear, thus resulting in its almost triple growth compared to the material with a larger fraction of heterophase reinforcement. An increase in the reinforcing phase fraction allowed the elimination of the phenomena connected with adhesion wear. At the same time, this did not change the friction coefficient value, which in both of the cases analyzed, stabilized after the grinding-in period at μ=0.4. An increase in the reinforcing phases' fraction did not result in increased wear of the cast iron partner in the friction process. Therefore, it can be affirmed that a 10% fraction of a carbide reinforcing phase ensures a uniform wear mechanism and has a beneficial influence on the operation of the tribological couple: cast iron – heterophase composite, during which no negative effects of increased wear of the cooperating material are observed.

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References

[1] J.I. Song, S.I. Bae, K.C. Ham, K.S. Han: Abrasive Wear Behavior of Hybrid Metal Matrix Composites, Key Engineering Materials, vol. 183-187, 2000, p. 1267-1272.

[2] Y. Watanabe, T. Nakamura: Microstructures and wear resistances of hybrid Al-(Al3Ti+Al3Ni) FGMs fabricated by a centrifugal method, Intermetallics 9 (2001), p. 33-43.

[3] J. Myalski, J. Wieczorek, J. Śleziona, A. Dolata-Grosz, M. Dyzia: Tribological properties of heterophase composites with ceramic and amorphous carbon particles composition, Materials Science-Poland, no 3 (2005), p. 93-104, (In polish).

[4] A. Dolata-Grosz, J. Wieczorek: Tribological properties of heterophases aluminium cast composites contained chromium and titanium carbides, Composites, (2006), (In polish), in press.

[5] S.C. Lim, M. Gupta, L. Ren, J.K.M. Kwok: The tribological properties of Al–Cu/SiCp metal–matrix composites fabricated using the rheocasting technique, Journal of Materials Processing Technology, vol. 89-90, (1999), p. 591-596.

[6] R.L. Deuis, C. Subramanianian, J.M. Yellup: Dry sliding wear of aluminium composites - a review, Composites Science and Technology 57, 1997, p. 415-435.

[7] J. Zhang, A.T. Alpas: Wear regimes and transitions in $A1_2O_3$ particulate-reinforced aluminum alloys, Materials Science Engineering, 1993, A161, p. 273-284.

[8] A. Posmyk, J. Śleziona, A. Dolata-Grosz, J. Wieczorek: Reibungs – und Schmierungsverthalten von Aluminium – legierungen mit einem verstärkten Oberflächenbereich, Technische Akademie Esslingen, 12th.International Colloquium, January 11-13 2000, Tribology 2000 – Plus.

[9] E. Fraś, A. Jonas, S. Wierzbiński, A. Kolbus: Synthesises of Aluminium Composites Reinforced with titanium carbides particles, in. Proceedings of the Int. Conf. Light Metals and Composites, Zakopane 1999, p. 323, (In polish).

[10] A. Dolata-Grosz, J. Śleziona, B. Formanek: Aluminium matrix cast composite (AMCC) with hybrid reinforcement, Archives of Faundry, 2005, vol. 5 No 15, p. 70-78, (In polish).

[11] A. Dolata-Grosz, B. Formanek, J. Śleziona, J. Wieczorek: Structure of heterophases aluminium cast composites contained chromium and titanium carbides, Composites, 5 (2005) 3, 2005, p. 81-85, (In polish).

[12] A. Dolata-Grosz, B. Formanek, J. Śleziona: Aluminium alloy reinforcement NiCr-Cr_3C_2-TiC Composites powder, 10th International Conferences Aluminium 2005, 12-14 October 2005, (In polish).

[13] G. Dercz,B. Formanek, K. Prusik, L. Pająk: Microstructure of Ni(Cr)–TiC–Cr_3C_2–Cr_7C_3 composite powder, Journal of Materials Processing Technology, vol.162–163 (2005), p.15–19.

[14] B. Formanek, K. Szymański, B. Szczucka-Lasota: Structure of composite powders with Ni-Cr matrix and FeAl phases, carbides and aluminium oxide, Composites, no.5, (2002), p. 278-282, (In polish).