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Tribological properties of hybrid composites containing two carbide phases

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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 hybrid 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 – hybrid 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

PROPERTIES

1. Introduction

In the process of designing the composition and structure of a composite material intended for tribological cooperation, both externals factors enforcing a certain set of the material reaction are taken into consideration, including: the load, operational temperature, lubrication type, speed of movement, presence of vibration, as well as a broad range of structural properties of the material: the type of matrix and the reinforcing phase, the fraction and size of the reinforcing phase and its morphology [1-8]. Each of these factors has a direct influence on durability and reliability of a tribological pair. The common correlation between the structure and technology of composites production and their properties under the given operational conditions is the source of continuous scientific investigations. A majority of publications concerning the tribological properties of composite materials refer to aluminium alloys reinforced with hard ceramic particles such as SiC, TiC or Al_2O_3 [3-8]. The research conducted on these materials, apart from many advantages, such as enhancement of physical and mechanical properties or a reduction of the weight of constructional components (pistons, connecting-rods), testifies to a negative effect of ceramic particles, i.e. increased wear of the materials cooperating with them.

An interesting solution to this problem are hybrid composites formed by adding to the matrix a reinforcing phase of two types. A material known and examined the best in this area is an aluminium composite containing silicon and graphite carbide particles; such solutions are described in papers [9, 10]. The results of investigations conducted for steel under dry friction conditions have shown almost ten times lower wear of the steel in a cooperation with a hybrid composite reinforced with 20% of SiC with a 10% addition of graphite compared to a composite containing one type of reinforcement, i.e. SiC particles, only. Yet another material and constructional solution proposed by the Honda Company are cylinder liners produced from a composite with heterophase reinforcement, where aluminium oxide in the form of short fibres (12%) is combined with graphite particles (9%). In the solution proposed, the frictional layer thickness is reduced to 2/3 compared to the aluminium alloy previously used, with keeping the same weight. However, in comparison with cast iron inserts, the weight is reduced to 50%. This has also enhanced the effectiveness of cooling in a significant way [9]. 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. 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 [9-17].

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 [12, 13, 21]. 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 [14-20].

2. Aim 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 hybrid 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,
- examination of the structure and phase composition of a composite formed by mechanical stirring,
- 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, methodology and structure of the composites

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) [22,23]. 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]. View of system using to the centrifugal casting of composite is presented in Figure 1.

Fig. 1. View of system using to the centrifugal casting of composite

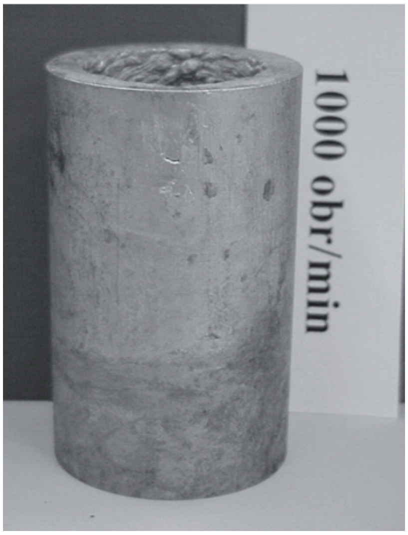

Fig. 2. View of an aluminium composite sleeve obtaining by the centrifugal casting method

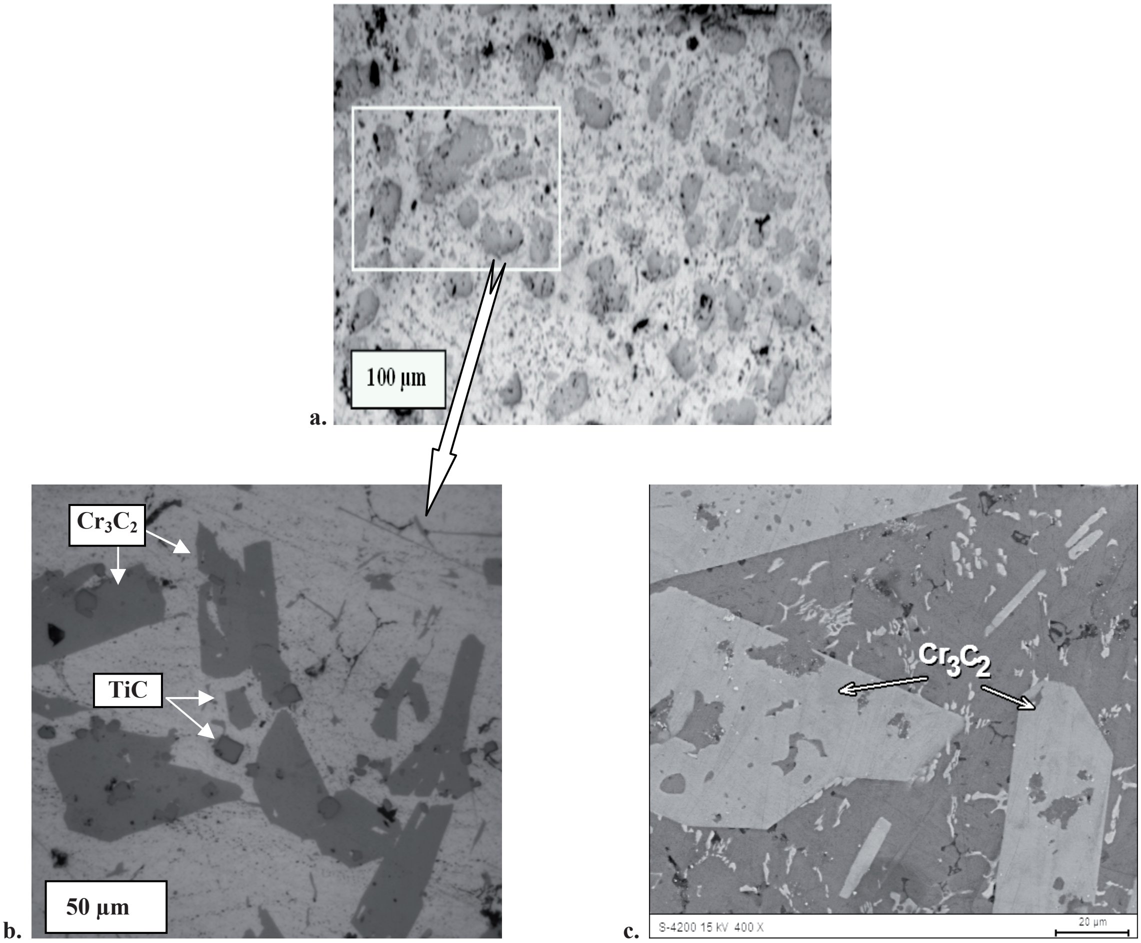

Fig. 3. The structure of aluminium cast composite with hybride reinforcement phases obtaining by the centrifugal casting: a) structure of outside layer, OM; b) microstructure of outside layer, SEM

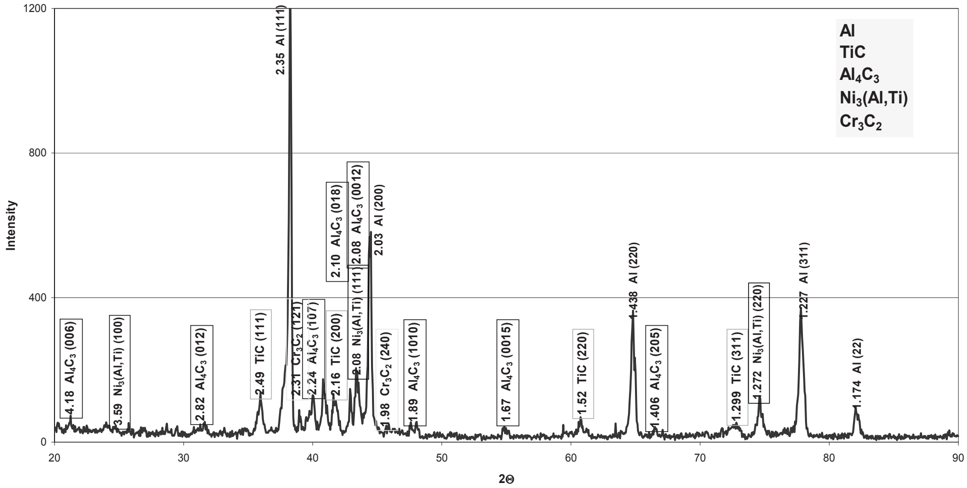

Fig. 4. X-ray diffraction patern (XRD) of the AlMg+NiCr/Cr_3C_2-TiC composite

View of an aluminium composite sleeve obtained by the centrifugal casting is presented in Figure 2. The microstructures of the composite layer obtained as a result of centrifugal casting of the suspension formed after the incorporation of the NiCr-Cr_3C_2-TiC composite powder into the AlMg10 alloy are presented in Figure 3. Based on optical and scanning structural investigations and an X-ray analysis, whose detailed results are presented in papers [14, 15 ,18-20], the presence of phases of different dispersion, morphology and chemical composition in the aluminium matrix was corroborated (Fig. 3, 4).

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 [14-17]. 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. View of the tribological pin-on-disc tester (T-01M) using for research is presented in Figure 5.

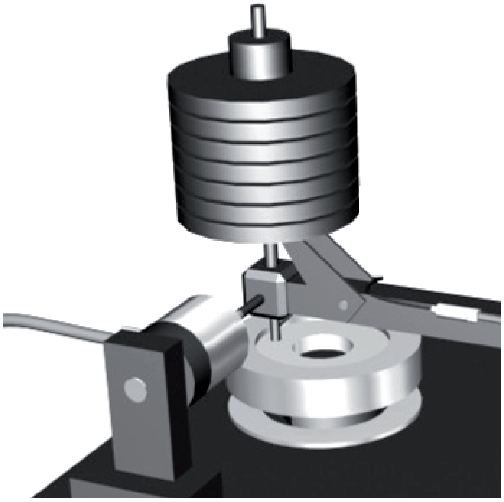

Fig. 5. View of the tribological pin-on-disc tester (T-01M)

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 6 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 7 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.

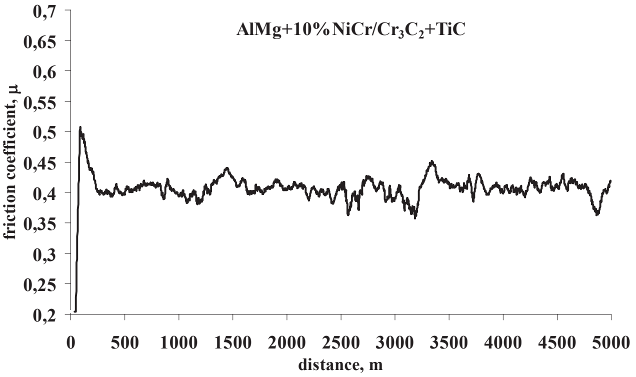

Fig. 6. The diagram of friction coefficient shifts in track function for AlMg+10% NiCr/Cr_3C_2+TiC composite

Figure 8 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.

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. 10) for the cooperating elements as well as measurement of the composite layers' hardness (Fig. 11).

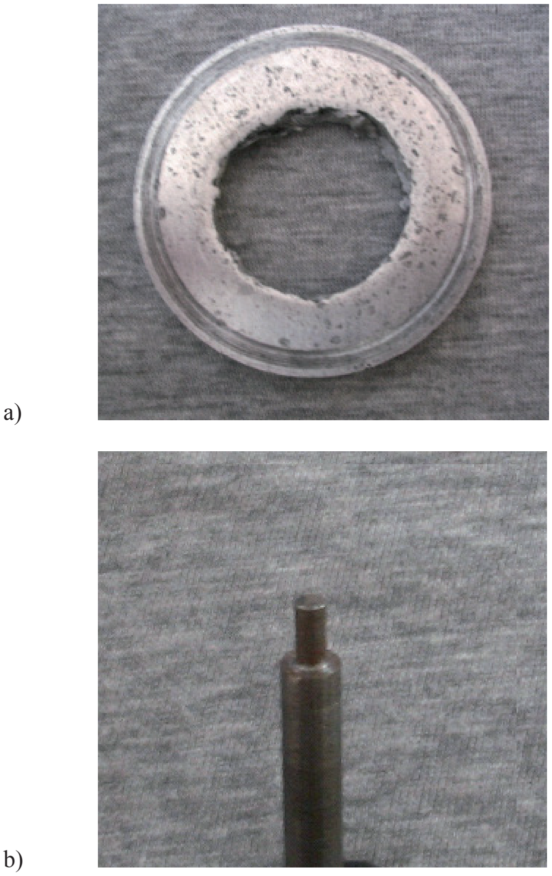

Fig. 7. View of the frictional coupe cast iron- AlMg+10% NiCr/Cr_3C_2+TiC composite: a) composite ring, b) cast iron pin

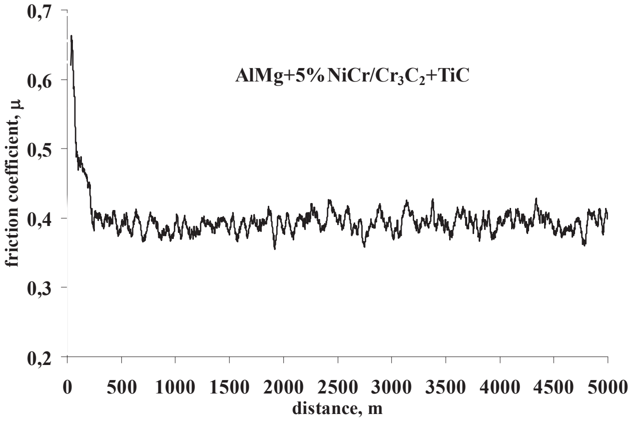

Fig. 8. The diagram of friction coefficient shifts in track function for AlMg+5% NiCr/Cr_3C_2 + TiC composite.

Figure 12 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.

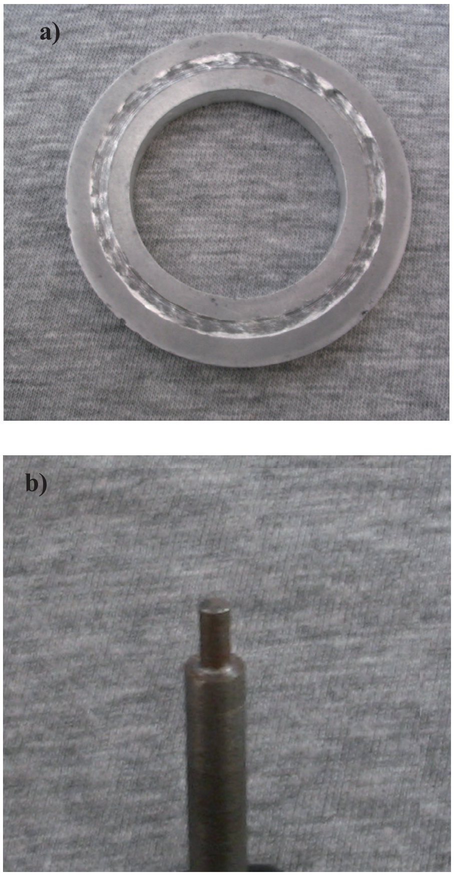

Fig. 9. View of the frictional coupe cast iron- AlMg+5% NiCr/Cr_3C_2+TiC composite: a) composite ring, b) cast iron pin

Figure 13 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.

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. 10). 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.

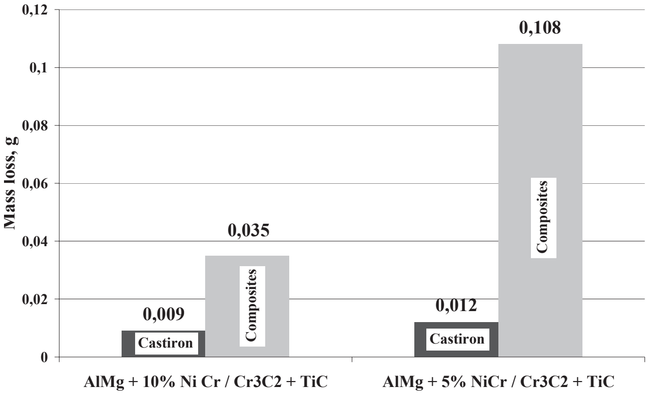

Fig. 10. The loss of cast iron counter sample mass after collaboration in dry sliding conditions at the 5000m distance.

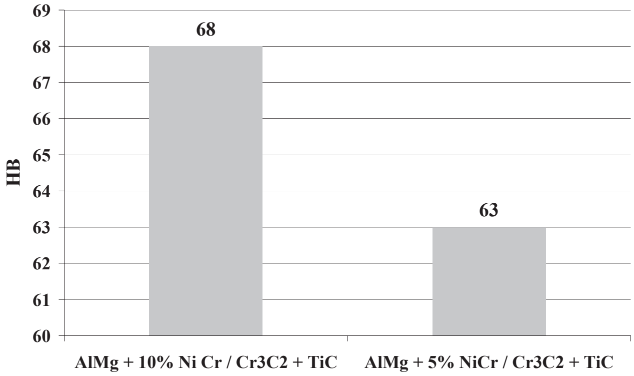

Fig. 11. The hardness of HB Composites layers under the process of wear

Fig. 12. Erosion rack on the AlMg+10%NiCr/Cr_3C_2+TiC composite layer, mag. 50x.

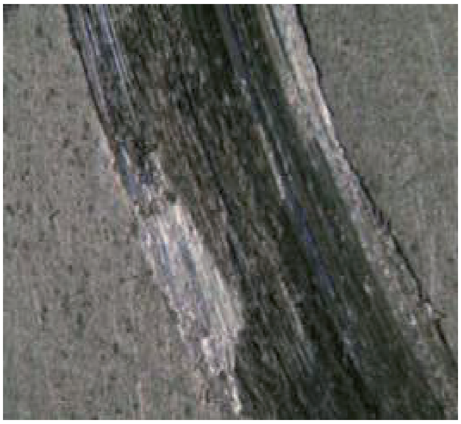

Fig. 13. Erosion rack on the AlMg+5% NiCr/Cr_3C_2+TiC composite layer, mag. 50x

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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Additional information

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