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Influence of manufacturing technology on tribological properties of A390.0 alloy

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ABSTRACT

Purpose: In this paper, results of tribological studies on AlSi17Cu5Mg alloy subjected to a modification (CuP10) and a significant overheating above Tliq are presented, referring them to the starting material.

Design/methodology/approach: The influence of the applied technologies on the refinement of the primary crystals of Si was defined by determination of stereological parameters. In case of the overheated alloy, the primary crystals of silicon assume the forms of polygons with sharp edges after the overheating. In practice, it results in a decrease in tribological properties and an increase in the coefficient of friction in relation to the alloy modified with phosphorus.

Findings: The result show that all investigated properties were changed. Significant differences between the analyzed specimens were proved in the friction coefficient and in the wear rate of the tested friction connections.

Research limitations/implications: The application of modified by CuP10 aluminum alloy allows to reduce the friction coefficient between tested surface and counter-samples and also reduce the wear rate. This property's causes that this material can be used in many applications where the aim is to reduce friction coefficient and wear rate.

Practical implications: Reducing of friction coefficient and increase wear resistance causes that these materials can be used in many applications in the automotive industry such as blocks of engines, cylinders etc.

Originality/value: Influence of aluminium modification on chosen tribological properties have been investigated.

Keywords: Al-Si casting alloys; Microstructure; Stereological parameters; Coefficient of friction

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PROPERTIES

1. Introduction

In construction of internal combustion engines used in automotive industry, AlSi alloys are one of the main groups of structural materials [1]. They are characterized by a relatively low melting point, low density, good electric and thermal conductivities; they exhibit good casting properties (high castability, low shrinkage), and a high corrosion resistance [2].

However, their propensity to form a coarse-grained structure, having an adverse effect on the utility properties, constitutes a problem. Application of modifications is therefore necessary [3]. Unfortunately, the sole refinement of the structure is sometimes little effective, as the silicon crystals formed are characterized by sharp edges, resulting in a decrease of the utility properties. Thus, it is necessary to search for such modification methods which – apart from the refinement of the primary Si crystals – will allows for obtaining a spherical form or similar [4,5].

2. Aim and scope of studies

The aim of the studies was to define:

- coefficient of friction for the silumin-cast iron friction pair;
- the influence of the stereological parameters of the primary Si crystals on the coefficient of friction.

3. Test materials and methods

An AlSi17Cu5Mg alloy, close to A390.0 type of the A3XX.X series for casting in sand molds and metal molds, intended for, among others, cast of pistons for internal combustion engines, was studied.

The modification was carried out using a Cu-P master alloy (~9.95% P). The refinement was executed using "Rafglin-3" preparation in the amount of 0.3% by wt. The technology for preparation of hypereutectic silumins with additions of Cu and Mg is detailed in [6]. In order to limit the adverse effect of phenomena connected with gassing of the liquid bath, resulting from a significant overheating of the alloy above $T_{liq.}$ (920°C), a 0.4% Protecol-Degasal protective coating was used. Metallographic studies were carried out using a MeF-2 Reichert optical microscope. The results of the chemical composition analysis are shown in Table 1.

The investigations were carried out using a T-01 tribological tester (Fig. 1) in a mandrel-disc connection. The testing connection consists of an stationary mandrel pressed with a force *P* to a disc rotating with a given speed *n*. The T-01 tester allows for determining the coefficient of friction and wear resistance of the studied materials. The drive of the device is stopped automatically after a defined time or a defined friction distance is travelled, enabling precise control of the measurement process. The test was carried out according to the requirements of the DIN 50324 standard.

Table 1.
Chemical composition of A390.0 alloy, in mass %

	Element	% Share
A390.0 alloy	Si	16.64
	Cu	4.78
	Ni	0.11
	Mg	0.94
	Fe	0.67
	Mn	0.03
	Ti	0.009
	Cr	0.01
	Al	rest

Fig. 1. T-01 tribological tester used for the studies

The test parameters were assumed to reflect the conditions of cooperation of the piston skirt with the cylinder barrel most fully for an internal combustion engine having power up to about 100 kW. The diameter of the mandrel cast made of A390.0 alloy was 4 mm, while the diameter of the disc made of EN-GJL-350 cast iron was 42 mm. The feed force was 0.8 MPa, and the given speed 0.55 m/s. Every test was repeated ten times. During the test, a measurement of the friction force F_t was recorded and the force was converted to the coefficient of friction μ by the measurement system. The measurement of mass losses of the mating mandrel-disc elements was carried out using a Radwag AS 220/C/2 scale with precision of 0.1 mg. The path of friction amounted to 1800 m.

4. Results and discussion

During the tests, wear of a mandrel made of the AlSi17Cu5Mg alloy (Z_t) and a disc mating with it (Z_z) made of EN GJL-350 cast iron. Also, friction force was measured and converted to coefficient of friction (μ). In Table 2, the obtained results are gathered, while in Fig. 2, an exemplary, instantaneous course of coefficient of friction for the tested AlSi17Cu5Mg alloy manufactured by various techniques is shown.

The studies indicate that the starting alloy, characterized by coarse-grained silicon crystals, while mating with the cast iron disc, obtained a coefficient of friction of μ = 0.27 under dry conditions.

Table 2.
Results of studies on the AlSi17Cu5/EN GJL-350 friction pair

Studied alloy	Measurement results			
	Z_t, mg	Z_z, mg	μ	σ_μ
Starting material	2.52	4.42	0.27	0.014
Material after modification	3.24	2.80	0.25	0.009
Material after overheating	3.02	3.05	0.26	0.008

Z_t – AlSi17Cu5Mg mandrel wear;
Z_z – EN GJL-350 disc wear;
μ – coefficient of friction.

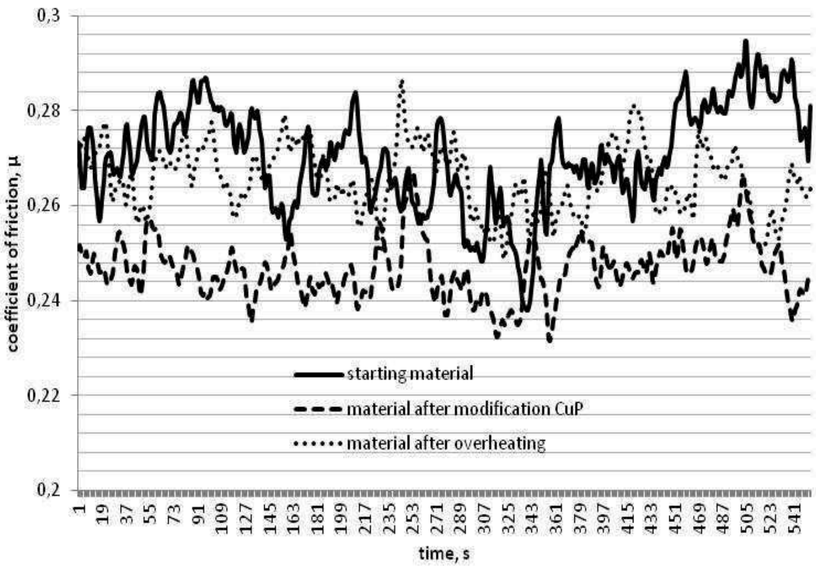
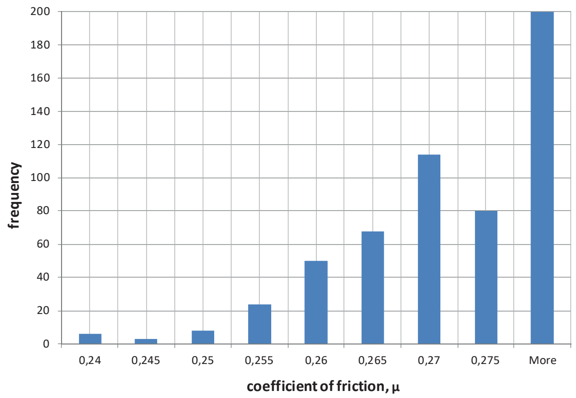


Fig. 2. Course of the coefficient of friction for the investigated materials

Standard deviation for this material amounted to 0.014. Coefficient of friction for the alloy with CuP modification amounted to μ = 0.25 with a standard deviation of 0.009. The material subjected to both modification and then overheating, while mated with the cast iron disc, reached the coefficient of friction on the level of μ = 0.26 with a standard deviation of 0.008.

One should note the fact that in case of the starting alloy, the coefficient of friction has the highest value, but also with the highest standard deviation value. It indicates a high amplitude of the instantaneous force occurring in the contact point of the two studied materials, being a highly unfavorable effect. In order to discern the problem more thoroughly, in Fig. 3, histograms of the coefficient of friction course for the studied materials are shown. One may observe there that the material subjected to modification has clearly the lowest coefficient of friction, and its mean values are concentrated in the range of 0.25-0.255. The coefficient of friction course for the alloy subjected to an overheating is characterized by the lowest oscillation amplitude, being clearly visible in Fig. 3c. The course of the histogram is the gentlest, and the frequencies of the coefficient of friction in the individual ranges are close. An inverse situation occurs in the case of the starting alloy, with the majority of the values in the range of 0.275-more, which was shown in Fig. 3a.

a)



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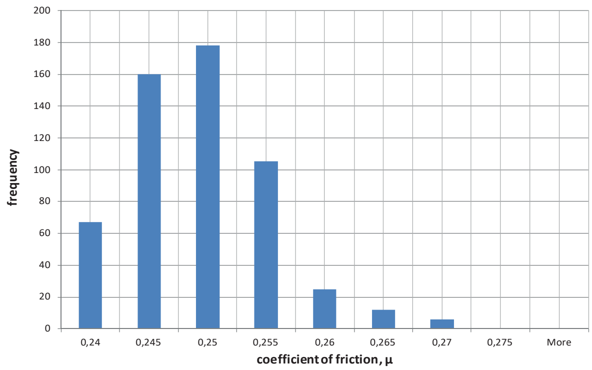


c)

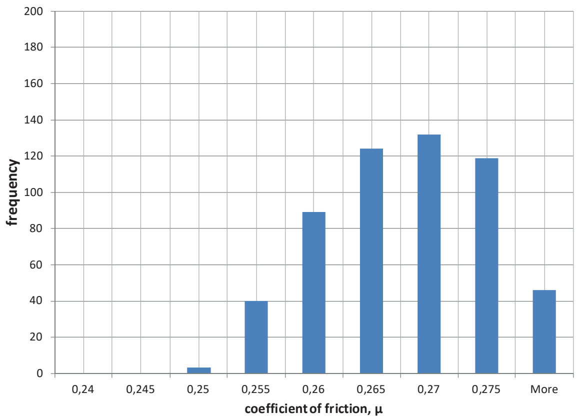


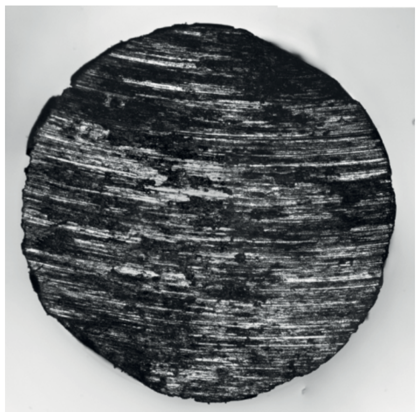
Fig. 3. Variability histogram of the instantaneous coefficient of friction: a) starting alloy, b) after the CuP modification, c) after the overheating

The wear of the mandrel made of the AlSi17Cu5Mg alloy amounted to Z_t = 2.52 mg ±0.52 for the starting material, Z_t = 3.24 mg ±0.46 for the material modified with CuP, and Z_t = 3.02 mg ±0.49 for the material subjected to overheating. The wear of the disc made of the EN GJL-350 cast iron in connection with the starting alloy was on the level of Z_z = 4.42 mg ±0.54, Z_z =2.80 mg ±0.45 for the modified alloy, and Z_z =3.05 mg ±0.37 for the material subjected to overheating (Table 2).

In Figure 4, post-friction appearance of mandrels made of the AlSi17Cu5Mg alloys using various techniques. In Fig. 4a, detachments of the material caused most probably by significant increases in the instantaneous friction force are clearly visible on the edges.

a)

b)



c)

Fig. 4. A390.0 mandrel after the friction test: a) starting alloy, b) after the CuP modification, c) after the overheating

A thorough observation allows for noticing that the mandrel of the material subjected to overheating is also characterized by a most uniform wear, manifesting itself with a lack of visible breaches in the surface while compared to the other two tested materials.

5. Summary

The studies carried out on A390.0 alloy using a T-01 tribological tester allowed for a more exact defining of the influence of manufacturing technology on tribological properties. Significant differences between the individual samples were proved in the coefficient of friction and in the wear of the tested friction connections. It is also noteworthy that not only differences in the coefficient of friction value were observed, but a variability of the course of the instantaneous friction for the studied materials were found too.

Summarizing, one may state that:

- a modification of the A390.0 alloy with CuP master alloy results in a decrease in the coefficient of friction while connected with the tested cast iron;
- for all tested connections, total wear of the disc and the mandrel is similar and it amounts to about 6.2-6.9 mg;
- the mandrel wear is higher in the case of the modified material, while a higher disc wear has been observed in the case of the starting material. In the case of the material after overheating, life of both the mandrel and the disc was on the same level.

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