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Influence of Casting Conditions on Tribological Properties of A390.0 Alloy

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Abstract

The paper presents tribological properties of A390.0 (AlSi17Cu5Mg) alloy coupled in abrasive action with EN-GJL-350 grey cast-iron. The silumin was prepared with the use of two different technologies which differed in terms of cooling speed. In the first case the alloy was modified with foundry alloy CuP10 and cast to a standard tester ATD and in case of second option the modified alloy was cast into steel casting die. Due to different speed of heat removal the silumins varied in structure, particularly with size of primary crystals of silicon and their distribution in matrix which had a significant influence of friction coefficient in conditions of dry friction.

Keywords: The Al-Si cast alloys, Tribological properties, Friction coefficient, Casting conditions

1. Introduction

A strive for continuous improvement of mechanical and technological properties of casts made of Al-Si(Me) alloys leads to a necessity for a repeated analysis of the modification process and conditions of heat removal. In the case of hypereutectic alloys, phosphorus-based master alloys are the basic modifier [1–4]. However, structural changes in machines and equipment, for which these alloys are used, e.g. in internal combustion engines, result in a necessity for an expansion of knowledge on the influence of various technological solutions on excessive requirements of casts particularly exposed to high loads. Such conditioning includes tribological properties, determining the applications of the casts and their wear rate in various connections of friction nodes. The friction and wear process is conditioned by numerous factors taking into account mechanical properties of

cutting materials, their surface roughness, plastic deformation, ambient temperature or presence of a lubrication medium [5–7].

Al-Si alloys with hypereutectic silicon content are used, among others, as a material for pistons of internal combustion engines. Currently, such engines, mainly spark-ignition engines and hybrid engines undergo a process of technological changes, consisting in introduction of turbocompressors. Until recently, turbocompressors were installed only in Diesel engines with compression ignition, thus the material requirements varied depending on the vehicle power system. Technological changes enforced by environmental protection standards caused an increase in the compression ratio in internal combustion engines from approx. 9 to 13 MPa, with a simultaneous reduction of the engine displacement. These changes, consisting in a pressure increase in the combustion chamber with accompanying reduction of the piston diameter forced manufacturers to use materials with modified chemical composition and known utility properties,

including tribological properties, for various conditions of melting and casting.

However, these solution must take into account one important aspect, namely economics of the process. Development of entirely new materials and production techniques would be very expensive, therefore studies on improvement of existing alloys, obtained by various technologies [4, 5], are carried out. Thus, expansion of knowledge on the influence of history of manufacturing technology of Al casting alloys on tribological properties under industrial conditions seems rational.

2. Aim and scope of the research

The aim of the paper is to evaluate the influence of casting conditions determined by the cooling rate on tribological properties of the A390.0 alloy (pin) in an abrasive connection with EN-GJL-350 grey cast iron (disk). The connection was selected so as to mirror the cylinder-piston system most precisely. In order to achieve the assumed goal, the scope of works includes, among others:

- assumptions of tribological studies methodology using a T-11 tester,
- determination of friction coefficient for dry friction conditions in the piston-cylinder barrel connection,
- structural studies.

3. Materials and research methodology

The AlSi17Cu5Mg cast alloy according to ASTM standard – A390.0) was chosen for the studies. It was casted to sand moulds and casting dies and meant for i.e. castings of pistons of internal combustion engines, blocks, and cylinder bodies of compressors, pumps and brakes. This silumin was used as pin. EN-GJL-350 grey cast iron obtained according to PN-EN 1561:2012 was used as the disk.

The selected silumin was prepared from EN AM-ALSi20 alloy (according to PN-EN 575) and pure Al (according to PN-EN 576) in the form of pig-iron and master alloy AlCu50 and AG10 as the magnesium carrier. The alloy was melted in a melting pot from SiC with capacity of 200 cm³ in induction furnace VSG 02/631.

Modification with 0.05% by wt. of was carried out using CuP10 master alloy. Refinement was carried out using 0.3% by wt. of Rafglin3. One part of the alloy was cast into a standard ATD sampler from Heraeus Elektro Nite, obtaining:

1. a cooling rate of approx. 1°C·s⁻¹ (designation: A390.0 ATD),
2. while the other part was cast into a steel permanent mould with a cooling rate of 10°C·s⁻¹ (designation: A390.0 K).

Metallographic specimens were prepared according to the standard procedure. Metallographic studies were carried out using an MeF-2 Reichert optical microscope. The results of measurements of the stereological primary silicon crystals made using AnalySiS® program, under observation in the bright field.

Tribological studies were carried out using a T-11 device in the mandrel-disk connection shown in Figure 1.

The device allows for determining the friction coefficient for any material connection, operating in sliding motion, depending on the ambient temperature of the friction node, slide velocity, as well as surface pressures. It is particularly useful for tribological tests under conditions of boundary lubrication. The friction connection is composed of a fixed mandrel (A390.0 alloy) pressed with a force “P” to the disk rotating with a given rotational speed “v” (EN-GJL-350 cast-iron).

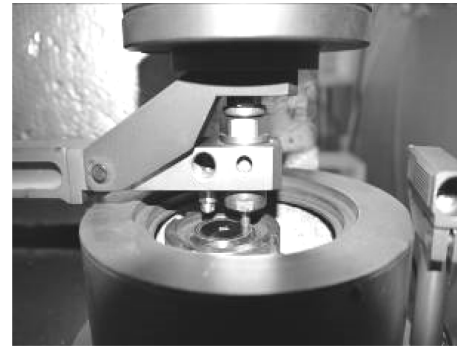


Fig. 1. The tribological tester T-11

The friction node is placed in an insulated chamber equipped with a heating element, for heating and maintaining a constant temperature inside the testing chamber. The tests were carried out according to the requirements of the ASTM G 99 standard. Parameters of the friction node were chosen so as to they correspond to conditions inside an internal combustion engine of up to 100 kW.

The path of friction was 1000 m, and the temperature was 90°C.

4. Results and their analysis

Chemical composition of AlSi17Cu5Mg alloy is shown in Table 1.

Table 1. Chemical composition of AlSi17Cu5Mg alloy (A 390.0)

Alloy	Si	Cu	Mg	Ni	Ti	Mn	Fe	Al
A390.0	16,36	4,48	0,92	0,02	0,01	0,09	0,21	rest

The results of the friction coefficient measurements at various parameters are shown in Table 2.

Table 2. Test results for the connection A390.0 alloy vs EN GJL-350 cast iron at 90°C

Tested alloy/ type of mould	v, m/s	P, MPa	μ	σ _μ
A390.0 ATD	0,1	0,4	0,27	0,007
A390.0 K	0,1	0,4	0,27	0,006
A390.0 ATD	0,55	0,4	0,25	0,006
A390.0 K	0,55	0,4	0,26	0,006
A390.0 ATD	1,0	0,4	0,23	0,003
A390.0 K	1,0	0,4	0,23	0,002

where:

- v – disc rotational speed.
- P – pin to disc pressure force.
- μ – friction coefficient.
- σ_{μ} – standard deviation of friction coefficient.

An exemplary microstructure of the A390.0 alloy in unmodified (different magnifications) is shown in Figure 2. Microstructure of the A390.0 alloy after modification with CuP10 master alloy cast into the ATD sampler and steel permanent mould is shown in Figure 3. The after-friction surface of the mandrel made of the A390.0 alloy is shown in Figure 4, while the surface of the disk made of the EN-GJL-350 cast iron is shown in Figure 5.

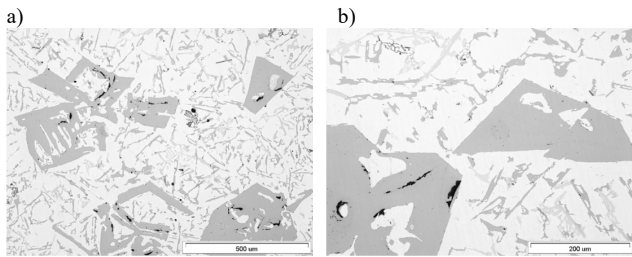


Fig. 2. Microstructure of A390.0 alloy in unmodified: a) magnifications 100 ×; b) magnifications 200 ×

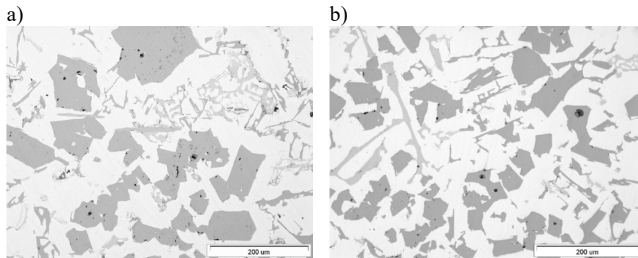


Fig. 3. Microstructure of A390.0 alloy after modification CuP10: a) A390.0 ATD; b) A390.0 K

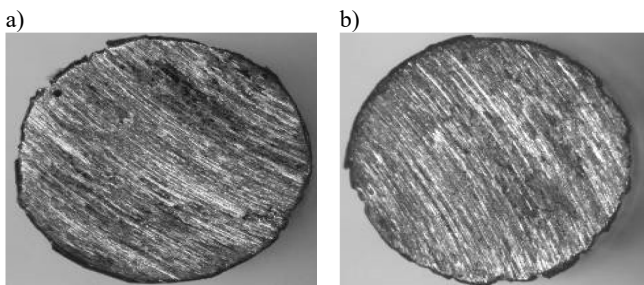


Fig. 4. Surface of pin after friction: a) A390.0 ATD alloy, b) A390.0 K alloy

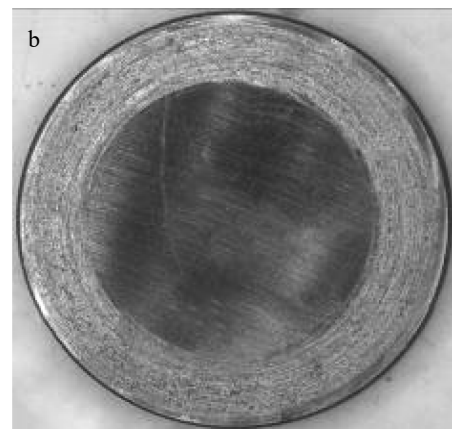
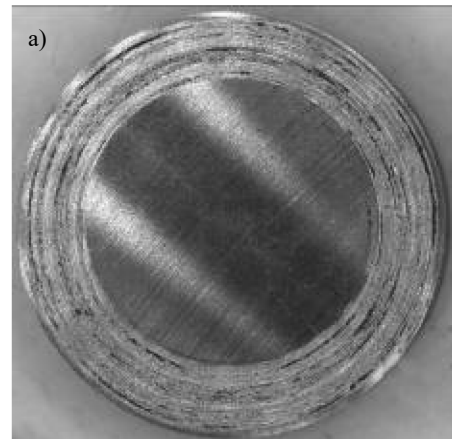


Fig. 5. Disk surface after friction in connection with the alloys: a) A390.0 ATD; b) A390.0 K

An exemplary course of the change in the friction coefficient value for the A390.0 alloy cast into the ATD sampler and permanent mould, for the speed of $0.55 \text{ m}\cdot\text{s}^{-1}$ is shown in Figure 6.

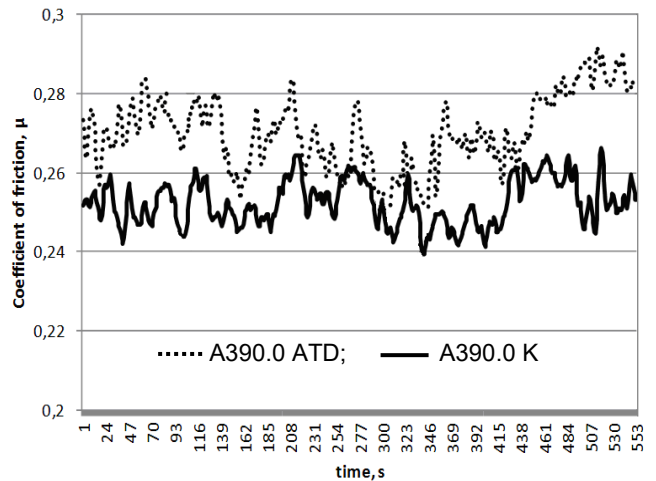


Fig. 6. Course of friction coefficient for the A390.0 alloy

Microstructures of the AlSi17Cu5Mg (A390.0) alloy shown in Figure 3 indicate that the modification with CuP10 master alloy lead to a significant refining of primary silicon crystals in the matrix of the Al solution.

Additionally, it can be observed that the achievement of the fast crystallisation conditions as a result of casting to a steel casting die caused even bigger refining of the microstructure, although this influence is not as clearly visible. As a result of the fragmentation of the structure (due to the modification process and intensive cooling) measurements stereological parameters of the primary silicon crystals in the A390.0 alloy. These results are shown in Table 3.

Table 3.
Stereological parameters of the primary silicon crystals in the A390.0 alloy

Stereological parameters	A390.0 alloy unmodified	A390.0 ATD alloy	A390.0 K alloy
surface area, μm^2	2150	12	9
circumference, μm	763	9	6
average diameter, μm	178	3	2,9
intermolecular distance, μm	192	4,7	4,4

Results of tests allow to conclude that quick cooling, despite its influence of the primary structure change of tested alloy, does not reflect in the change of tribological properties coupled with cast-iron disc. Conducted tests have shown that, in the given friction conditions, the friction coefficient for A390.0 silumin casted into two types of moulds (tester ATD and steel casting die) had similar values in both cases (see Table 2). Also the standard deviation which shows the spread of results of the influence of instantaneous values of friction force was also on similar levels. This tendency does not refer to all tested speeds ($v = 0.1 \text{ m}\cdot\text{s}^{-1}$; $0.55 \text{ m}\cdot\text{s}^{-1}$ and $1 \text{ m}\cdot\text{s}^{-1}$).

The analysis of microscope tests of the surface after friction did not show bigger differences between each of samples. The surface of the pin from AlSi17Cu5Mg (A390.0) cast alloy both to tester ATD and steel casting die looked similarly. It is worn off at a uniform rate without noticeable breaches. The analysis of the depth of the friction mark also did not show significant differences. The only visible difference are the fuzzy edges of the pin cast from A390.0 alloy subject to quick cooling in reference to material cast according to standard speed if heat removal.

In case of microscope analysis of disc prepared from cast-iron EN GJL-350 there were no significant differences observed. The size of mark after friction of pin was the same. The surfaces did not have significant breaches and were evenly worn off.

5. Summary

The conducted tribological tests with the use of tester T-11 (Fig. 1) allow to conclude that the conditions of heat removal intensity regulated with the type of casting mould by A390.0 casting alloy do not have direct reflection in the changes of tribological properties by the assumed testing parameters. The friction coefficient for all samples, by the same speeds and given

temperature of 90°C , was on a similar level. Amplitude of the instantaneous friction force described with the value of standard deviation was also on a similar level. It should be pointed out, however, that the accelerated cooling did not influence the deterioration of tribological properties of the tested alloy. It is important due to the fact that the previous tests have shown that accelerated cooling because of the application of casting die causes the increase of mechanical [10] and plastic [11] properties of tested alloy.

Continue tribological research was to be conducted with the use of a lubricant and using other pin pressure and rotational speed of disc.

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