www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES
of
FOUNDRY ENGINEERING

DOI: 10.1515/afe-2015-0043

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 15
Issue 2/2015

79 – 84

Shaping the Microstructure of Cast Iron Automobile Cylinder Liners Aimed at Providing High Service Properties

A.W. Orłowicz*, M. Mróz, M. Tupaj, A. Trytek
Department of Casting and Welding, Rzeszow University of Technology,
al. Powstańców Warszawy 12, 35-959 Rzeszów
*Corresponding author. E-mail address: aworlow@prz.edu.pl

Received 23.02.2015; accepted in revised form 31.03.2015

Abstract

The paper presents an analysis of factors affecting the wear of cylinder liners. The effect of the graphite precipitation morphology on the cylinder liner wear mechanism is presented. Materials used to cast cylinder liners mounted in a number of engines have been examined for their conformity with requirements set out in applicable Polish industrial standard. A casting for a prototype cylinder liner has been made with a microstructure guaranteeing good service properties of the part.

Keywords: Cast iron, Automobile cylinder, Service properties

1. Introduction

Materials testing carried out with cylinder liners taken from many different car engines proved that they demonstrate a variety of wear mechanisms depending on the morphology of graphite precipitations [1–6]. To determine the wear mechanism prevailing in the material used for cast iron cylinder liners [7], abrasive wear tests were carried out on samples with graphite precipitation size of up to 15 µm (Gw15), 31–60 µm (Gw45), and 61–120 µm (Gw90). For the graphite precipitation sizes and thus also for its distribution, decisive are conditions in which crystallization occurs. With increasing casting solidification rate, intensified tendency to growth of fine graphite precipitations characterized with interdendritic distribution (Gr6, Gr7) can be observed. With decreasing solidification rate, the tendency to development of large graphite precipitations increases with even (Gr1) or uneven (Gr2) distribution.

Graphite precipitations with size of up to 15 µm are usually arranged in the form of clusters (interdendritic distribution). In the areas characterized with such precipitations, the material demonstrates deteriorated mechanical properties and is therefore susceptible to tear-outs occurring in the course of variable cyclic load exerted on the liner bearing surface by piston rings (Fig. 1a).

In case of cast iron with graphite precipitation sizes ranging from 31 µm to 60 µm, they are distributed in the matrix either evenly or unevenly. As a result, the material in the area of continuous oil film is subject to even wear, without any tear-outs (Fig. 1b).

In case of a casting iron with graphite precipitation sizes exceeding 60 µm, the matrix contains evenly distributed, sometimes coarse graphite precipitation. Some of these precipitations are oriented parallel or at a small angle with respect to the load bearing surface. As a result of cyclic interaction of variable loads coming from piston rings, the matrix bridges between graphite vertices and the bearing surface are locations where fatigue damage of the material occurs resulting in occurrence of tear-outs (Fig. 1c).

a) b) c)

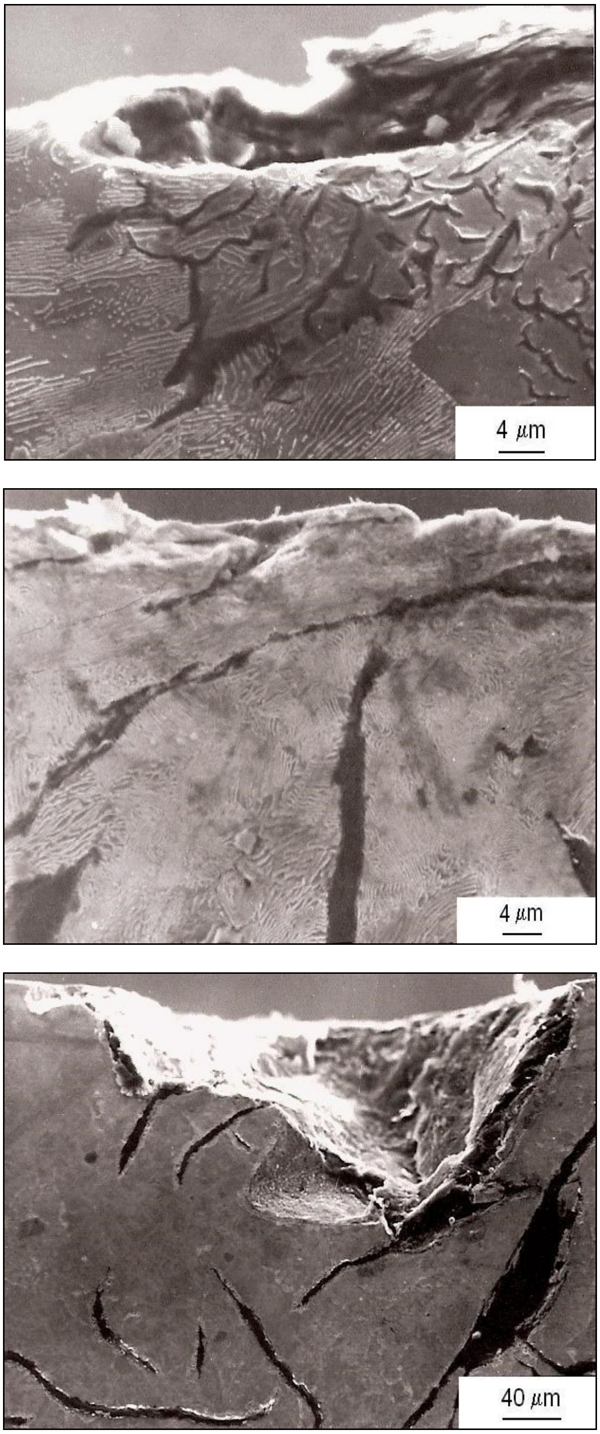


Fig. 1. Cylinder liner material wear with a diversified morphology of flake graphite precipitations. Visible are material tear-outs in the area of fine graphite precipitations sites with sizes of up to 15 µm and interdendritic distribution; (a) a view of the load bearing surface; (b), (c) views in the plane perpendicular to the bearing surface

An issue important from the point of view of extending engine service life is to ensure appropriate quality of cylinder liner bearing surface. Such surface should ensure continuous maintenance of a permanent oil layer on it and should be characterized with a satisfactory load bearing capacity. The factors decisive for stability of the lubricating layer include engine oil properties [8] and geometrical structure of surfaces remaining in frictional contact [9]. Particularly good capacity to create the oil film as early as in the engine starting stage, is demonstrated by synthetic oils. These lubricants are less sensitive to viscosity changes resulting from oil temperature variations which is of great significance for maintaining the stability of oil film thickness.

Cylinder liners with high level of smoothness make retaining the oil film on the bearing surfaces very difficult. To increase the ability of cast iron cylinder liners to retain oil on their bearing surfaces, the operation of honing is typically performed, consisting in making scratches with appropriate profile, arranged in the form of a mesh. Different manufactures recommend their proprietary micro-geometry parameters for cylinder liner bearing surfaces. The company Goetzewerke [10] recommends application of a two-stage honing aimed at shaping the load bearing surface (plateau) with a profile as this shown in Figure 2.

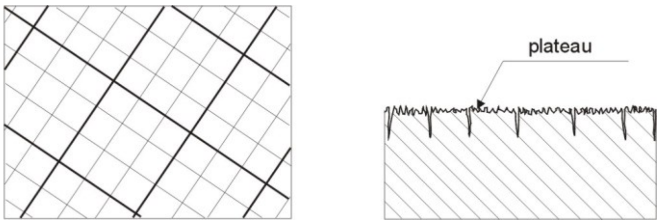


Fig. 2. Schematic diagram of a surface honed to shape a plateau

A view of the test cylinder liner bearing surface after durability tests is shown in Figure 3 [11].

Cast iron cylinder liners can be machined in the engine block casting. They can be also cast as separate components and then mounted in the engine block. They can be also given a form of cast-in sleeves in engine blocks made of Al-Si alloys. If a particularly high resistance to abrasive wear of the cylinder liner must be ensured, it can be increased by surface hardening in the cylinder bearing surface area or by application of the surface remelting process [12].

Analysis of materials used by renowned carmakers to manufacture components of their motor cars reveals that special operations aimed at improvement of resistance of cylinder liners to abrasive wear are usually dispensed with in view of high manufacturing costs.

General requirements applicable to castings for engine cylinder liners are provided in the standard BN-78/1372-01 [13]. The norm recommends to use a cast iron with the following composition: 3.0–3.7% C, 2.0–2.8% Si, 0.7–1.2% Mn, 0.25–0.55% Cr, 0.4–0.8% P, up to 0.15% S, Fe to balance. Such cast iron should be characterizes with graphite precipitations with simple flake (Gf1) or warped flake (Gf2) shape. Graphite precipitation sizes should range from 31 µm to 250 µm (Gw45–Gw180). Acceptable is occurrence of graphite precipitation sites with sizes of up to 15 µm (Gw15) and with sizes ranging from 16 µm to 30 µm (Gw25). Graphite distribution may be even (Gr1), uneven (Gr2), rosette-shaped (Gr5), and interdendritic (Gr6). The cast iron should be characterized with a pearlitic matrix, possibly with a small admixture of ferrite precipitations (P-P92). Phosphide eutectic in such iron should constitute either well-developed (Fr3) or poorly developed (Fr2) network. The cast iron should demonstrate hardness from 210 HB to 280 HB. Its tensile strength should not be lower than 225 MPa.

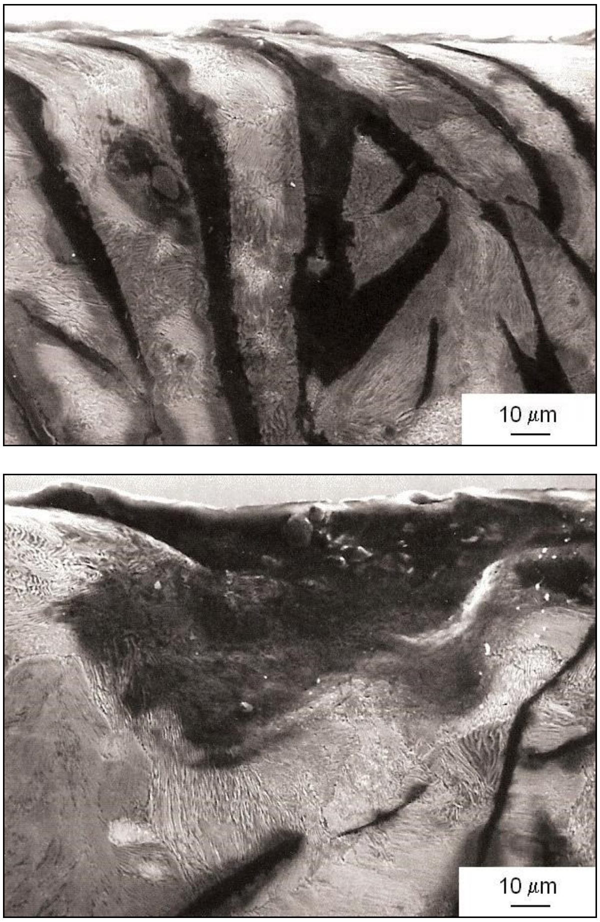
a)
b)


Fig. 3. A view of the cylinder liner bearing surface in the piston dead center region (a-b)

Car engine cylinder liners are usually fabricated with the use of centrifugal casting. In view of specificity of this casting method, the obtained liners demonstrate a varying structure with some gradient along the wall thickness cross-section. For this reason, in order to obtain a repeatable structure in the cylinder liner bearing surface area, it is necessary to keep regimes of the technological process on the required level with particular accuracy.

Much less risk of arriving at a strong gradient structure exists when castings for cylinder liners are cast into sand moulds. A well-known drawback of this technology is the longer manufacturing cycle.

2. The experiment

The objective of the study was to assess compliance of microstructure observed in cylinder liners taken from foreign engines with requirements set out in the industry standard.

A practical target of the study reported in this paper was to develop and describe such microstructure of a casting for engine cylinder liner cast in a sand mould that that the required high resistance to abrasive wear and low susceptibility to seizing will be ensured.

The scope of the study included:

- material examination of two reference cylinder liners taken from foreign engines (denoted as No. 1 and No. 2),
- fabrication of an experimental cylinder liner and carrying material tests.

Reference cylinder liners were taken from engines with mileage of 600 thousand kilometers.

Chemical composition of cast iron used to make the cylinder liner No. 1 was as follows: 3.4% C, 2.4% Si, 0.5% Mn, 0.39% Cr, 0.22% Cu, 0.5% P, 0.027% S, Fe to balance. In such cast iron, presence of graphite precipitations with sizes ranging from 25 µm to 60 µm (Gw25–Gw45) was found. The observed precipitation shapes included simple flake (Gf1) and warped flake (Gf2) forms. They were distributed in the matrix unevenly (Gr2) and rosette-shaped (Gr5). Despite manganese content lower than required by the standard, the cast iron, thanks to higher content of copper, had the pearlitic matrix structure (P) with well-developed phosphide eutectic network (Fr3). Hardness of the cast iron has turned out the be in the range 212–264 HB. Therefore, the material was found to be conforming with requirements set out in the industry standard as far as its structure and hardness were concerned.

A cast iron with the following chemical composition has been used to fabricate the cylinder liner No. 2: 3.2% C, 2.0%Si, 0.7% Mn, 0.2% Cr, 0.3% Cu, 0.14% P, 0.1% S, Fe to balance. In such cast iron, presence of graphite precipitations with sizes ranging from 31 µm to 120 µm (Gw45–Gw90) was found. The precipitations had simple forms (Gf1). They were evenly (Gr1) and unevenly (Gr2) distributed in the matrix. The cast iron was characterized with pearlitic structure (P) and poorly developed phosphide eutectic network (Fr2). Hardness of the cast iron was found to be within the limits of 121–179 HB. Therefore, requirements were fulfilled as far as the material microstructure was concerned, but hardness was slightly lower than this required by the industry standard.

To sum up, with the chosen chemical compositions, conditions of solidification of these cylinder liner castings were selected in a way securing development of pearlitic structure of the matrix, with either poorly- or well-developed phosphide eutectic network and graphite precipitation sizes ranging from 6 µm to 120 µm. One of the liners turned out to have hardness lower than this required by the industry standard.

The experimental cylinder liner with internal diameter 70 mm, external diameter 370 mm, and length 370 mm was cast into bentonite clay mould. The liner was cast in vertical position. Liquid metal was supplied to the mould cavity from above. To ensure good feeding, a feedhead has been designed. The liquid metal was prepared in an induction stove with capacity of 1500 kg. Chemistry of the material is given in Table 1.

Table 1.
Chemistry of the cylinder liner material

Element content, %							
C	**Mn**	**Si**	**Cr**	**Cu**	**P**	**S**	**Fe**
3.20	0.77	1.65	0.38	1.26	0.52	0.11	balance

Metallographic examination was carried out on samples taken from the cylinder liner area located 10 mm and 170 mm (at half height) from the base, close to the outer surface.

In view of the fact that microstructures of samples taken from both areas subject to analysis were similar to each other, examples of metallographic examinations presented in the following refer the samples taken at half height of the casting.

Evaluation of size, shape, and distribution of graphite precipitations was performed on non-etched metallographic sections (Fig. 4).

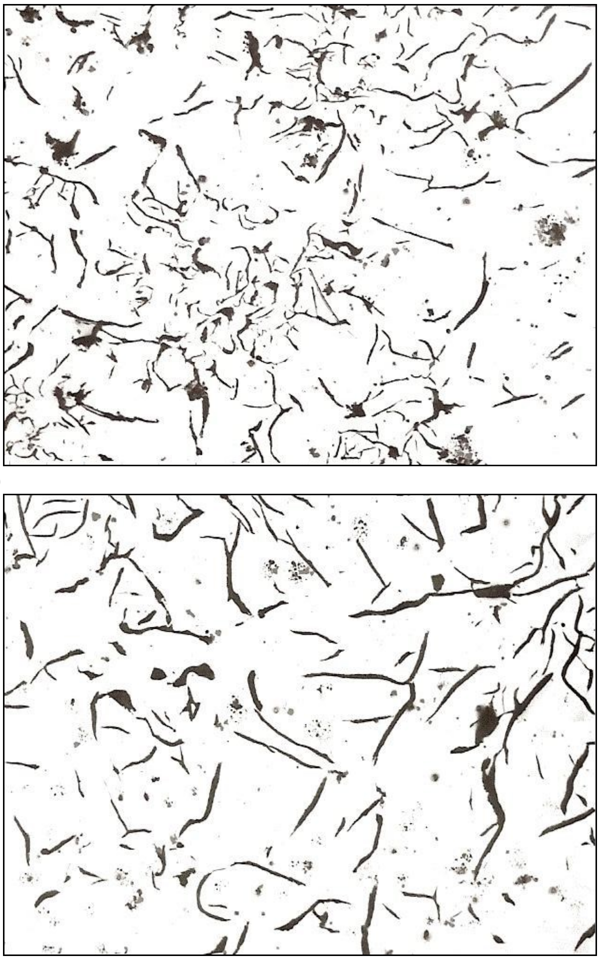
a)
b)


Fig. 4. Structure of the experimental liner casting: (a) in the area adjacent to the inner surface and (b) at half thickness of the casting wall. Non-etched section. Magnification 110×

The matrix was assessed on metallographic sections etched in 4% HNO_3 (Fig. 5). The phosphide eutectic was analyzed on metallographic sections etched in 4% HNO_3 for a sufficiently long period of time (Fig. 6).

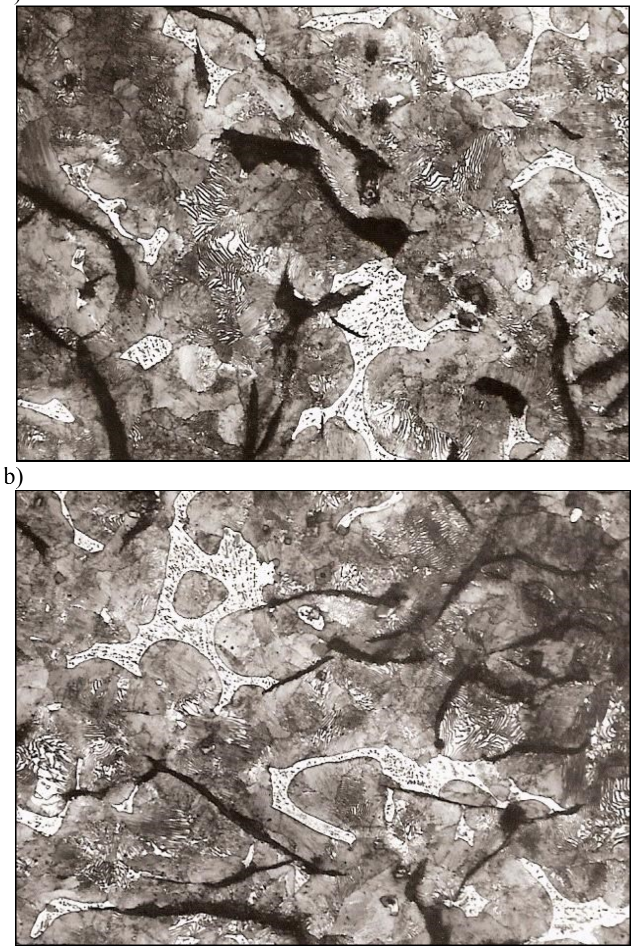
a)
b)


Fig. 5. Structure of the experimental liner casting: (a) in the area adjacent to the inner surface and (b) at half thickness of the casting wall. Etching in 4% HNO_3. Magnification 250×

Graphite precipitations found in the analyzed experimental liner casting in its area adjacent to the inner surface included apparently dominant precipitations with sizes ranging from 31 μm to 60 μm (Gw45), as well as larger precipitations with sizes ranging from 61 μm to 120 μm (Gw90). Dimensions of graphite precipitations observed at half wall thickness were similar, however in this case precipitations with size ranging from 61 μm to 120 μm (Gw90) prevailed. These were precipitations with simple shapes (Gf1), distributed in the matrix unevenly (Gr2) in case of the superficial area and evenly (Gr1) at half thickness of the casing wall.

It has been found that over the whole cross-section of the experimental liner casting, the material was characterized with pearlitic matrix structure, phosphide eutectic precipitations, and flake-shaped graphite. On the whole cross section of the experimental casting, a well-developed network of phosphide eutectic (Fr3) could be observed. Hardness of the experimental cylinder liner casting ranged from 250 HB to 263 HB.

The obtained results indicate that with the proposed chemical composition and adopted casting wall thickness, the experimental cylinder liner casting cast into a sand mould is characterized with such graphite precipitation morphology, matrix structure, and phosphide eutectic network which guarantee good service properties.

a)

b)

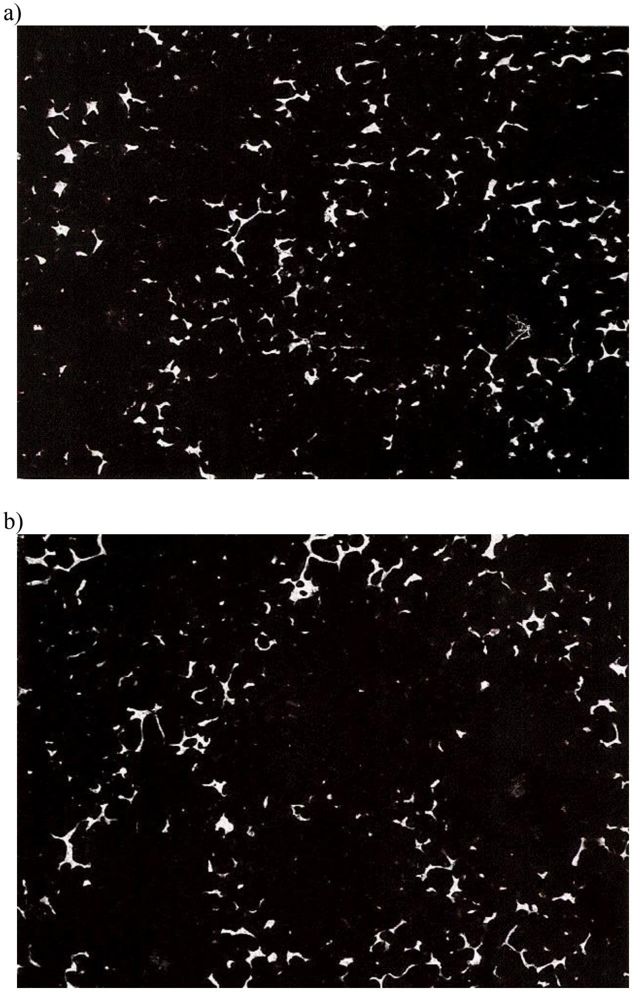


Fig. 6. Distribution of phosphide eutectic in the experimental liner casting: (a) in the area adjacent to the inner surface and (b) at half thickness of the casting wall. Etching in 4% HNO_3. Magnification 50×.

3. Conclusions

1. The analysis of microstructure of cast iron used for car engine cylinder liners indicates that the technological process of manufacturing liner castings should be carried out in a way ensuring that the area from which the bearing surface will be machined will be characterized by graphite precipitations with size ranging from 31 µm to 60 µm (Gw45). Such graphite precipitations, accompanied by pearlitic matrix and satisfactory phosphide eutectic network, are capable to ensure the best performance properties of a cylinder liner.
2. The analysis carried out on a sample of cylinder liners mounted in both domestic and foreign engines indicates that materials used to cast them were characterized with graphite precipitation sizes ranging from 16 µm to 120 µm (Gw25–Gw90).
3. It must be concluded that the requirement concerning graphite precipitation dimensions and providing for acceptability of sizes up to 15 µm (Gw15) and from 121 µm to 250 µm is oriented rather at preferences of the manufacturer than at those of the user. Cylinder liners with graphite precipitations of that size would be too susceptible to accelerated wear.
4. It has been found that with the proposed chemical composition, a casting for cylinder liner cast into a sand mould was characterized with a microstructure (graphite precipitation morphology. matrix, and phosphide eutectic network) that should ensure good service properties.

References

[1] Orłowicz, W., Opiekun, Z., Kościelny, E. (1985). *Structural examination of DX 03/2000 engine cylinder liner for Renaul and Opel cars* An unpublished study. Warszawa: OBR SO. (in Polish).

[2] Orłowicz, W., Opiekun, Z., Kościelny, E. (1986). *Materials analysis of cylinder liners denoted with symbols 1 and 2* An unpublished study. Warszawa: OBR SO. (in Polish).

[3] Orłowicz, W., Opiekun, Z., Kościelny, E. (1986). *Materials analysis of cylinder liners denoted with symbols 1 through 64* An unpublished study. Warszawa: OBR SO. (in Polish).

[4] Orłowicz, W., Opiekun, Z., Kościelny, E. (1986). *Materials analysis of a cylinder liner manufactured by Ricardo company* Warszawa: OBR SO. (in Polish).

[5] Orłowicz, W., Opiekun, Z., Kościelny, E. (1987). *Fabrication of castings for WARS engine cylinder liners* An unpublished study. Warszawa: OBR SO. (in Polish).

[6] Orłowicz, W. & Trytek, A. (2003). Effect of rapid solidification on sliding wear iron castings. *WEAR. 254*, 154–163.

[7] *Gray, ductile, and malleable cast iron. Metallographic examination. Determination of microstructure* (in Polish). Polish standard PN-75/H-04661.

[8] Pytko, S. & Pytko, P. (1991). Issues concerning lubrication of future combustion engines, *Tribologia. 3*, 57–60.

[9] Okulicz, W., Pawlus, P. (1998). Cylinder liner wear in automotive combustion engine. Proceedings of the conference MECHANICS 98 (pp. 195–204). Rzeszów: Politechnika Rzeszowska.

[10] Goetzewerke company information materials.
[11] Kościelny, E., Orłowicz, W., Opiekun, Z., Michalski, J. (1987). *Automotive engine materials tests* Warszawa: OBR SO. (in Polish).
[12] Orłowicz, W. & Trytek, A. (2007). *Shaping microstructure and service properties of cast iron castings with surface improved by means of electric arc plasma*. A monograph Archiwum Odlewnictwa. 7(23). (in Polish).
[13] *Alloyed cast iron cylinder liners. General requirements* Industry standard BN-78/1372-01. (in Polish).