CHARACTERISTICS OF THE SEIZURE PROCESSOF AIR COMPRESSOR PISTONS OF AUTOMOTIVE VEHICLES

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Abstract

The subject of the investigations are cast pistons used in air compressors. The goal of this work was characterization of the wear of pistons made by aluminium-silicon alloys and showed differences in material characterisation for different aluminium-silicon alloy. A few kinds of pistons were chosen for investigations-pistons made by an aluminium-silicon alloy AK12 and AK7. The scope of the work included the observation of pistons using light microscopy and scanning electron microscopy with X-ray microanalysis of chemical composition (EDS - energy dispersion spectrometer). Next the measurements of hardness were carrying out with the Vickers method. The research shows that the wear resistance increases depending on the amount of silicon. Microscopic examinations confirmed the presence of chemical elements which are part of the castings of AK12 and AK7 alloys.

Keywords: Air compressors, pistons, types of wear, microscopic examination

1. INTRODUCTION

As a result of the development and needs of modern technologies, we still get and we improve new materials. In the automotive industry, composites are increasingly used - often with a matrix of aluminum alloys, e.g. aluminum-silicon, called silumin, and nanomaterials, i.e. materials with reduced grain sizes, thanks to which it is possible to obtain much better physical and mechanical properties, including an increase in hardness and strength. Currently, on an industrial scale, components operating in conditions of high frictional loads are manufactured. An example of such an association are pistons and cylinder liners used in motor vehicle engines. In this case, there is a separation of the cooperating parts with a lubricating film, which is engine oil. Another example is air compressors. It is important to use appropriate materials and coatings that ensure the proper operation of the mating parts. The pistons used in compressors should therefore be light, have high mechanical strength, dissipate heat well and have low thermal expansion. A very important feature is also a low coefficient of friction and resistance to operational wear therefore, aluminium casting alloys with additives such as silicon or magnesium are used for the production of pistons [1÷3]. As a result of the development and needs of modern technologies new materials are still improved. In the automotive industry aluminium alloys are increasingly used so it is possible to obtain much better physical and mechanical properties, including an increase in hardness and strength. But another solutions for pistons and for its operational conditions are use too [4,5].

2. AIR COMPRESSORS

Compressors are machines used to compress air continuously. They are classified as thermal machines because during compression some mechanical work is converted into heat. The gas pressure can be increased by reducing its volume or speeding it up. So we distinguish between positive displacement and vortex compressors. Displacement compressors are divided into reciprocating compressors with a reciprocating movement of the piston and rotary compressors with rotary motion [6].

This work is focused on reciprocating compressors (**Figure 1**), which are divided into single-stage and two-stage compressors. Single-stage compressors usually have a vertical structure, less often they are built in a V or W system. The compression process in single-stage piston compressors begins with taking a certain volume of air from the environment, then its volume is reduced by the movement of the piston, which results in an increase in pressure. The piston connected to the connecting rod is set in motion and doing a specific job. The efficiency of a reciprocating compressor depends on two factors: the cylinder volume and the pressure ratio (compression - the ratio of the discharged pressure to the suction pressure). An important aspect in the case of reciprocating compressors is to maintain the tightness between and the cylinder in order to obtain the highest possible work efficiency. It also depends on the wear of the piston and the wear of the cylinder [6,7].

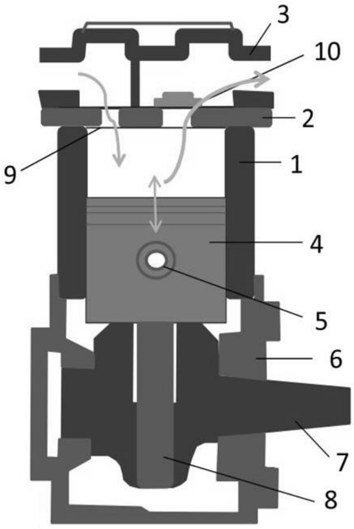


Figure 1 Construction of a reciprocating compressor [8]; 1- cylinder, 2 - valve plate, 3-head, 4-piston, 5 - piston pin, 6-housing, 7-crankshaft, 8 - connecting rod, 9 - bottom plate (suction plate), 10 - pressure line valve

3. MATERIALS USED FOR PISTONS

The materials used for pistons installed in air compressors are mainly cast aluminium alloys, magnesium alloys, composites, alloy steels and cast iron [6]. Alloy steels have high strength and thermal expansion, alloy steels are increasingly used for pistons. Despite the high density, steel pistons are equal to aluminium pistons in terms of total weight, thanks to the possibility of using shapes with small cross-sections. Magnesium is a metal 75% lighter than steel. The automotive industry uses magnesium alloys with the addition of manganese, aluminium, zinc and zirconium. Magnesium alloys are characterized by low density and high fatigue strength comparable to aluminium alloys. They are also characterized by the possibility of casting parts with large surfaces and thin walls with high dimensional accuracy of the casting and shape stability [10]. The strength properties of technically pure aluminium are relatively low. Therefore aluminium alloys are used with additives such as: silicon, copper, magnesium, manganese, nickel. They are characterized by favourable mechanical parameters, they have smaller mass than steel and cast iron, and their impact strength does not decrease with lowering the temperature. Moreover, they have good thermal conductivity, low thermal expansion, low friction coefficient and high resistance to corrosion and operational wear [9,10,13].

Silumins are aluminium-silicon casting alloys with a content of silicone about 2-30 wt% (most often 5-13.5 wt%) and with additives such as magnesium, nickel, copper, manganese and titanium. Alloy additions such as magnesium and copper increase strength, while nickel improves the corrosion resistance of the alloy. Silumins with a silicon content of less than 4 wt% are also suitable for plastic working. Due to the low thermal expansion, the low friction coefficient is mainly used in the automotive industry, e.g. for the production of pistons and cylinders. The most popular silumins are AK7, AK12 and AK20 [9-12,14,15].

AK7 (AlSi7Mg) it is a casting aluminium-silicon alloy with a silicon content of about 7 wt%. It is characterized by lower strength properties than AK9 alloy, good machinability and corrosion resistance. The advantages of these materials also include good castability and the possibility of making connections by welding. It is used for castings of complex shape, high strength and ductility for medium loaded parts. AK12 (AlSi13Mg1CuNi) it is an aluminium-silicon casting alloy with approximately 13 wt% silicon. It is characterized by high strength properties at elevated temperature, high abrasion resistance, low thermal expansion and high corrosion resistance, especially in an acidic environment. Has insufficient machinability. It is used for the castings of highly loaded elements, such as pistons of combustion engines [16]. AK20 (AlSi21CuNi) it is a casting aluminium-silicon alloy with a silicon content of about 21 wt%. It is characterized by high strength properties at elevated temperature, high abrasion resistance, low thermal expansion and low machinability. It is used for castings of highly loaded parts, including pistons of combustion engines [10]. However, despite these efforts, piston wear occurs, and not infrequently, there are serious failures that exclude the profitability of the repair of the entire technical device [17-20].

4. SUBJECT OF STUDY AND RESEARCH

The subject of the research were pistons made by casting from an aluminium-silicon alloy used in air compressors, marked 601.17.910. The piston not subjected to a friction test (marked as 1 - **Figure 2**) was made of an aluminium-silicon AK12 alloy, while two pistons for friction tests (marked as 2 - **Figure3**) were made by an aluminium-silicon alloy - AK7. The pistons had the following dimensions: diameter 65 mm, height 50 mm.

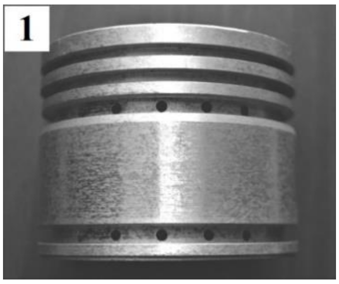


Figure 2 Casting piston made of an aluminium-silicon alloy AK12 marked as 1 [own study]

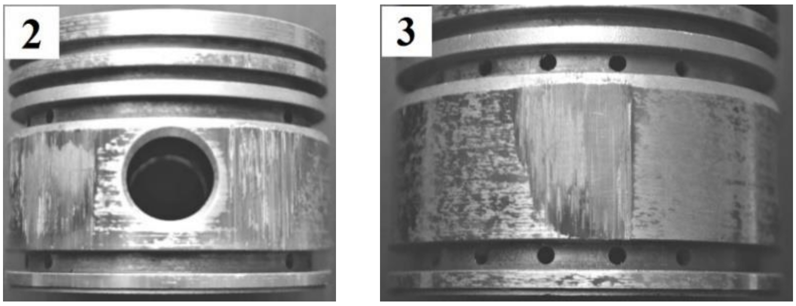
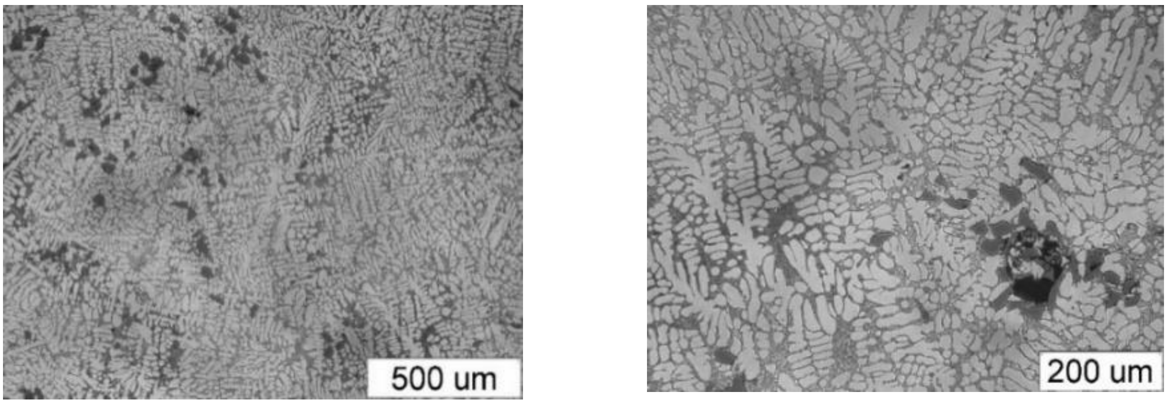


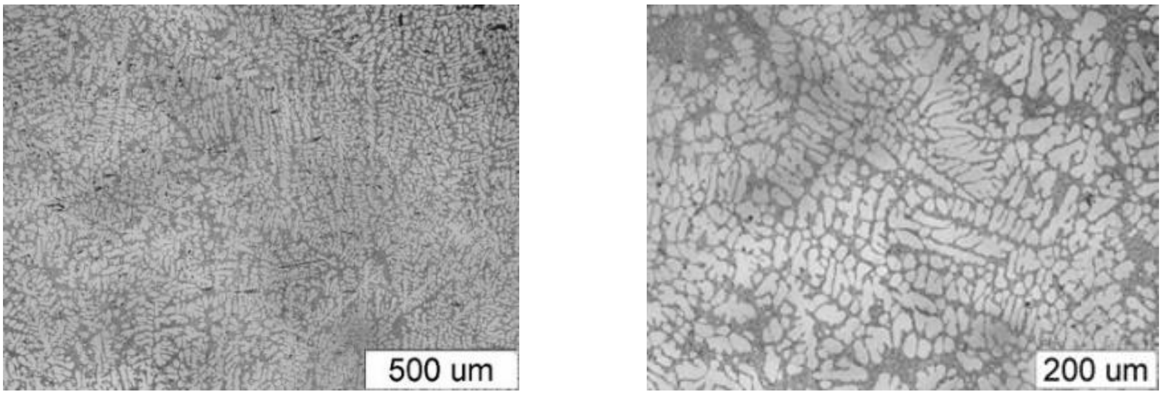
Figure 3 Casting piston made of an aluminium-silicon alloy AK7 marked 2 with visible signs of seizure [own study]

An optical method was used for the initial observation and determination of piston wear; scanning electron microscopy was used for more detailed observation and determination of the chemical composition and hardness measurements with using the Vickers method [23].



a) b)

Figure 4 Dendritic microstructure of the casting aluminium-silicon alloy AK12 of the piston marked as 1 [own study]



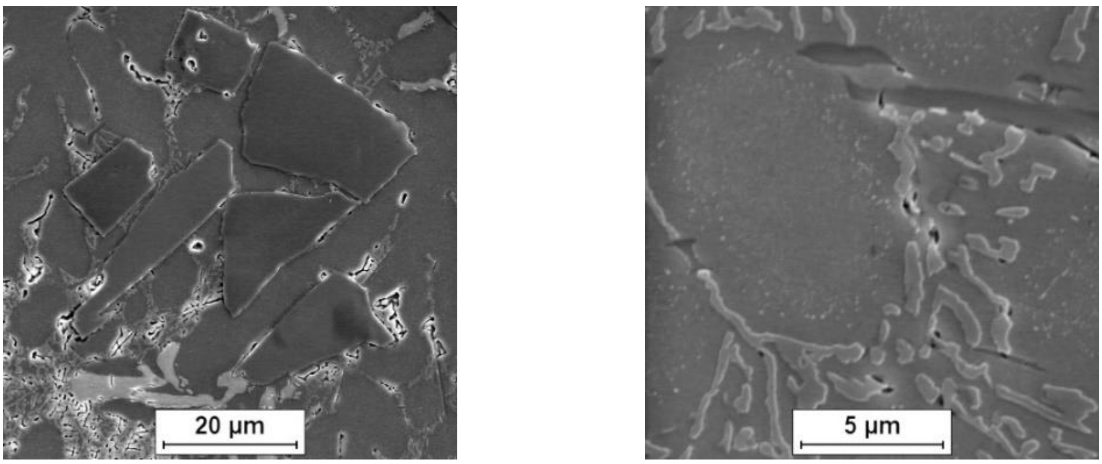
a) b)

Figure 5 Dendritic microstructure of the casting aluminium-silicon alloy AK7 of the piston marked as 2 [own study]

The examination of the piston microstructure was carried out using the light microscope in the bright field. The observations were made on metallographic specimens etched at the various magnification. Samples for microstructure studies were taken on the piston cross-sections. The example of test results are shown in **Figures 4** and **5**.

On the basis of tests carried out using light microscopy, differences in the microstructure of the material of the piston marked 1, made of cast aluminum-silicon alloy AK12, and pistons made of aluminum-silicon alloy AK7 marked 2 were shown. It was found that all tested pistons had a dendritic microstructure. Silicon precipitates were found in both cases, but more were found in the piston marked 1.

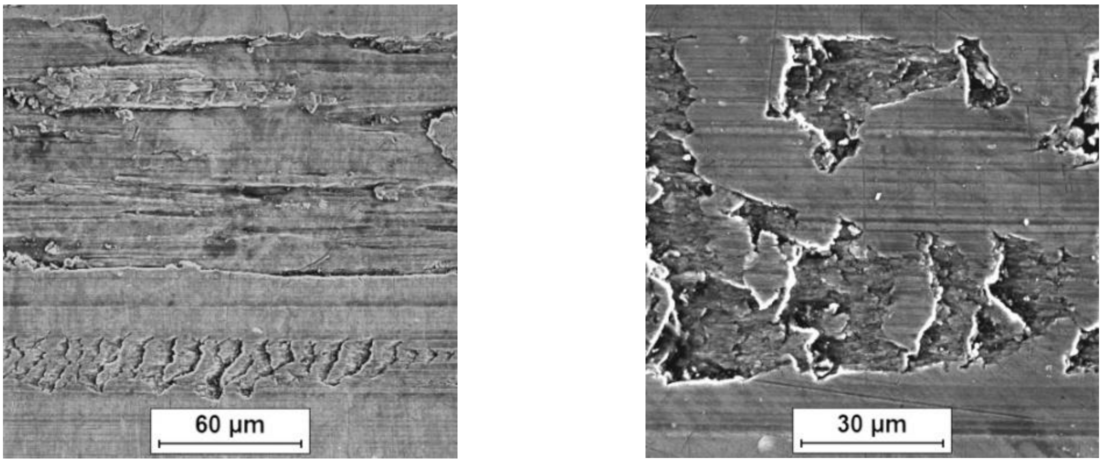
The next stage of the investigations was to determine the chemical composition of the piston marked 1 (**Figure 6**), piston marked 2 (**Figure 7**). Pistons marked 2 were after the friction test. The analysis of the microstructure of the pistons was performed using a Scanning Electron Microscopy (SEM-Scanning Electron Microscopy) using a Hitachi S-4200 microscope with the use of secondary electron (SE) detectors (**Tables 1** and **2**). The chemical composition tests were carried out using the spectrometer at a voltage accelerating the electron beam of 15 kV. This spectrometer is coupled to a Hitachi S - 4200 microscope.



a) b)

Figure 6 Pictures of the piston marked 1 taken with a scanning electron microscope [own work]

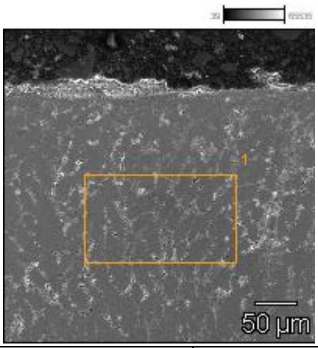
The elemental composition of the selected area of the 1 piston cast from the Al-Si AK12 alloy was determined. It was found that the dominant element is aluminium (Al), and the low content of silicon (Si) proves that it is silumin, i.e. an aluminium-silicon alloy.

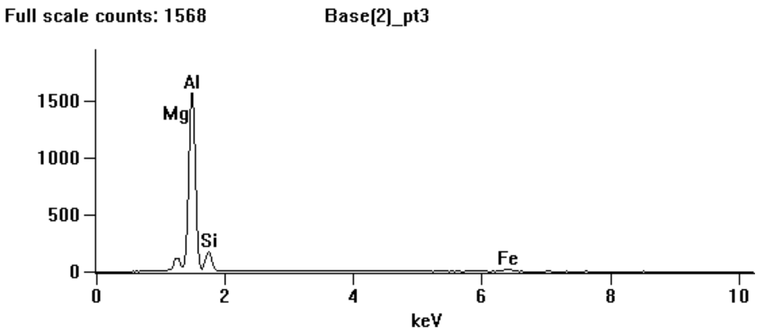


a) **b)**

Figure 7 The sliding part of the piston surface made of an aluminium alloy - AK7 silicon marked as 2 made with a scanning electron microscope [own elaboration]

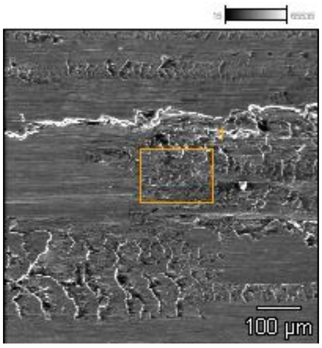
Table 1 Example of X-ray microanalysis of the EDS chemical composition of the 1 piston [own study]

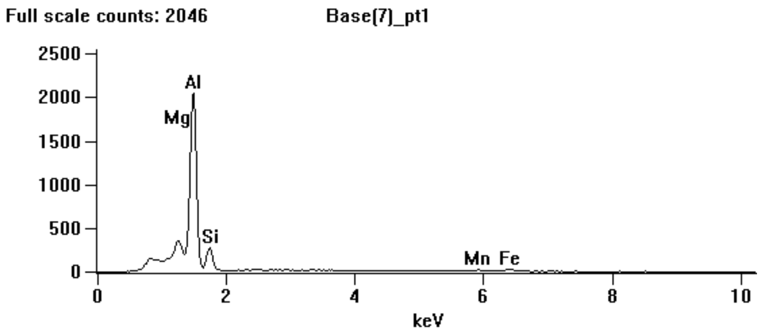




Area	Mg	Al	Si	Mn	Fe
1	7.4	62.2	26.1	1.4	2.9

Table 2 Example of X-ray microanalysis of the EDS chemical composition of the 2 piston [own study]





Area	Mg	Al	Si	Mn	Fe
1	7.8	70.5	17	1.5	3.2

The results of X-ray microanalysis of the chemical composition of EDS in the area of the seizure of pistons made of AK7 alloy after seizure tests, confirmed the presence of aluminium and silicon, i.e. the elements of the alloy from which the pistons were made. There were no other elements that could constitute impurities or the material of the cylinder in which the piston worked.

Hardness measurements were carried out on metallographic samples taken from a piston made by AK12 alloy and pistons after seizure tests made by AK7 alloy. Measurements were made using the Vickers method in accordance with PN-EN ISO 6507-1 at a load of 9.81N (HV1). Results were shown in **Figures 8** and **9** and in **Tables 3** and **4**.

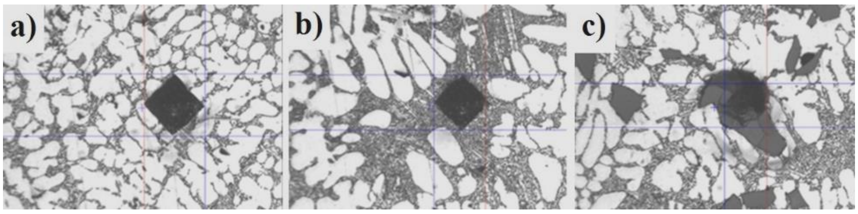


Figure 8 Example of results of hardness investigations for new piston made by AK12 alloy (piston marked as 1): a) dendritic microstructure, b) interdendritic area, c) precipitation [own study]

Table 3 Results of hardness investigations for new piston made by AK12 alloy (piston marked as 1) [own study]

Area	Hardness	Average
Dendritic	87; 89; 93; 91; 98	91.6
Interdritical	117; 119; 111; 109; 115	114.2
Extractions	187; 174; 134; 145; 176	168.2

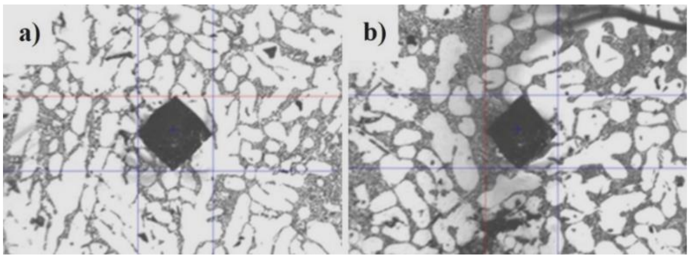


Figure 9 Example of results of hardness investigations for new piston made by AK7 alloy (piston marked as 2): a) dendritic microstructure, b) interdendritic area [own elaboration]

Table 4 Results of hardness investigations for piston made by AK7 alloy (piston marked as 2) [own elaboration]

Area	Hardness	Average
Dendritic	88; 89; 81; 86; 92	87.2
Interdendritic	95; 92; 96; 94; 98	95.0

In the case of the piston made of aluminium-silicon AK12, the hardness is greater than that of pistons made of aluminium-silicon AK7, while in the case of these two pistons their hardness is similar.

7. CONCLUSIONS

Based on the research and analysis of its results, the following conclusions were drawn:

- microscopic examinations confirmed the presence of chemical elements that are part of the AK12 and AK7 foundry alloys,
- hardness in the interdendritic region for AK7 cast aluminium silicon pistons is approximately 87 and it is smaller than hardness for AK12 cast aluminium alloy piston (about 10 units higher),
- the seizure process of the piston-cylinder pair is also dependent on the roughness,

- in the analyzed case, seizure could be accelerated as a result of exceeding the sliding part of the piston surface roughness,
- the influence of roughness on the scuffing process of air compressor pistons requires further research.

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