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Conference Article

Effect of Microstructure of Al-Si-alloy on the Quality of the Layer Formed with Micro-Arc Oxidation Method

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Abstract

This investigation is on the properties of hardened layers, developed with the micro-arc oxidation method (MAO) on the surface of the ingots from an Al-Si alloy. It has been established that the properties (microhardness, thickness, porosity) of the generated surfaces depend on the structure of the alloy.

Keywords: micro-arc oxidation, aluminium alloys, microstructure, microhardness, porosity

1. Introduction

The internal combustion piston engines (ICE) are being widely used in aviation. Improving the efficiency of the engine is possible by ensuring reliable and durable operation of the cylinder group. The pistons of internal combustion engines are made mostly of eutectic and hypereutectic silumins. However, these alloys have a number of disadvantages, including low heat and wear resistance. Therefore it is necessary to apply a protective coating.

Today a sufficient number of methods to modify the surface layer exist, such as anodizing, coating, plating and micro-arc oxidation (MAO). MAO is the most advanced and rapidly developing technology. The method consists of forming on the surface of the part a high-strength wear-resistant coating, consisting mainly of α-Al_2O_3 (corundum).

The MAO technique is widely used for hardening the surfaces of the details of aluminum alloys parts. The possibility of obtaining the quality coating has been demonstrated with the alloys of the Al-Cu-Mg, Al-Zn-Mg, Al-Mg-Si systems and etc. [1]. As for the possibility of obtaining a quality coating on high-silicon aluminum alloys, there are not many works on this subject in scientific literature [2], and the conclusions reached appear quite contradictory.

It is known that the quality of the coating is depended on several factors of the MAO process: the composition of the electrolyte, electrical modes and duration of processing [3-9]. The microstructure of the samples is another important factor affecting the quality of the MAO-layer. Thus, in [10] it is shown that the initial shape and size of silicon particles in the structure of Al-Si alloys of different composition (6-22% Si) determine the formation of the MAO-layer. In the initial rod the silicon can be located non-uniformly in the volume of matrix solution, for example in the form of lines.

Thus, the aim of this work is to investigate the influence of the microstructure of high-silicon aluminum alloy on microhardness, porosity and thickness of the oxide layer formed with MAO.

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2. Experimental

The eutectic silumin AK12D (Al-Si-Fe) has been chosen as the experimental material. The initial billet was a hot-rod.

Two states of AK12D alloy have been investigated:

State 1 – initial rod;

State 2 – after deformation-thermal treatment (DTT) consisted of two stages. In the first stage, the workpiece was subjected to a comprehensive semi-enclosed forging with decreasing temperature from 400 °C down to 320 °C. This method of deformation was chosen to eliminate the non-uniform distribution of silicon particles, typical of a rod. Ultrafine-grained (UFG) structure formed in the aluminum matrix in this deformation process, could also affect the quality of the MAO-layer. To eliminate the UFG state and preserve the uniform distribution of silicon particles, the workpiece after forging has been subjected to quenching with temperature 515 °C and aging at T=190 °C for five hours.

The samples in the shape of a disk were subjected to MAO. The surface of the rods had a roughness of Ra 0.5 μm. The surface was not subjected to preliminary washing and degreasing. The MAO modes were as follows: concentration of soluble water glass Na_2SiO_3 – 3.5 g/l; concentration potassium hydroxide (KOH) – 3.5 g/l. In the process of treatment the interrelation of cathode and anode currents kept constant $I_a/I_k=1$. The electrolyte temperature has not exceeded 52 °C.

The microstructure has been examined with an optical microscope Olympus GX51. The microstructure parameters have been evaluated by standard methods with a probable statistical error less than 5% [11].

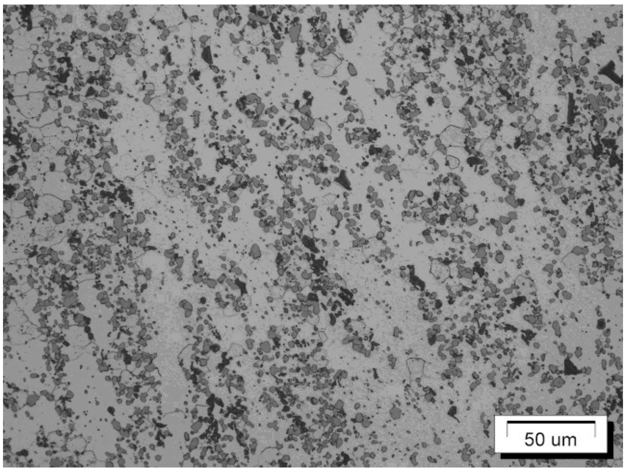
To estimate the thickness of the layers the image of the system «alloy AK12D-layer» the scanning electron microscope (SEM) «JEOL JSM 6390» was used at a magnification of 500. The shooting has been made in the mode of the back scattered electrons. Before shooting the samples were encapsulated into fluid epoxide resin and after setting they were put into the microscope column

The shooting of the pores in MAO layers have also been made with SEM.

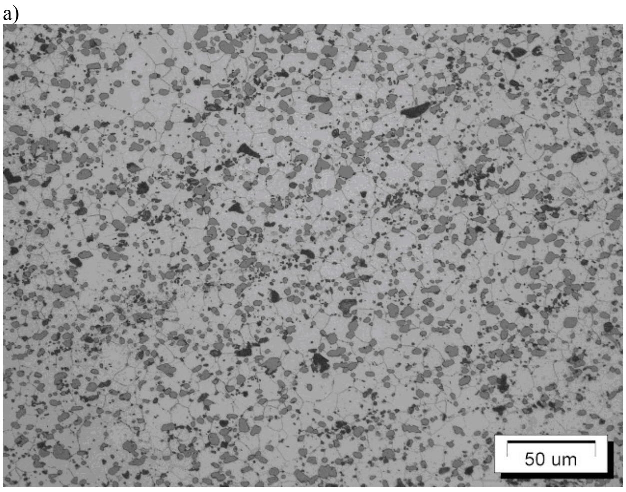
The Vickers hardness of the MAO-layers was measured with the microhardometer «Struers Duramin», for a load of 100 g applied to the samples for 10 seconds.

3. Results

The microstructure of samples of the AK12D alloy before MAO in the initial state 1 is presented in Fig.1a. As it can be seen, the silicon phase is distributed inhomogeneously. The areas in the form of lines, enriched with silicon particles with an average size of 3.0±0.5 μm and a volume fraction of 22%, are observed. The average grain size of aluminum matrix is 14±4 μm. In addition, the θ-phase ($CuAl_2$) with a volume fraction of 3% and an average size close to the size of the silicon particles is detected in the structure.



a)



b)

Fig 1. Microstructure of AK12D alloy: a) state 1, b) state 2

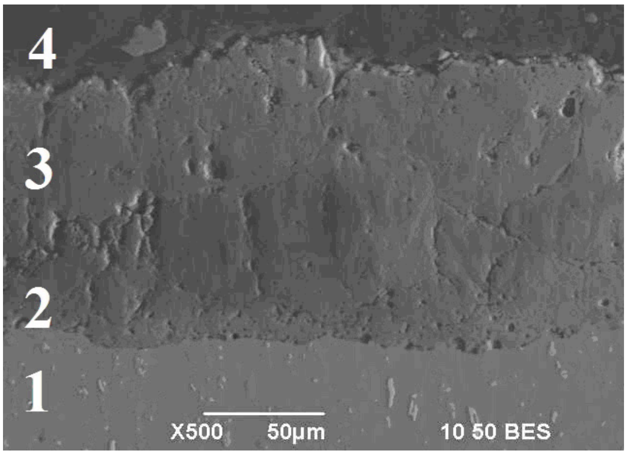
The microstructure of the samples after the DTT (state 2) is significantly different to state 1 (Fig. 1b). The uniform distribution of silicon particles throughout the volume of matrix solution is observed. The average grain size is higher and amounts to 18±4 μm. The size of silicon particles and their volume fraction did not change – 3.2±0.5 μm and 23% respectively. In the microstructure θ-phase is also presented, size and volume fraction which has not changed in comparison with state 1.

Therefore, the examined states of the AK12D alloy differ in the grain size of matrix phase and distribution of silicon particles.

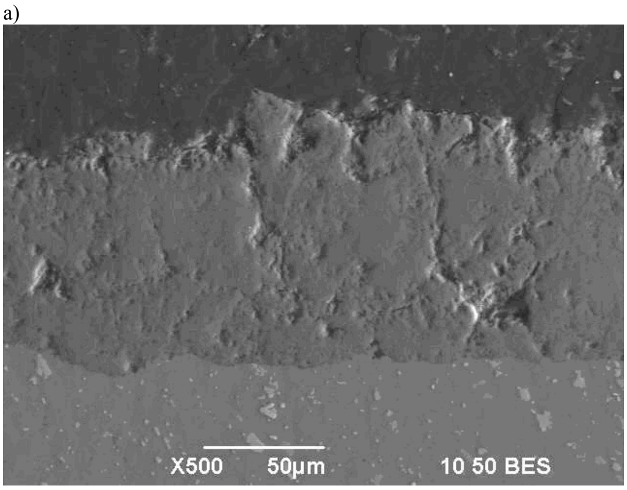
In the end of the experiments two samples with MAO-layer were produced.

The thickness of the layer obtained in the result MAO is different all over the surface of the samples (Fig. 2). The average thickness of the MAO layer in sample №1 is t_{mean}=120 μm, in sample №2 – t_{mean}=90 μm.

A lot of pores can be observed in the MAO-layer (Fig. 2). There are both separate pores and whole networks of them in various directions. There are also fine cracks, which start from the pores.



a)



b)

Fig. 2. The image of the system «AK12D alloy – MAO-layer»: a) state 1, b) state 2; 1 – metal; 2 – transition layer; 3 – base layer; 4 – epoxide resin

The highest porosity in the state 1 can be observed in the layer adjusting to the metal (Fig. 3a). This is the so-called transition layer [4] (area 2 in Fig. 2a). As moving to the base layer (area 3 in Fig. 2a), which consists of aluminum oxide Al2O3, the porosity is decreasing (Fig. 3a). The transition layer is absent in state 2 and the MAO coating consist of a base layer (Fig. 2b).

The average value of the porosity all over the thickness of the MAO-layer for sample №1 has come to 4.5%, for sample №2 – 9.3%.

The aluminum oxide Al_2O_3 which is the base of the working layer, as it is known, is characterized by high microhardness [4]. The microhardness results prove the development of the aluminum oxide during MAO (Fig. 3).

The microhardness distribution is not homogeneous in the thickness of MAO-layer (Fig. 3). During the transition to the main working layer the values of microhardness increase. The maximum value of microhardness is observed for sample №2 and is 1300 HV at a distance 40 μm from the surface of the metal. While the distance from the surface of the metal is increasing, the microhardness is decreasing slightly. The maximum value of HV is observed in the middle of the MDO-layer for both conditions: in state 1 – at a distance of 60 μm from the substrate (total thickness of the MGO layer is 120 μm); in state 2 – at a distance of 40 μm from the substrate (total sample thickness is 80 μm).

The characterteristics of the distribution of porosity and microhardness over the thickness of the layer corresponds to the dependencies, presented earlier in literature [12]. In our case a great number of pores is observed in the transition layer as well, which is characterized by the low value of microhardness. While increasing the distance from the surface of the metal, the porosity is decreasing. At the same time the microhardness is increasing due to the development of the working layer, consisting mostly of aluminum oxide Al2O3. With a further increase of the distance from the metal surface, the porosity should increase due to the development of the technologic layer, consisting of the mullite. The mullite, as it's known, is characterized by low value of microhardness. However, in our case the increase of porosity with the simultaneous microhardness decrease didn't take place. Obviously, it is related to the fact that the most part of the mullite has been removed during the preliminary preparation of the samples.

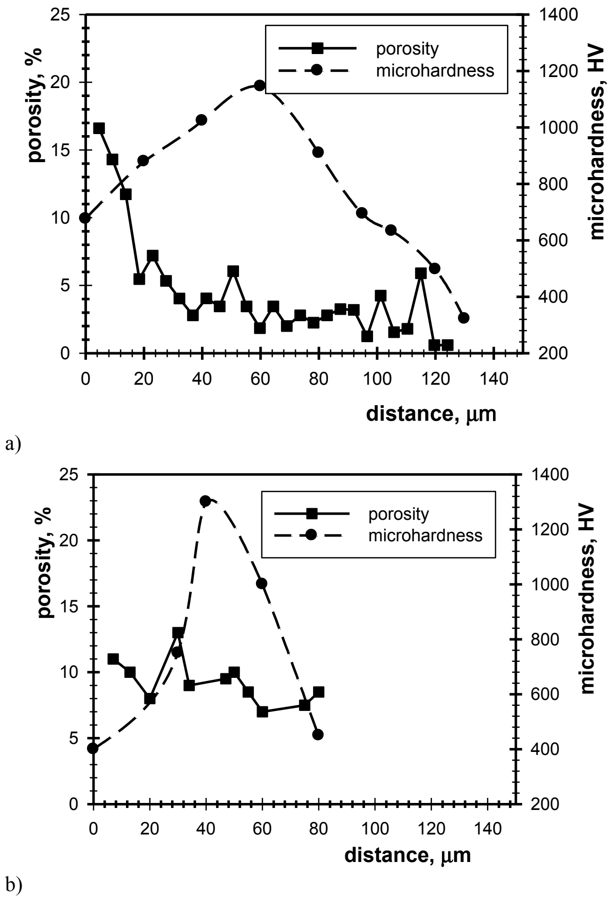


Fig. 3. The graphs of the dependencies of porosity and microhardness of the coatings against the distance from the metal surface: a) state 1, b) state 2

4. Discussion

It's a common knowledge that there are many difficulties with obtaining a quality MAO-layer while MAO-treating high-silicon aluminum alloys. This fact is usually related to the presence of silicon in the composition of cast alloys. The last one has areas of pitting, impeding the interaction between the aluminum and oxygen, blocking up the development of oxide layer and cropping out the working surface during its treatment. In the areas of silicon crop up the surface either do not develop or it's quality is not good enough [2].

The analysis of the results has shown that the MAO method allows to obtain quality cover on the high-silicon aluminum AK12D alloy containing up to 13% of silicon.

However, MDO-layers with different characteristics have been formed depending on the microstructure of the alloy. So, the greatest thickness of the MAO-layer has been observed for the sample in the initial state (state 1) with the minimum value of porosity. The transition layer has not been formed on the samples after the DTT (state 2). These samples are characterized by the highest porosity.

The melting matrix material and its interaction with the atoms of the electrolyte, form the coating [13], while under the action of the arc and spark discharges occurring on the surface of the workpiece. As it is known, electrical discharges get extinguished on the silicon particles [14]. Therefore, more sites, free from silicon particles in the material of the workpieces the better of the micro-layer will form. The analysis of the microstructure showed that state 1 has been characterized by a linear separation of silicon particles. There are long sections of the initial matrix phase, free from silicon between the lines of silicon. Due to this structure the quality MAO-layer having a greater thickness and lower porosity has been obtained on the samples of condition 1.

It is interesting note that the formation of closed pores in the transition layer is indicated in state 1 after MDO. Since the porosity depends on the corrosion resistance of the coatings [15], it can be assumed that the corrosion properties of state 1 will be higher than that of state 2, which is characterized by porosity throughout the thickness of the layer.

5. Conclusions

1) the MAO-process was carried out and two modes the coatings have been developed on the high-silicon aluminum AK12D alloy.
2) The microstructure of aluminum alloy and affects the quality of the coating formed as a result of the MAO treatment.
3) Deformation-heat treatment of alloy sample which was forged, quenched and aged before MDO leading to the deterioration of quality of the formed layer.
4) The present results can be useful to describe an adequate model of the MDO process.

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