Investigation of optimal chemical composition of cast aluminum alloys for vibrational mechanical-chemical polishing and deposition of protective and decorative coatings

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Abstract. The article suggests the technology of vibration finishing processing of aluminum alloys with simultaneous coating. On the basis of experimental studies, cast alloys, working media, operating modes of equipment, activating solutions were chosen. The practical application of the developed technology on real parts is shown.

1. Introduction
Aluminum and its alloys are used in almost all branches of modern industry due to their high physical and mechanical properties. The main advantage of this metal is its casting properties which have been known for a long time in the modern world but have not lost their relevance.

Analyzing the current requirements for the surface of products made of aluminum and its alloys in the given case (geyser-type coffee maker) for surface roughness, depth of cold work, reflectivity and adhesion, hardness, and corrosion resistance, and methods used to achieve them, it should be noted that using only traditional methods of processing such as: chemical polishing, electrochemical anodizing and oxidation, belt grinding does not allow one to obtain fully the required surface quality indicators and provide economic benefits [1, 2]. In addition, the parts of the product are obtained by different methods of GC (galvanic casting) and PD (pressure casting); therefore the application of these methods is associated with the use of special rooms, treatment facilities, expensive equipment, serious restrictions on environmental and sanitary standards [3].

Therefore, the selection of the optimal chemical composition of the aluminum surface and its alloy, obtained by gravity casting and injection molding, as well as studies of combined vibration processing, polishing, coating technology are relevant and promising.

The main purpose of the experimental studies was the development of the optimal chemical composition of the surface of aluminum and its alloy for the technology of finishing and applying decorative coating in conditions of VTS.

The studies provided for the solution of the following problems.
1. Justification of the quality of the initial workpieces obtained by gravity casting (GC) and pressure casting (PC).
2. Selection of modes and parameters of processing, equipment, working fluids in vibro-abrasive finishing.
3. Elaboration of the vibration control process, which provides hardening of the aluminum alloy surface with simultaneous formation of a mirror shine under conditions of VTS.
When justifying the quality of the initial workpiece obtained by gravity casting (GC) and pressure casting (PC), a particular attention was paid to: microstructure of aluminum alloys, gas saturation (H2), hardness of the surface layer (HB).

2. Results of the research
Measurements of the gas saturation parameters were carried out by introducing moistened wood into the melt or degassing the melt by blowing inert gas. The selection of the optimal chemical composition of the aluminum alloy in terms of hardness was carried out by doping in the range of Si = 2.9-13.48% and Cu = 0.055-5.65%. Based on the research conducted, the following requirements to the quality of the workpiece were formed:

1. The surface of the workpiece obtained by the GC and PC methods should not have visible surface defects in the form of cracks, shells, gas porosity, shrinkage, oxidized metal films, etc.
2. The maximum gas saturation of an aluminum alloy for workpieces produced by GC is no more than 0.08-0.09 cm$^3$/cm$^3$ for workpieces of PC no more than 0.05-0.06 cm$^3$/cm$^3$.
3. The roughness of the workpiece surface should be within Ra = 2.5-4 µm, which will allow one to ensure the roughness of the new part Ra = 0.2-0.4 µm (Figure 1a). Change of workpiece surface roughness and hardness depending on the percentage of copper alloying element with an average value of Si = 6-8% is presented in Figure 1b.

4. The optimum microstructure of the workpiece of the obtained due to PC is a finely dispersed Al + Si eutectic with uniformly distributed Si particles of up to 100 µm in size (Figure 2a).

Figure 2b shows the defects in the workpiece surface produced by the GC in the form of porosity and shrinkage. The microstructure of this sample is a large-dispersed eutectic of Al + Si; Al particles are larger than 100 µm; there are large inclusions of magnesite spinel and shrinkage pores.

![Figure 1](image1.png)

![Figure 2](image2.png)
5. The hardness of the workpiece must be at least HB = 60-68 for workpieces produced by GC and PC. This hardness is achieved by introducing alloying elements, such as Si and Cu, into the melt. The greatest change in the workpiece hardness, observed when alloying with copper, should be in the range of 1.2-3.5%. On the basis of the results obtained, it is proposed using aluminum alloys of the following chemical composition presented in Table 1 and 2 to cast products using the method of GC and PC

Table 1. Gravity casting (GC), %.

| Mg   | Si    | Mn   | Cu   | Fe   | Zn   | Ni   | Pb   | As   | Cr   | Ca   |
|------|-------|------|------|------|------|------|------|------|------|------|
| 0.2-0.8 | 5.5-6.5 | 0.2-0.8 | 3.5-4.5 | 0.8-1.2 | Up to 0.3 | Up to 0.5 | Up to 0.15 | Up to 0.015 | 0.0001 | 0.0004 |

Table 2. Pressure casting (PC), %.

| Mg   | Si    | Mn   | Cu   | Fe   | Zn   | Ni   | Pb   | As   | Cr   | Ca   |
|------|-------|------|------|------|------|------|------|------|------|------|
| 0.2-0.8 | 9.5-11.5 | 0.2-0.8 | 3.5-4.5 | 0.8-1.2 | Up to 0.3 | Up to 0.5 | Up to 0.15 | Up to 0.015 | 0.0001 | 0.0004 |
As the primary alloy, it is recommended to use AK5M2 (GOST 1583 - 89) with subsequent alloying of Si and Cu, depending on the method of obtaining the workpiece.

When justifying the modes of vibration abrasive finishing, the maximum loading of the working chamber, the purity and amplitude of the oscillations (working chamber) were determined, the working media and solutions were selected, and the processing time was established. The experiments were carried out on a VTU-100 l unit and UGW - 100 liters.

The samples were aluminum workpieces obtained by GC and PC with a roughness of $Ra = 2.5\text{-}4.0\ \mu m$, a thickness of the stratum of 0.1-0.5 mm and a height of 2-4 mm, on the surface of which there were stains from the lubrication of casting machines, potholes and scratches obtained in the process of casting and transportation. The authors supervised a batch of products (a geyser-type coffee machine) made of aluminum alloy in an amount of 500 pieces, consisting of a casing, a storage ring, a lid. The choice of these parts is not accidental, they have a number of typical defects after casting, which are difficult to eliminate without the use of vibration treatment. For example, the body is strewn with small potholes similar to the “orange peel” [4]. On the surface of the storage unit and the cover there are other defects, such as silicon stains, shrinkage ruts, oblong. It is interesting to note that the storage unit has an internal conductor for supplying liquid with hard-to-reach areas for machining (Figure 3).

![Figure 3. a- casing, b- storage unit, c- cover.](image)

The selection of the working environment was given special attention since 80% of the successful application of vibrational technologies depends on this. The working environment should provide a number of technological tasks: removing the oblong within 0.1-0.5 mm, rounding the edges, processing the inner and outer surfaces of the workpiece without jamming in them, as well as reducing the roughness with $Ra = 2.5\text{-}4.0\ \mu m$ to $Ra = 0.2\text{-}0.4\ \mu m$ [5]. Taking into account that aluminum and its alloys are soft metals, the working medium should not leave nicks and scratches on the metal surface and at the same time the workpiece should not darken during processing.

For the experimental studies, the following media were chosen:
- TP of Moscow abrasive plant (triangle prism) - the size of 5x5x5 mm to 15x15x15 mm, with a high degree of wear resistance, granularity of M40.
- TP of Volzhsk abrasive plant – the size of 15h15h15 mm with an average degree of wear resistance, M 12 granularity. Granules are polymer based cone shaped with the size of : base D15 mm, height 15 mm, M 40 granularity, having a high degree of wear resistance. Porcelain balls from D 5 mm to D 15 mm, without abrasive properties, the degree of wear resistance is very high [6].
The conducted studies showed that the best results were achieved when using a medium consisting of polymer based granules. The machining of parts in this medium ensures that the surface roughness within $Ra = 0.4-0.8 \mu m$ does not darken during the part machining, nicks and scratches do not form. However, the operating modes of the installation had to increase the working element oscillation amplitude from $A = 2 \text{ mm}$ to $A = 5 \text{ mm}$, frequency from $f = 25 \text{ Hz}$ to $f = 35 \text{ Hz}$, time from 60 min. up to 100 min. It should be emphasized that, when treated in this medium, the oblong should not exceed 1 to 2 mm.

Vibrational mechanical-chemical polishing of the surface (VMCSP) for the purpose of imparting a specular luster to parts was worked out on the UVG-100 equipment. As a working medium, balls of 5 mm in diameter made of stainless steel and a specially developed polishing solution were used. The details were immersed in the working chamber not in the bulk, but each in a separate cell in order to prevent the impact of the parts and the appearance of nicks and scratches. The amplitude of the working chamber oscillation was set within 2 mm, the frequency was 25 Hz, the processing time was 25 min [7, 8].

As a result of the sliding of the balls relative to the surface of the parts, the mutual vibrations of the atomic groups that make up the molecule and the increased energy of the working sphere movement, the polishing solution is activated, due to the production or additional energy, which results in the formation of a mirror film on the metal surface (Figure 4).

![Figure 4](image)

**Figure 4.** An increase of 100 times: a- Surface of the initial sample before vibroprocessing, b - surface of the sample after vibration processing in the polymer medium $T = 100 \text{ min}$, c- the surface of the sample after vibration-mechanical-chemical polishing $T = 20 \text{ min}$. d- product assembly after processing.

The process of applying a vibrational mechanical-chemical oxide coating (VMCSP) is interesting, both scientifically and from the applied point of view, and under certain conditions can be combined with vibration control [9]. The interest in applying the oxide coating is caused by the increase in consumer demand for products of different color spectrum. The equipment used for a combined process in the conditions of HHC and oxidation is the same as for vibration shredding, except for the absence of separation cells in the working chamber, and polyethylene balls used as a working medium component [10]. When combining the process of vibration treatment and chemical oxidation, the speed of the chemical reaction plays an important role, which depends on the number of active molecules, the activity of which is indicated by an increase in the thickness of the oxide film obtained under conditions of HHC 5-6 $\mu m$ (without vibratory action 2.5 - 3 $\mu m$).
As a result of the conducted studies, oxide films were obtained on the surface of an article with a thickness of 5-6 microns for 10-15 minutes in the spectrum of colors from golden to brown. This process has a number of advantages over conventional chemical oxidation: the absence of a hydrogenated layer, an increase in micro hardness of the surface layer by 25%, coating thickness and corrosion resistance by 40-50%.

3. Conclusions
Industrial tests showed that the chemical composition of the workpiece alloy obtained, as a result of GC and PC, is optimal for the application of combined treatment processes in HHC conditions.

As a result of the vibration mechanical-chemical polishing usage, a uniform surface of the product consisting of two workpieces obtained by different methods is formed. The surface of the product had a mirror gloss superior to the world analogs and showed the economic feasibility of the proposed technical solution, improving the operational properties of the product, reducing the processing cycle as well as the economic costs and improving the environmental situation.

The investigation of the possibilities of using vibrational mechanical-chemical oxidation showed that a protective and decorative coating of different spectrum can be applied to the product.

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