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CONSTRUCTION SOLIFIDIFICATION APPARATUS OF ALUMINUM ALLOYS UNDER DIFFERENT COOLING CONDITIONS USING RECYCLABLE MATERIALS

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Abstract: In today's world, the need for new technologies that meet the growing market and industry demand is perceived daily. Therefore, in the area of materials engineering, the aluminum alloy stands out among the others, due to its excellent mechanical characteristics, which facilitates its application in different situations. In the present work, we start from the hypothesis that, during the solidification process of aluminum alloys, if we subject an aluminum alloy to different cooling conditions after casting, we could improve and improve its mechanical properties. For this purpose, we cast aluminum alloy Al - 6061, poured and cooled with: oil, water, ambient air and compressed air. We submitted the molten samples to sanding and chemical attack and finally we evaluated their macro and microstructure. In the end, it was possible to observe in the verification of the macrographs, different morphologies and the occurrence of porosities, greater formations occurred in the sample cooled by compressed air. In the micrograph samples, all showed grain formation very different from each other. We concluded that the ingots under different cooling resulted in different morphologies and microstructures; in oil-cooled samples it was possible to identify the phases present in the alloy.

Keywords: Aluminum alloys; Macrostructure; Microstructure; Solidification device.

INTRODUCTION

Faced with the great need to implement new technologies in the manufacturing processes, which meet the requirements for greater efficiency and the claims of sustainability, which many industries seek to achieve, aluminum alloys stand out, because it is a metal that has an excellent combination of mechanical properties, in addition to being a sustainable material, and yet can be easily transformed by means of metallurgical processes, and can be used in numerous industrial applications [1].

According to CALLISTER [2], some aluminum alloys can become heat treatable as a result of alloying, which happens with the precipitation of intermetallic compounds. Thus, the mechanical properties of aluminum alloys can be improved by controlling the heating and cooling of the solidified alloys.

Since aluminum has a CFC crystalline structure, its ductility is maintained even at very low temperatures. The main limitation of aluminum is its low melting temperature (660°C, 1200°F), which restricts the maximum temperature at which it can be used [3]. The aluminum alloy used in the project was Al 6061 due to its easy availability as a scrap material and its mechanical properties.

Whether aluminum alloys can undergo heat treatments in order to improve their mechanical properties. The hypothesis we have is that during the solidification process of aluminum alloys, they can solidify with cooling rates which cause the macro and microstructures of the alloys to undergo variations or transformations in a way that this positively affects the properties mechanics of cast alloys.

Within this context, the present work aims to compare the macrostructures, microstructures and mechanical properties of the cast samples submitted to different cooling conditions, these by forced water circulation or circulating compressed air or mineral oil, of aluminum alloy Al-6061, in order to analyze the difference in the properties of aluminum.

MATERIALS AND METHODS

DESIGN AND MANUFACTURE OF SOLIDIFICATION DEVICE

For the manufacture of the prototype of the device, it was necessary to prepare technical drawings, with exact measurements and formats of the molds and other parts. The drawings were designed using the SolidEdge® ST6 software. Figure 1 shows, for example, the design drawings of the solidification mold and crucible:

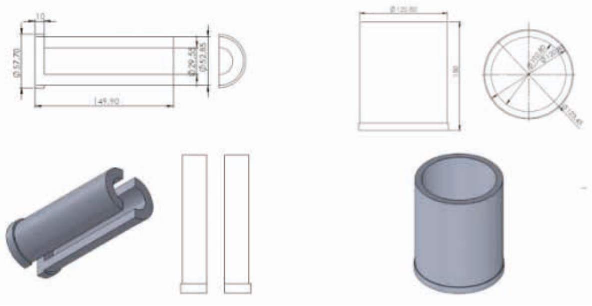

Figure 1: Design drawings of the bipartite solidification mold and crucible.

Source: Authors.

After the prototype was modeled, the parts for the device were made. For this step, the following materials were used: Used air conditioning gas cylinder; Machining equipment; Welding equipment; Steel dowel for mould.

The air conditioning cylinder (scrapped) was used to serve as a housing for the device due to its shape, dimensions and material. The cylinder was cut in half and then the parts were welded to it, being them; foot; latch, and water or oil inlet and outlet connections. The solidification mold was manufactured according to the technical drawings through machining processes and in such a way that it could be disassembled into three parts: bipartite mold and bottom. Figure 2 shows the frame of the manufactured device and its accessories:

Figure 2: a) AC gas tank used for solidification device; b) Cylinder already divided with feet; c) Connections for the inlet and outlet of water, oil and air to be mounted on the device.

Source: Authors.

Figure 3: Left: the bipartite pouring mold and base; in the center: The assembled mold; Right: The crucible for smelting aluminum.

Source: Authors.

The pouring crucible (seen in figure 3 on the right) was manufactured from a scrap cylinder of an internal combustion engine of a diesel utility vehicle. The cylinder made of steel has an internal diameter of 102.80mm and a height of 150mm, as can be seen in figure 1. The bottom of the crucible was made by welding two superimposed A36 structural steel sheets. In addition to these, reused pvc tubes, gate valve and transparent pvc flexible hose were used to circulate water to cool the device (see figure 4):

Figure 4: Left: Water or oil outlet piping; Right: Water or oil inlet hose.

Source: Authors.

CASTING AND CASTING OF THE ALLOY CHOSEN FOR THE JOB

For the casting of aluminum alloys we use the following materials and methodology: Aluminum frames; muffle furnace; Tweezers to move the crucible; Cooling mold; Infrared pyrometer.

For casting and pouring of the alloy, small pieces of aluminum frames (alloy Al-6061) were placed inside the crucible and from this to the furnace at a high temperature until the melting point. Pure aluminum has a melting point of 660 °C, and its alloys depend on the constituents present [1].

For casting and pouring of metallic alloys, it is necessary that the molten alloy be at a temperature higher than the melting temperature, which is known as pouring temperature [4]. This temperature is also known as superheat. This is necessary for the aluminum alloy to flow easily from the crucible to the solidifying mold. Thus, it was defined that the pouring temperature would be approximately 720 °C. Figure 5 shows a schematic flowchart of the casting and pouring process using the device with cooling using a stream of water or oil:

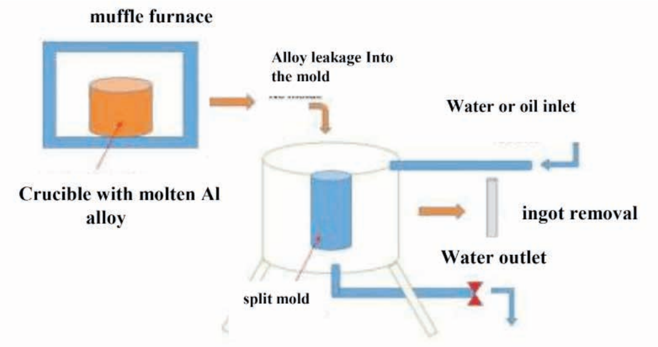

Figure 5: Schematic flowchart of the casting and pouring process using the device with cooling using water or oil stream.

Source: Authors.

In the case of cooling with oil, the oil will be previously placed in the device and kept static during the sample solidification process. Figure 6 below shows the schematic Flowchart of the casting and pouring process using the device with cooling using compressed air:

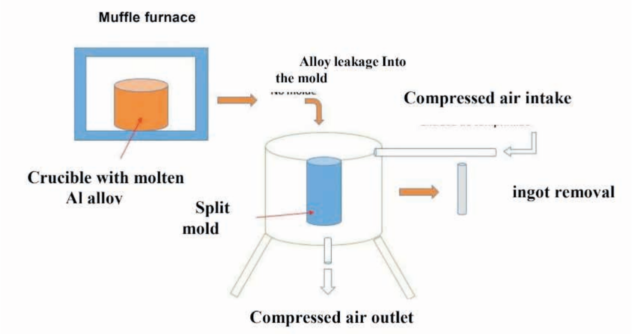

Figure 6: Schematic flowchart of the casting and pouring process using the device with cooling using compressed air.

Source: Authors.

SAMPLE PREPARATION FOR METALLOGRAPHIC ANALYSIS

For the preparation of samples for analysis, we use:

- sandpapers;
- Polishing machine;
- Chemical reagents for surface etching for macrography and micrography.

To carry out the analyses, parts of the

molten samples were first removed, which will later be prepared for the analyses. For this, the ingot samples were sectioned longitudinally for the macrographs and transversally for the micrographs.

After the sample cutting step, those that would be used for macrographic tests were sanded on a rotary sander in a sequence of sandpaper with granulometry ranging from 80 to 600 mesh. The samples to be used for the micrograph tests were sanded sequentially using sandpaper with granulometry 100, 220, 320, 300, 600, 1200 and 1500 mesh in rotary sanders, in addition to the use of Alumina for polishing. Figure 7a shows how the samples are sanded, and figure 7b shows the polishing machine, the equipment used to sand the parts:

Figure 7: 7a: Grinding of cast samples; 7b: Polisher used for sanding the samples.

Source: Authors.

After this step, the samples were chemically attacked with suitable chemical reagents, to highlight the heterogeneities. The samples used for macrography tests were chemically attacked by passing an aqueous solution of 5 ml HF, 30 ml HNO3, 60 ml HCl and 5 ml H2O for a time of 20 seconds [6]. Samples of cross sections to be used for micrographs were chemically attacked by immersing the samples in an aqueous solution of 0.5% HF (hydrofluoric acid) for a time between 10 to 20 s in the sample [6].

CHARACTERIZATION OF MOLTEN SAMPLES

To analyze the macro and microstructure of samples of cast alloys (ingots), the following were used:

- Samples of test specimens;
- Optical microscope, for observation of microstructures;
- Stereoscope microscope, for observation of macrostructures

After preparing the samples, the samples were submitted to macrostructural analysis with the aid of a stereoscopic microscope, to determine the morphological characteristics of the macrostructure, such as the presence of porosities, the direction of heat withdrawal by the sample and other solidification defects that may be present; and the microstructural analysis through the optical microscope, in order to observe the microstructural modifications of the samples.

RESULTS

ALLOY CASTING AND CASTING

As described in the methodology, the casting of the Al-6061 alloy was carried out using scrap of frames, cast in a muffle furnace. In figure 8a, the device ready for use can be seen and in figure 8b, the moment of pouring the molten alloy inside the bipartite mold of the device can be seen.

Figure 8: 8a: Mounted solidification device for water cooling configuration; 8b: Moment of casting of the aluminum alloy into the mold inside the device.

Source: Authors.

The liquid metal was poured at a temperature of approximately 720°C in all cases of cooling mode. It was found during tests with solidification using a forced water stream for cooling, that for the pouring of liquid aluminum in the bipartite mold, a flow rate of 4.90 L\min was first studied and calculated for the circulation of cooling water inside the device, with the water flow adequate for the process.

CHARACTERIZATION OF MOLTEN SAMPLES

After the solidification of the alloy inside the device, sample preparation procedures for metallographic analysis were carried out. The samples were cut and prepared for the subsequent steps of characterization of the cast samples and evaluation of mechanical properties. The cast aluminum ingots had few surface defects, as can be seen in figure 9 below:

Figure 9: Cast aluminum alloy ingot and cut to make samples for characterization and evaluation of mechanical properties.

Source: Authors.

MACROGRAPHS

Figures 10, 11 and 12 show the macrographs made on samples of Al-6061 alloy solidified under cooling with water, air and oil respectively:

Figure 10: Macrograph of sample solidified by cooling with circulating water.

Source: Authors.

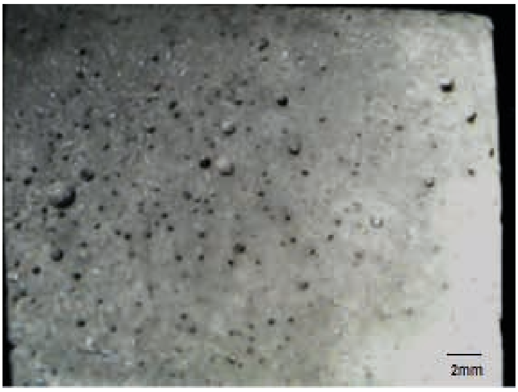

Figure 11: Macrograph of sample solidified by cooling with compressed air.

Source: Authors.

Figure 12: Macrograph of sample solidified by oil quenching.

Source: Authors.

In the macrograph of the sample solidified after cooling with forced water circulation (figure 10), it can be seen that porosities formed during solidification and that the chemical attack was able to reveal the morphology of the more pronounced equiaxed macrostructure on the sides of the longitudinal section of the sample. This would suggest that heat extraction takes place uniformly in all directions within the mold.

In the sample solidified after cooling with compressed air (figure 11), it is verified that there was the formation of porosities in greater quantity than in the other two forms of cooling, this being the most notable characteristic in the morphology of the macrostructure. There is also a coarser morphology. We can infer that this porosity may have been generated due to an operational error in the device or due to the entry of compressed air through the mold during solidification.

In the macrograph of the sample solidified with cooling with oil (figure 12) a morphology similar to the macrograph of the sample solidified with water is verified. It presents little porosity and a more refined equiaxed morphology than in the first case. As a last comparison, we poured the molten alloy into the metallic mold outside the device, so that the alloy cooled and solidified at room temperature, the resulting macrograph is shown in figure 13:

Figure 13: Macrograph of samples solidified by cooling to room temperature.

Source: Authors.

It is clear that at temperature the presence of much larger grains is noticeable than in other cases, with columnar morphology close to the sample surfaces and coarse equiaxial in the interior, which leads to believe that the cooling rate was higher than in other types of cooling.

MICROGRAPHS

Figures 14 and 15 show the macrographs made on the Al-6061 alloy samples solidified under water cooling:

Figure 14: Micrograph of sample solidified by cooling with water (400x).

Source: Authors.

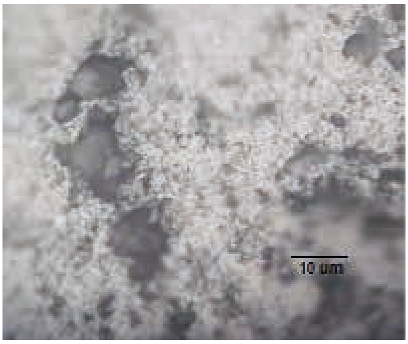

Figure 15: Micrograph of sample solidified by cooling with water (800x).

Source: Authors.

In the micrograph shown in figure 15, it is possible to observe the presence of dispersed phases in the aluminum matrix with average equiaxed morphology with large grains. In the micrograph shown in figure 16 (800x magnification) it is possible to visualize the present phases in greater detail. For the characterization of these phases, it will be necessary to use X-ray fluorescence spectrometry to identify the chemical composition of the present phases. Figures 17 and 18 below show the macrographs made on the Al-6061 alloy samples solidified under compressed air cooling:

Figure 17: Micrograph of sample solidified by cooling with compressed air (250x).

Source: Authors.

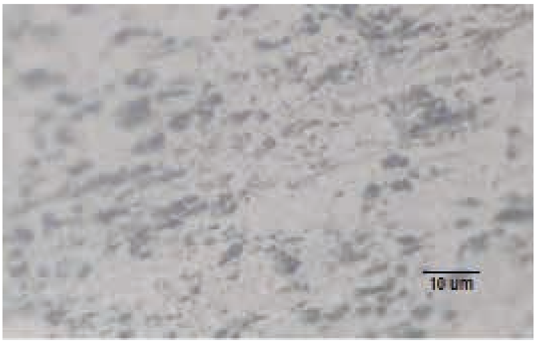

Figure 18: Micrograph of sample solidified by cooling with compressed air (800x).

Source: Authors.

From the micrograph shown in figure 17 (250x magnification) it is possible to observe the presence of dispersed phase in the aluminum matrix in the form of small grains, like very small rounded particles. In figure 18, the same sample, magnified by 800x, it is possible to see the grains dispersed by the matrix in more detail and it is also possible to verify that they have a morphology with smaller dimensions than in the case of cooling with forced water circulation. Figures 19 and 20 below show the macrographs made on samples of Al-6061 alloy solidified under oil cooling:

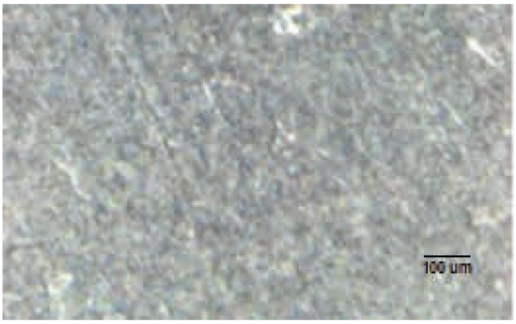

Figure 19: Micrograph of sample solidified by oil-cooling air cooling (300x).

Source: Authors.

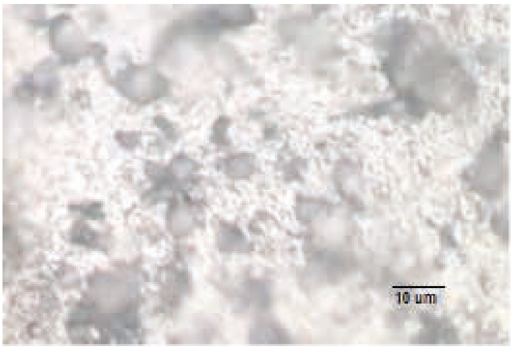

Figure 20: Micrograph of sample solidified by cooling with compressed air (800x).

Source: Authors.

CONCLUSIONS

Through the experiments carried out on the solidification of the Al - 6061 aluminum alloy, it was possible to conclude that the hypothesis of making the solidification of the alloy in a solidification device that is capable of removing heat (cooling) with different cooling rates, really results in solidified ingots with different macrostructure and microstructure morphologies of the material. It was verified that the samples solidified with oil cooling showed the smallest porosities in comparison with the samples solidified with cooling with force water and compressed air circulation, as it could be observed through the macrographs. It was also observed that samples solidified with compressed air cooling showed a lot of porosity, which is concluded that they can be generated by operational error of the device during pouring or air intake through the mold. It was possible to observe an equiaxed morphology in the macrograph.

Through micrographic tests, the chemical attack was able to reveal the constituent phases of the solidified metal alloy in most samples, making it possible to observe the morphology. The ingots solidified with water cooling presented the dispersed phase in the aluminum matrix with larger dimensions than in the other two cases. The specimens solidified with compressed air, despite high porosity, presented a microstructure with refined dispersed phase grains in the shape of small rounded particles. The micrograph of samples solidified with oil cooling showed intermediate characteristics of water and oil.

With regard to the constitution and chemical composition of the phases present, it will be necessary to carry out an analysis by X-ray fluorescence spectrometry. Finally, microstructures with refined phases lead to mechanical characteristics of the alloy, but a greater amount of porosity leads to its weakening, which is what can be estimated for the case of samples solidified with compressed air cooling. However, these cannot be attested after the mechanical properties evaluations have been carried out.

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