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Manufacturing Process of the Aluminum Alloy AA6063 for Engineering Applications

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Abstract

Aluminium alloys 6063 is a widely used material in various industries due to its favourable properties and versatility. Some common applications are in the fields of transportation, architectural applications, industrial applications, electrical enclosures, solar panel frames, heat sinks and sporting goods. Corrosion resistance, mechanical properties and cost less have made many researchers and manufacturers to focus on it. Furthermore, our paper will be focused on the manufacturing process of aluminium alloy AA6063 for usage in engineering applications. The main used processes were alloy formations, heat treatment, extrusion, cooling and aging which have been used respectively for improvement the mechanical properties and finishing operations. Quality control has been realized for ensuring the quality of the products.

Keywords: Manufacturing; aluminium alloys; engineering applications; extrusion; heat treatment.

1. Introduction

In the recent years, Aluminium Alloy AA6063 it has been widely used as aluminium alloy with various beneficial properties [1-3]. Furthermore, AA6063 responds well to polishing, chemical brightening, anodizing and dyeing [4-6]. Due to their excellent formability, corrosion resistance, moderate strength and low cost has made this material to be applied in many engineering applications. Some common applications are mentioned as follows:

- Industrial: Machinery components, conveyor systems, and equipment frames.
- Architectural and construction: Windows, doors, curtain walls, frames, and architectural structures.
- Electrical: Electrical enclosures, conductors, and bus bars

- Transportation: Automotive components, aircraft structures, and marine applications.
- Consumer goods: Furniture, fixtures, sporting goods, and consumer electronics.

In the last two decades many manufacturing companies in the world have been focused on the production of the AA6063 where the production line process can vary depending on the specific requirements of the end product and the manufacturer's practices. However, one of the leading manufactured companies in Albania called "Everest Construction Group" has been focused on the productions of different products with AA6063. The technological scheme for the manufactured process of AA6063 are shown in Figure 1.

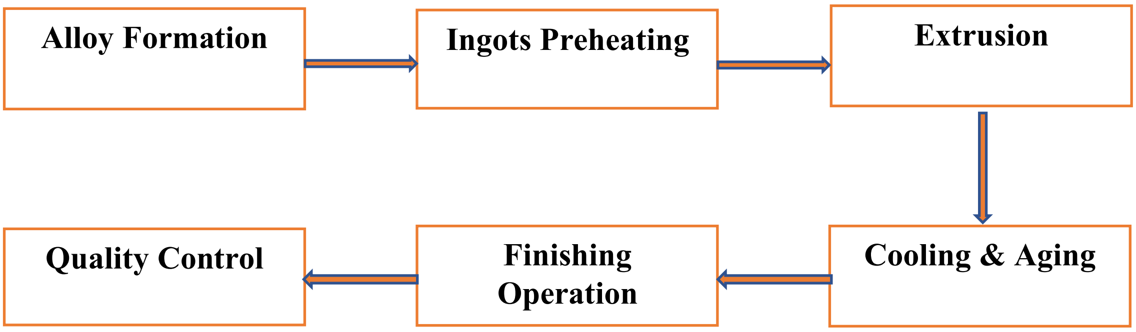


Figure 1. Technological scheme of the manufactured process of AA6063

Our research work will be briefly focused in most important processing steps chain by starting from alloy formation of AA6063, ingots preheating, extrusion, cooling and aging until the finishing operation that has been used during the production of AA6063. Throughout the manufacturing process, quality control has been implemented to ensure that the finished products meet the required specifications.

2. Materials and Production Process

For producing the AA6063 ingots we have focused firstly on the alloy formation in the furnace, see Figure 1. The production capacity of the furnace at Everest Company is 22 tons but the furnace is filled depending on the number of ingots to be produced.

Figure 1. Aluminium smelting furnace, located at Everest Company ltd.

In the furnace, aluminium scraps such as billets and scrap materials have been taken from different production sectors. The melting temperature of aluminium inside the furnace was 660.2 ˚C. Casting of aluminium takes place in the temperature range of 730 - 750 ˚C. AA6063 is composed primarily of aluminum, with specific amounts of other elements added to enhance its properties. The alloy is created by combining molten aluminum with a precise mixture of alloying elements as can be seen in the Table 1.

Table 1. Composition of AA6063 in percentage.

Elements	**Weight (%)**
Aluminium (Al)	98.58
Silicon (Si)	0.54
Iron (Fe)	0.22
Copper (Cu)	0.08
Manganese (Mn)	0.02
Magnesium (Mg)	0.48
Chromium (Cr)	0.01
Zinc (Zn)	0.06
Titanium (Ti)	0.01
Others	0.01

Afterward, the ingots have been heated to a specific temperature to improve their plasticity and facilitate subsequent forming processes. Preheating helps to reduce the force required for extrusion and ensures uniform material properties.

2.1 Extrusion Process

The primary manufacturing process for AA6063 is extrusion. Figure 2 depict the cutting process of the ingots before entering in extrusion process.

Figure 2. Aluminium smelting furnace, located at Everest Company ltd.

Since these ingots are too long to undergo the extrusion process, they are cut into smaller pieces as can be seen in the Figure 3. In the Figure 3(a) it has been shown the cutting machine of the ingots and the Figure 3(c) shows that every ingot has been cut into 12 pieces with approximately 48 cm length.

(a)

(b)

Figure 3. (a) cutting machine of the ingots, (b) ingots after the cutting process

Furthermore, the ingots have been sent to extrusion process. The preheated ingots are loaded into a hydraulic press and pushed through a die with the desired cross-sectional shape, see Figure 4. The high pressure and temperature cause the aluminum to flow through the die, taking on its profile.

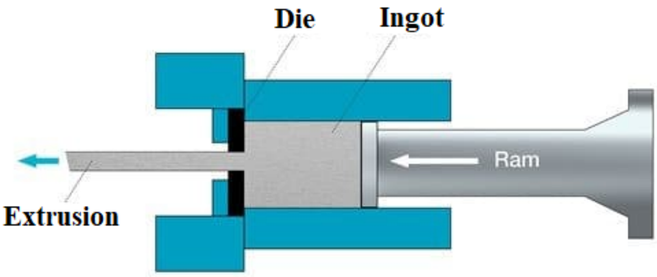


Figure 4. Schematic view of extrusion process [7].

After extrusion, the profiles are cooled rapidly to lock in the desired shape. The cooling process may involve air or water quenching. Subsequently, the profiles are subjected to a natural or artificial aging process to enhance their mechanical properties. Aging can improve the strength and hardness of the alloy. The aluminum profile has been placed and fixed in the tensile process machine where the tensile of the profile is not more than 5% of the length size. Tensile process of the aluminum profile has been done to ensure that the profile will be fully straight after its exit from the ward as well as to remove the remaining strands in the microstructure as a result of the extrusion process. Figure 5 depicts the tensile process of the AA6063 profiles.

Figure 5. Tensile process of the AA6063 profiles

2.2 Finishing Operations

Once the profiles have been extruded and aged, they undergo various finishing operations to achieve the desired surface finish and dimensions. This can include processes like cutting, milling, drilling, welding and surface treatment techniques such as anodizing or powder coating. Figure 6 depicts the important machines for processing different aluminum profiles AA6063 that need to be used in many engineering applications.

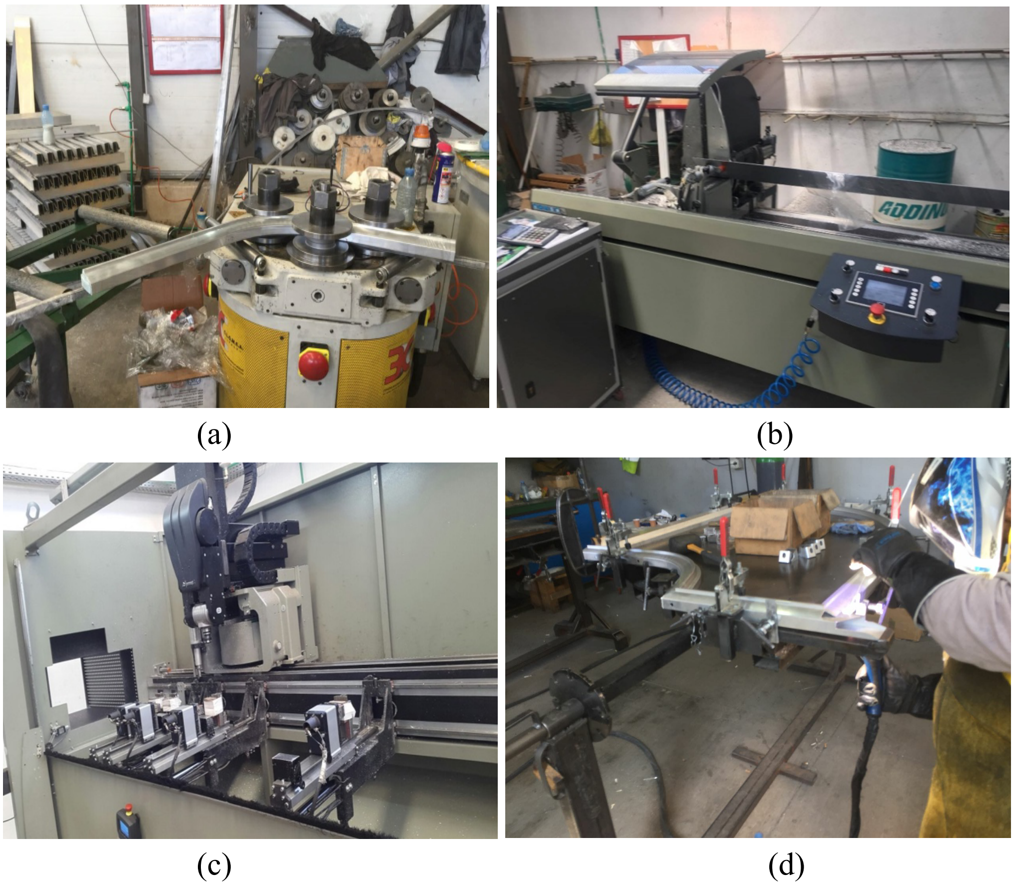


Figure 6. Finishing operations processes, (a) horizontal bending machine, (b) cutting machine (c) milling machine (d) TIG welding process

Moreover, Table 2 shows the physical, mechanical and thermal properties of AA6063.

Table 2. Physical, mechanical and thermal properties of the AA6063

Properties Type	Properties	Symbol	Units	Value
Physical	Density	P	g/cm^3	2.58
Mechanical	Young modulus	E	GPa	67.8
	Tensile strength	σ_t	MPa	142-184
	Extension to destruction	E	%	18-33
	Poisson's coefficient	V	---	0.33
Thermal	Melting temperature	T_m	°C	660.2
	Thermal conductivity	K	W/m·k	200-216
	Coefficient of thermal expansion	A	K^{-1}	$2.34 \cdot 10^{-5}$
	Specific heat	C	J/kg·k	900

In the Figure 7 it has been shown different aluminium alloys AA6063 profiles that can require to follow another important process called heat treatment for improving their physical and mechanical properties.

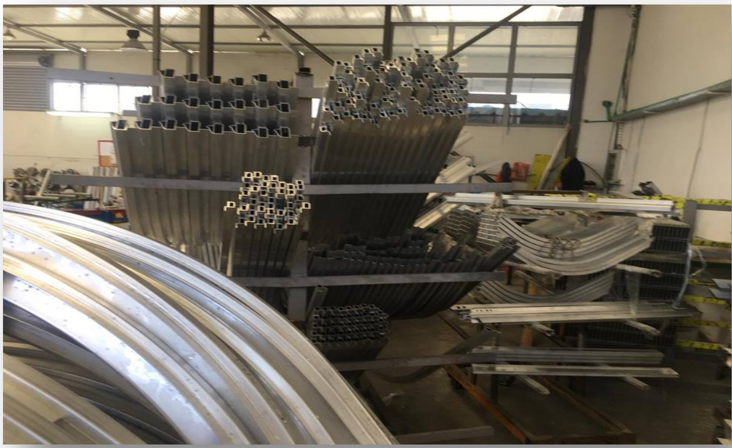


Figure 7. AA6063 profiles after the production process

2.1.1 Heat Treatment

Heat treatment is playing an important role for aluminum alloy AA6063 to achieve specific desired properties and improve its overall performance in various engineering applications. By subjecting AA6063 to the appropriate heat treatment processes, the alloy's mechanical properties, strength, hardness, formability, and corrosion resistance can be optimized to meet specific application requirements. Table 3 depicts the stability that has aluminum profile from heat treatment in assigned time and temperature.

Table 3. Stability of the aluminum alloy AA 6063 during the heat treatment

Temperature (°C)	**Time (Hours)**	**Tensile stress (MPa)**	**Stress in destruction (MPa)**
90	2	131.22	62.65
	6	162.32	86.77
	10	150.48	83.97
	20	181.12	108.32
120	2	141.13	83.49
	6	172.92	100.94
	10	194.88	120.73
	20	181.98	105.75
150	2	144.19	82.93
	6	164.34	95.91
	10	182.46	133.91
	20	117.28	53.79
200	2	174.91	115.79
	6	191.83	110.99
	10	162.16	103.73
	20	118.82	63.81

The produced aluminum profile has been entered in the special furnace at temperature 200-250°C. Once the profiles emerge from the furnace, we have measured their hardness to see the effectiveness of the treatment process. From the measurements has been resulted that the profiles have hardness between 9-14 Webster's. After the heat treatment process the profiles have been sent to the storage.

3. Quality Control

Throughout the manufacturing process, quality control measures are implemented to ensure that the finished products meet the required specifications. This may involve dimensional inspections, mechanical testing, and visual inspections to verify the quality and integrity of the aluminum profiles.

During the manufacturing process of the aluminum alloy AA6063, the quality control has been realized as follows:

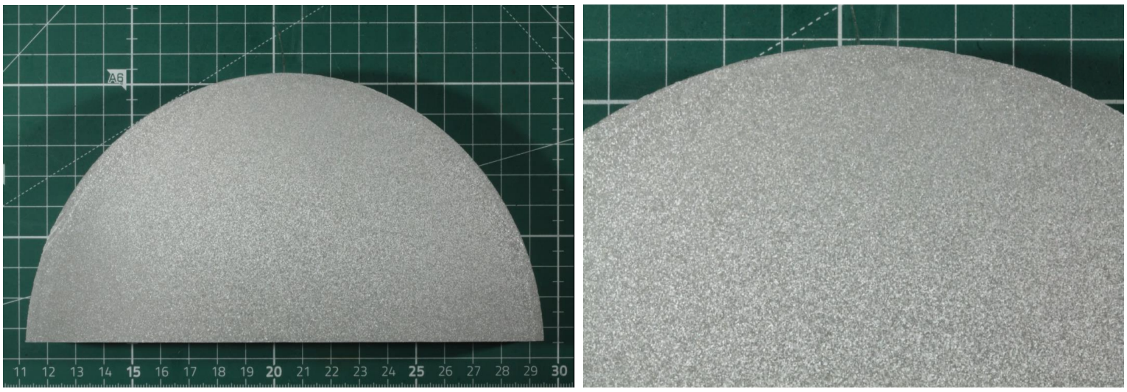
- Macrographic and micrographic examinations
- Tensile testing
- Response surface method

3.1 Macrographic and Micrographic Examinations

3.1.1 Macrographic Examination

Macrographic examination tests methods has been performed according to the ASTM E340-15 [8]. The test was carried out at the temperature 23°C. The macrographic has been investigated through the stereo microscope type LEICA Z16APOA [9]. The selected aluminum alloy AA6063 ingot has a diameter of Ø 176 mm as can be seen in the Figure 8. Furthermore, in order to perform macrographic examination we have selected half cross-section from this ingot sample. After macrographic etching, the half section shows a fine macrostructure free of significant macroscopic defects or abnormalities as can be seen in the Figure 9. The Figure 9a depicts the macrographic section with fine macrostructure, free of defects or macroscopic anomalies and Figure 9b presents the external surface of samples the samples during the preparation with etching tucker solution.

Figure 8. Selection ingot sample AA6063

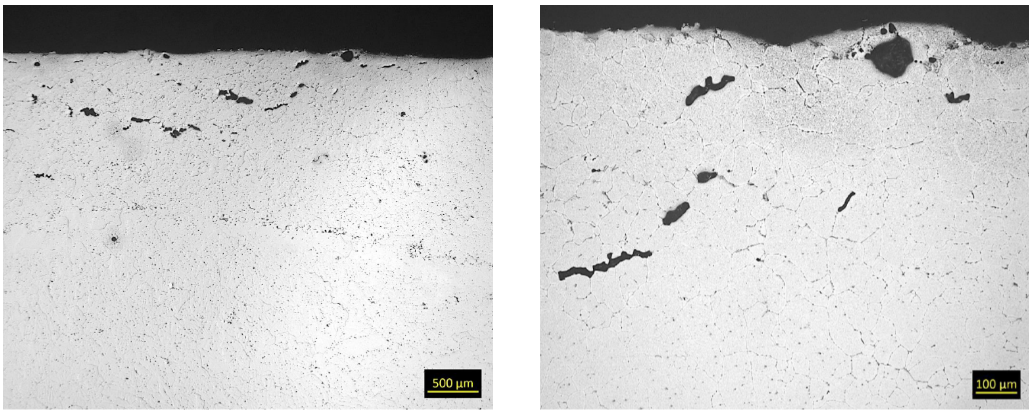


(a) (b)

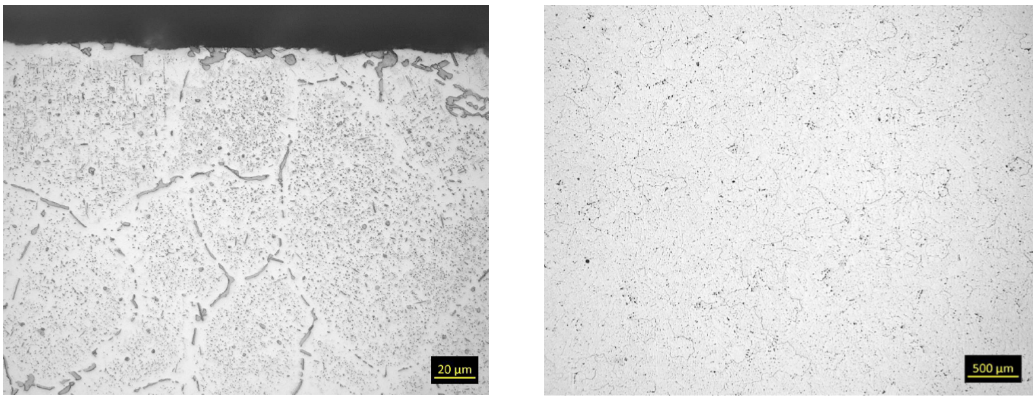
Figure 9. (a) Macrographic section, (b) external surface

3.1.2 Micrographic Examination

Micrographic examination tests methods has been performed according to the ASTM E112-13, ASTM E3-11 and ASTM E407-07 [10-12]. The test was carried out at the temperature 23°C. Three cross-sections were sampled from the billet: outer surface (des. S), half radius (des. R) and center (des. C), using the test methods according to the standards. The micrographic has been taken with optical microscope metallographic LEICA DMRM by using the ZEISS ZEN core v 3.1 [13]. Figure 10 depicts the micrographic examination test results.



(a) (b)



(c) (d)

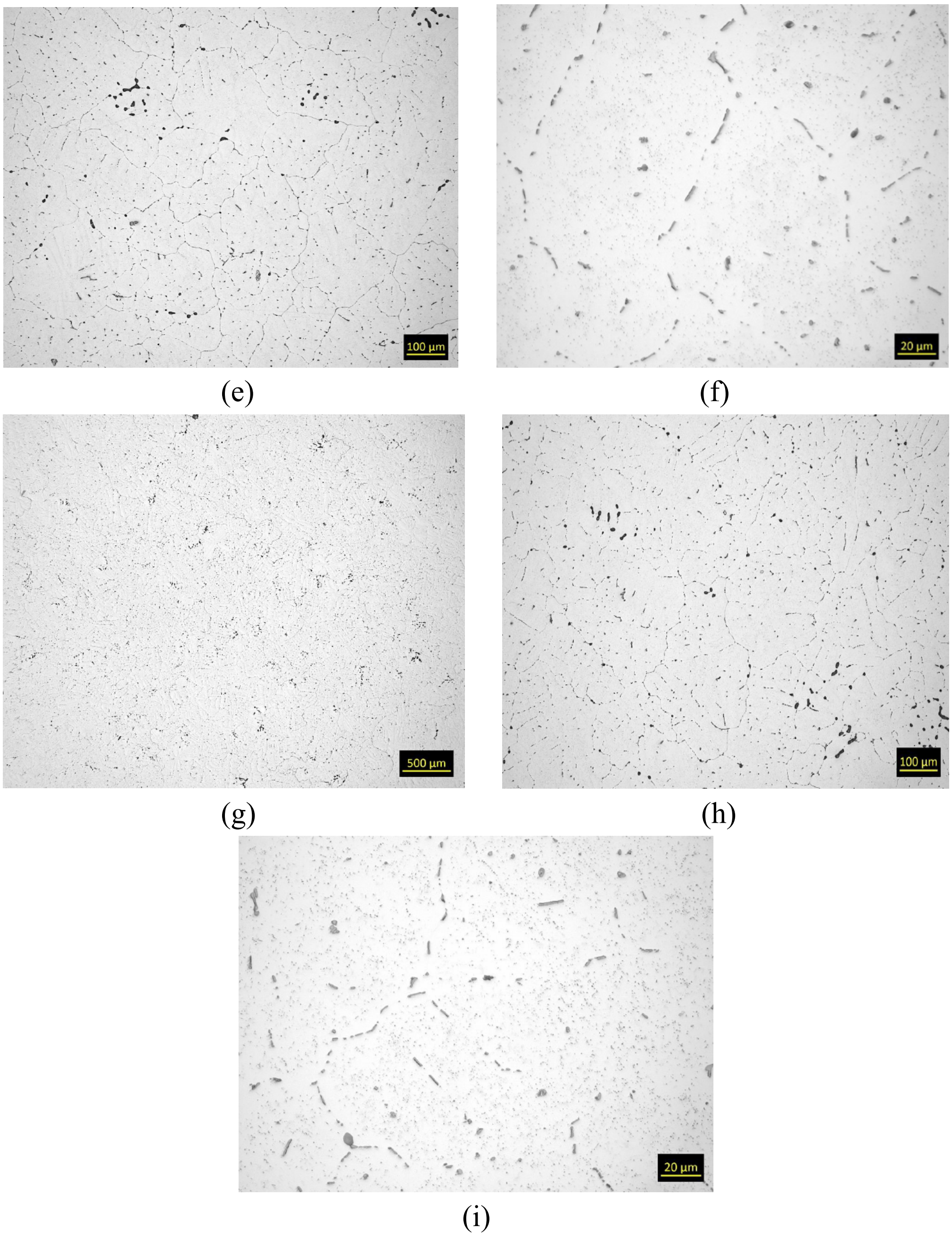
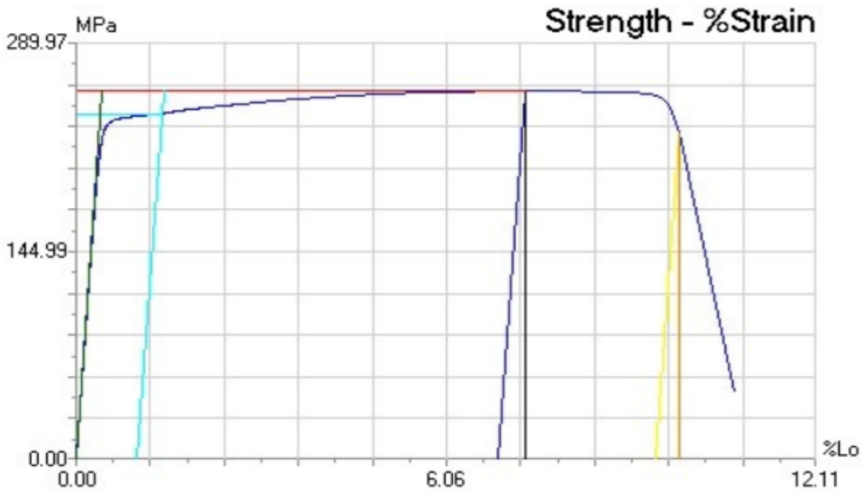


Figure 10. (a) Surface: Presence of frequent shrinkage cavities and gas porosity, (b) Surface: Grain size G = 3,5 ÷ 4, (c) Surface: Microstructure characterized by an alpha-aluminum matrix with precipitations of intermetallic compounds, (d) Half radius: Presence of micro shrinkage cavities, (e) Half radius: Grain size G = 2 ÷ 3, (f) Half radius: Microstructure characterized by an alpha-aluminum matrix with precipitations of intermetallic compounds, (g) Centre: Presence of micro shrinkage cavities, (h) Centre: Grain size G = 2 ÷ 3, (i) Centre: Microstructure characterized by an alpha-aluminum matrix with precipitations of intermetallic compounds

3.2 Tensile Testing

The tensile testing has been realized in accordance of the standard UNI EN ISO 6892-1:2020 [14]. The samples were analyzed in three different sections such as surface, half radius and center. In the Figure 11 are shown the of tensile testing device type Eurotest 100 and stress – strain diagram results for AA6063 [15].

(a)



(b)

Figure 11. (a) Tensile testing device, (b) Stress – strain diagram results for AA6063

In the Table 4 it has been presented the results of tensile test for aluminum alloy AA6063.

Table 4. Tensile testing results of aluminium alloy AA6063

	Dimensions			**Yield Strength**	**Tensile Strength**	**Elongation**
	b	So	Lo	Rp	Rm	A50
Requirements	5 mm	63 mm^2	50 mm	>=170 MPa	>=215 MPa	>=6%
Results	4.72mm	59.13mm	50mm	240.929	25617	9.865

3.3 Response Surface Method

Response surface method (RSM) is one of the common methods that can be used in metallurgy and is focused on the determination of the hardness during the time by using Design expert program. Two important parameters such as temperature and aging time has been chosen in approximate to the values applied by the manufacturers for some aluminum alloys with T = 185°C and time t = 8h. As a step value for these two parameters we have chosen: ΔT = 15°C and Δt = 3h. These steps values provide approximately the same effect on the process indicator (hardness HBN). Equations (1) and (2) are our experimental models which expresses the process indicator (hardness HBN) depending from the factors and the interaction between them [16].

- Final Equation in Terms of Coded Factors:

$$Hardness = +92.25 + 3.57 * A + 5.84 * B - 6.77 * A * B - 4.66 * A^2 - 6.66 * B^2 \quad (1)$$

- Final Equation in Terms of Actual Factors:

$$Hardness = -945.97537 + 9.10519 * A\ Temperature + 41.53821 * B\ Time - 0.15000 * A\ Temperature * B\ Time - 0.020722 * A\ Temperature^2 - 0.74028 * B\ Time^2 \quad (2)$$

The RSM response surface (3D) plot of Hardness vs Time-Temperature are shown in Figure 12.

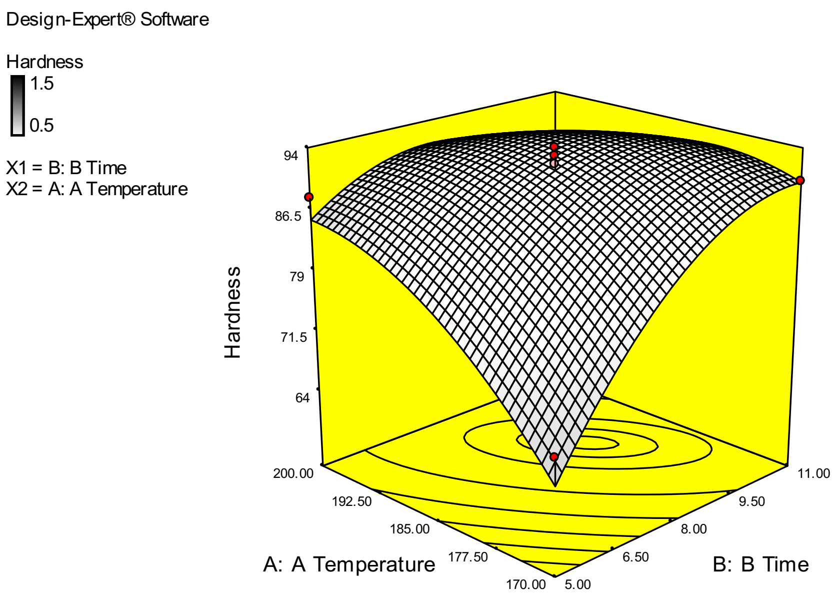


Figure 12. The RSM response surface (3D) plot of Hardness vs Time-Temperature

4. Conclusion

This paper presents the manufacturing process line for aluminum alloy AA6063. The main used processes were alloy formations, ingot preheating, extrusion, cooling and aging have been briefly described for improvement the mechanical properties by including finishing operations. Quality control has been realized for ensuring the quality of the products and avoiding technical barriers. The results have shown that AA6063 fulfil the requirements of the international standards.

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Conflict of Interest

The authors would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes

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