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Improvement of Grain Structure of AA6063 Alloy Billet Casting

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ABSTRACT

In this study; it was aimed to develop AA6063 alloy Aluminum alloy billet properties of 203 mm in diameter. For this purpose; metal temperature, casting and liquid metal height at the casting table. After the casting process, the homogenization process was carried out at different times, temperatures and different cooling rates. Microstructure, hardness and tensile tests were carried out on the samples taken from the test billets and parameters were determined for the production of AA6063 alloy billets with a diameter of 203 mm.

Keywords: Aluminum, Aluminum Alloy, AA6063, DC Casting, Microstructure, Metallography

1. INTRODUCTION

With the development of industry and technology, the use of aluminum and its alloys is increasing. Aluminum is used more and more in the world and in our country due to many advantages brought by its technical features. The fact that aluminum and its alloys can be compared with iron and steel products in consumption, and their increasing use in electricity, chemistry, medicine, construction, automotive and aviation industries and their sub-industries increases its importance. [1][3].

AlMgSi alloys, which have an important place in the aluminum industry and are known as the 6xxx series, are known for their good extrudability, high corrosion resistance, clean surface after hot deformation and low cost of the processes applied to obtain moderate strength. AlMgSi alloys are widely used in areas such as strength, good machinability, high corrosion resistance, in the automotive and aerospace industry, construction industry, transportation, architectural and decorative applications. [2][5]. Casting method and parameters play important role in AlMgSi alloys. The mechanica structure formed during the casting stage directly affects the extrusion process[4]. Parameters play a major role in the change of microstructure during casting[4].

In this study; It is aimed to examine the effect of casting production parameters on the mechanical and microstructural properties of AA6063 aluminum alloy produced by vertical continuous casting method.

Sin [9] used the Flemings model to show that the fluidity increases with increasing pouring and mold temperature. He found that increasing runner height fills the starting heads faster. Colak [10] said that the viscosity of sand in the molds varies according to the section thickness and is the highest after 5 mm and decreases exponentially up to 0.5 mm. He stated that the fluidity did not increase with the grain refiner.

2. EXPERIMENTAL STUDY

2.1. Production Process

In this study, AA 6063 aluminum alloy billet, the composition of which is given in Table 1., was produced by vertical continuous casting method by using the casting parameters given in Tables 2, Tables 3 and 4. These alloys were subjected to mechanical tests both as cast and homogenization heat treated. While the applied homogenization heat treatment was carried out at 580^{o}C for 8 hours, experiments were carried out with 2 different cooling rates after homogenization.

Table 1. Chemical compositions of 6063 alloy billets according to casting numbers

	Fe%	Si%	Cu%	Mg%	Zn%	Ti%	Al%
TS_EN_537_3	**Max.0.35**	**0.20-0.60**	**Max.0.10**	**0.45-0.90**	**Max.0.10**	**Max.0.10**	**Other**
Cast-1	0,23	0,42	0,058	0,52	0,008	0,017	98,65
Cast-2	0,24	0,43	0,07	0,54	0,008	0,015	98,61
Cast-3	0,22	0,41	0,04	0,55	0,01	0,016	98,66

Table 2. Metal temperature (^{0}C) values used in trial castings

Cast Lot Number	Metal Temperature (ºC)	Casting Speed (mm/min)	Metal Height at Table (mm)
Cast-1	690	105	45
Cast-2	700		
Cast-3	710		

Table 3. Casting speed (mm/min) values used in trial castings

Cast Lot Number	Metal Temperature (ºC)	Casting Speed (mm/min)	Metal Height at Table (mm)
Cast-1	690	100	45
Cast-2		105	
Cast-3		110	

Çizelge 4. Liquid metal height (mm) values on the table used in trial castings

Cast Lot Number	Metal Temperature (ºC)	Casting Speed (mm/min)	Metal Height at Table (mm)
Cast-1	690	105	25
Cast-2			35
Cast-3			45

2.2. Metallographic Process

The microstructure of the AA6063 aluminum alloy billet, which was produced by changing the metal temperature values with the vertical continuous casting method, and subjected to the casting and homogenization heat treatment, was examined with an optical microscope. Metallographic examination was carried out by sanding the samples up to 1200 mesh and then polishing with Al2O3 paste. After polishing, the sample surfaces were etched with Keller's Solution (95 ml H2O, 2.5 ml HNO3, 1.5 ml HCL and 1 ml HF) for 2 minutes. Afterwards, the surfaces of the samples were washed with distilled water and alcohol and dried, and the samples were examined under an optical microscope.

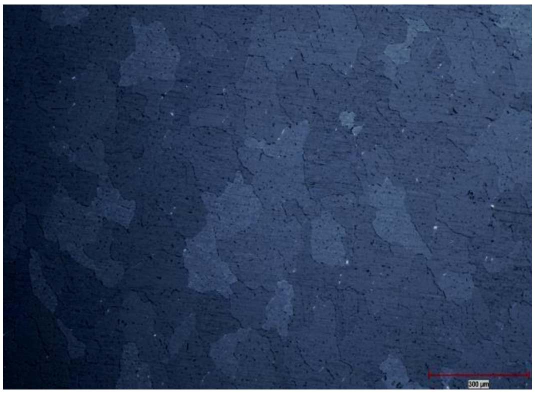
2.3. Mechanical Tests

The samples taken from the castings were examined in the Qness Hardness Tester and the results were shown as Vickers. Tensile test experiments were performed on the Zwick/roell device.

3. RESULTS AND DISCUSSION

3.1. Microstructure Analysis

Microstructure analyzes of AA6063 billets produced by DC casting method were carried out separately for each experimental group. In Figure 1, the microstructure images of the examination for different metal temperature values, in Figure 2, the microstructure images of the examination for different casting speed values, and in Figure 3, the microstructure images of the examination made for different liquid metal height values are given.

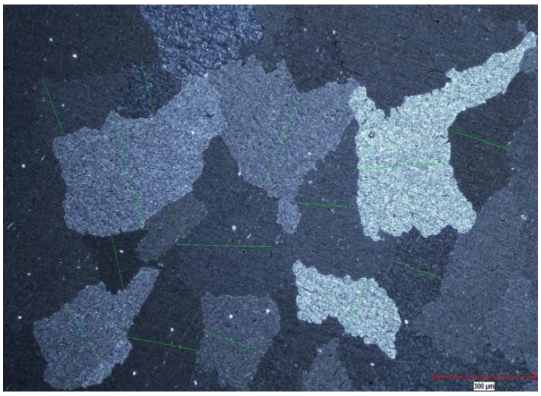


Magnify	100x
Length (µm)	
Min	71,00
Max	152,00
Average	94,00

a)

Magnify	100x
Length (µm)	
Min	98,00
Max	188,00
Average	140,00

b)

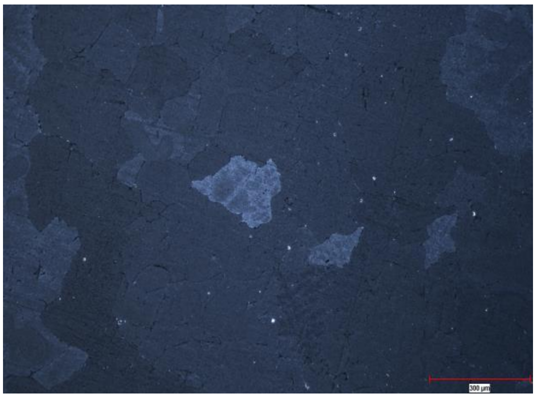


Magnify	100x
Length (µm)	
Min	189,00
Max	233,00
Average	202,00

c)

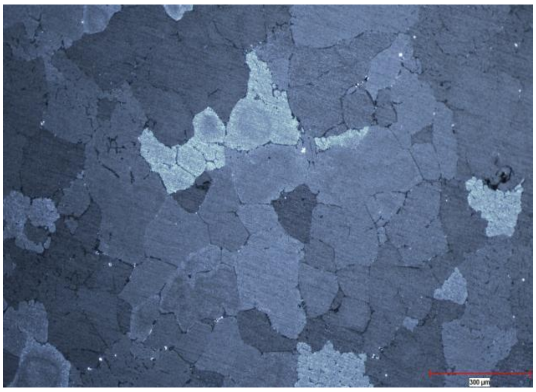
Figure 1. Microstructure images of AA6063 aluminum alloy billet; a) 690^0C and grain size 94 µm, b) 700^0C and grain size 140 µm c) 710^0C and grain size 202 µm

According to the samples examined, it was observed that the grains in the casting made at 690^0C were smaller and more homogeneous than the others.



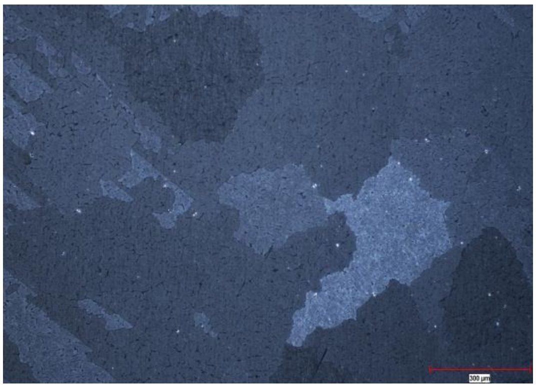
Magnify	100x
Length (µm)	
Min	110,00
Max	221,00
Average	158,00

a)



Magnify	100x
Length (µm)	
Min	77,00
Max	129,00
Average	89,00

b)



Magnify	100x
Length (µm)	
Min	80,00
Max	371,00
Average	256,00

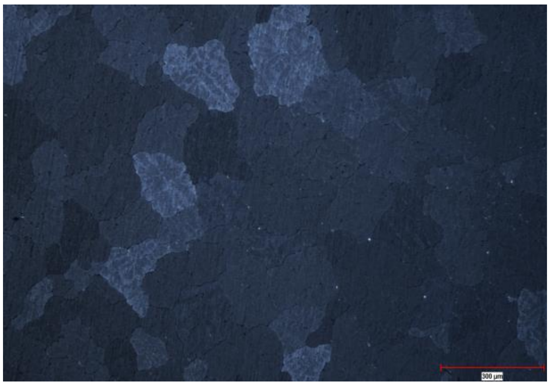
c)

Figure 2. Microstructure images of AA6063 aluminum alloy billet; a) 110 mm/min, b) 105 mm/min c) 100 mm/min

In castings made according to different casting speed values; It was observed that as the casting speed value increased, the grains in the microstructure became smaller.

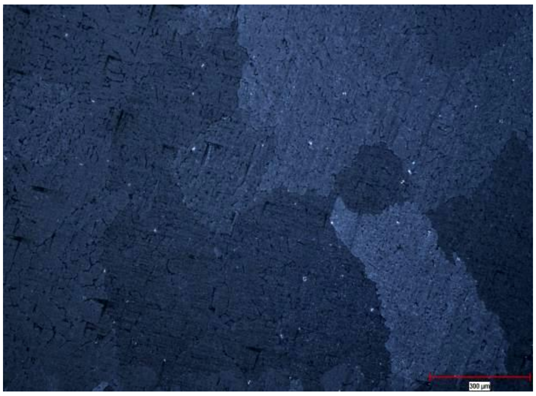
Magnify	100x
Length (µm)	
Min	71,00
Max	225,00
Average	149,00

a)



Magnify	100x
Length (µm)	
Min	81,00
Max	124,00
Average	101,00

b)



Magnify	100x
Length (µm)	
Min	144,00
Max	432,00
Average	241,00

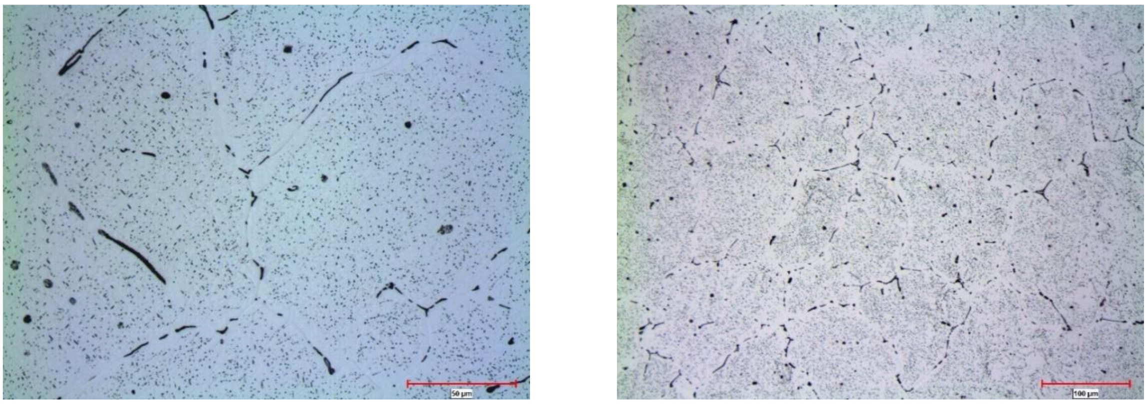
c)

Figure 3. Microstructure images of AA6063 aluminum alloy billets; a) 25mm, b) 35mm, c) 45mm

According to the results of the samples taken from the castings made according to the different values of the liquid metal height on the casting table; The microstructure of the casting made with liquid metal with a height of 35 mm had smaller grains than the others. The microstructure of the casting made with liquid metal with a height of 45 mm had larger grains than the others.

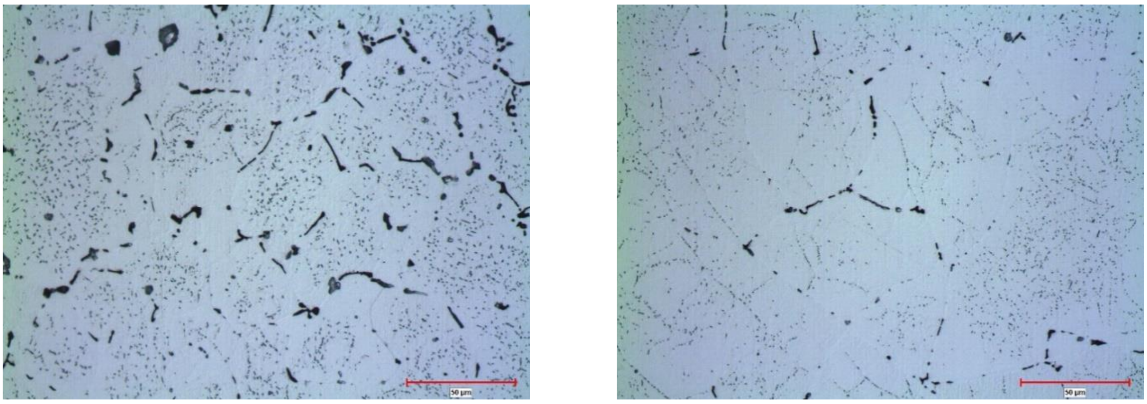
Afterwards, the homogenization process was applied to the billets produced by the continuous casting method. For this purpose, after 8 hours of homogenization process at 580^{0}C, the billets were subjected to cooling process. Temperature changes during the homogenization process and the subsequent cooling process were made using the JumoLogoscreen Nt model data logger device. For this, a thermocouple was driven up to the center of the billet, on which homogenization and cooling was applied, and temperature changes were recorded. In order to obtain the desired cooling rate in the cooling process, the air fans in the cooling section were operated in a controlled manner. Microstructure values of the samples were examined according to the cooling rate values of 150^{0}C/hr and 200^{0}C/hr.

After homogenization and cooling, samples were taken from the surface and center regions of the billet and microstructure studies were carried out. In Figure 4, the microstructure image of the center region of the Cast-1 lot numbered billet according to the cooling rate values of 150^{0}C/hour and 200^{0}C/hour, in Figure 5 the microstructure of the central region according to the cooling rate values of 150^{0}C/hour and 200^{0}C/hour of the Cast-2 lot numbered billet. The microstructure image of the central region is given in Figure 6 according to the cooling rate values of 150^{0}C/hr and 200^{0}C/hr of Cast-3 lot numbered billet.



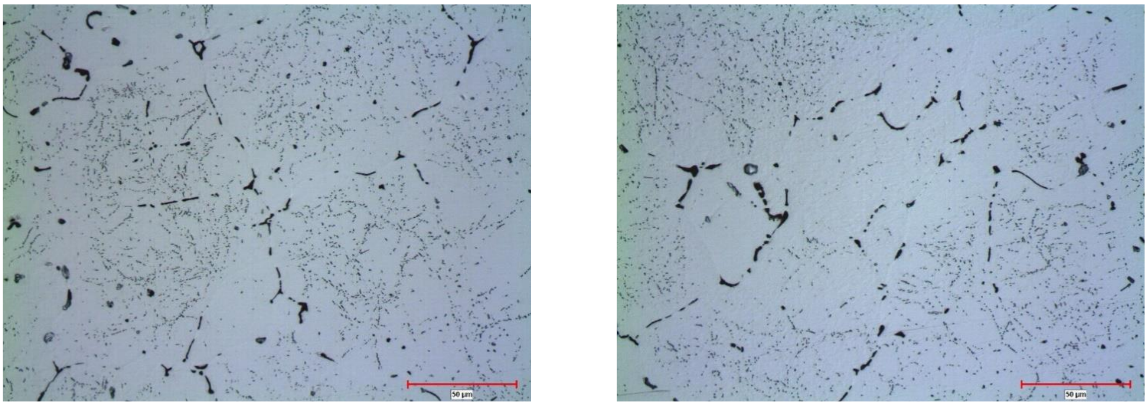
a) b)

Figure 4. Microstructure image of the central region of the Cast-1 lot numbered billet; a) 150^0C/hour, b) 200^0C/hour



a) b)

Figure 5. Microstructure image of the central area of the billet with Cast-2 lot number; a) 150^0C/hour, b) 200^0C/hour

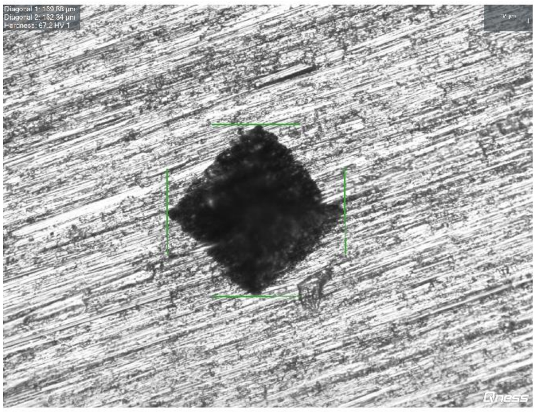


a) b)

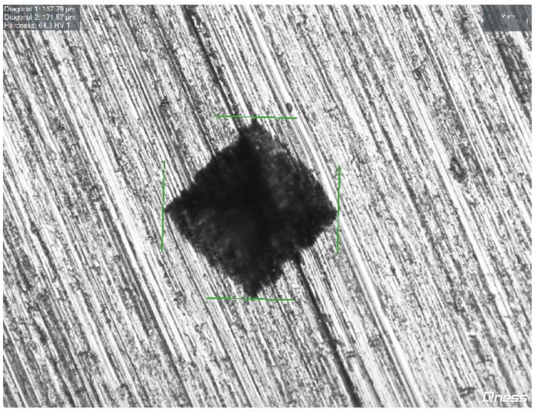
Figure 6. Microstructure image of the Cast-3 lot numbered billet center region; a) 150^0C/hour, b) 200^0C/hour

In microstructural studies, it is seen that as the cooling rate increases, both the phase transformation and the intragranular precipitate behavior are better.

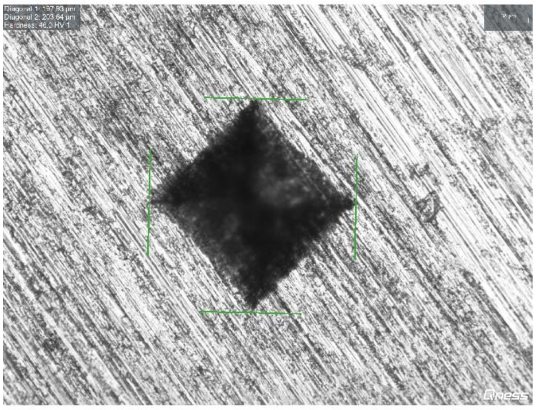
3.2. Mechanical Test Results



a)



b)



c)

Figure 7. (a) Cast-1, (b) Cast-2, (c) Cast-3 hardness sample images

Table 5. According to the liquid metal temperatures, the hardness values of Cast-1 690^{0}C, Cast-2 700^{0}C, Cast-3 710^{0}C, constant casting speed 105mm/min and height 45mm

Temperature(^{0}C)	No.	Value	Method	X pos. [mm]	Y pos. [mm]	d1 [mm]	d2 [mm]
690^{0}C	1	84,10	HV 1	0,20	0,00	0,17	0,16
	2	83,40	HV 1	1,40	0,00	0,17	0,17
700^{0}C	1	82,10	HV 1	0,20	0,00	0,17	0,18
	2	82,50	HV 1	1,40	0,00	0,17	0,18
710^{0}C	1	78,80	HV 1	0,20	0,00	0,17	0,17
	2	81,00	HV 1	1,40	0,00	0,17	0,17

Table 6. According to the variability of casting speeds, hardness values of Cast-1 100mm/min, Cast-2 105mm/min, Cast-3 110mm/min, constant casting speed 690^{0}C and height 45mm

Casting Speed(mm/min)	No.	Value	Method	X pos. [mm]	Y pos. [mm]	d1 [mm]	d2 [mm]
100 mm/min	1	78,90	HV 1	0,20	0,00	0,17	0,17
	2	79,50	HV 1	1,40	0,00	0,18	0,17
105 mm/min	1	84,90	HV 1	0,20	0,00	0,17	0,16
	2	85,10	HV 1	1,40	0,00	0,17	0,18
110 mm/min	1	82,20	HV 1	0,20	0,00	0,17	0,17
	2	81,50	HV 1	1,40	0,00	0,17	0,16

Table 7. Hardness values of Cast-1 25mm, Cast-2 35mm, Cast-3 45mm high, constant casting speed 690^{0}C and casting speed 105mm/min, according to the variation of metal level height in the table

Height (mm)	No.	Value	Method	X pos. [mm]	Y pos. [mm]	d1 [mm]	d2 [mm]
25 mm	1	81,10	HV 1	0,20	0,00	0,17	0,17
	2	82,70	HV 1	1,40	0,00	0,18	0,17
35 mm	1	84,90	HV 1	0,20	0,00	0,17	0,16
	2	85,30	HV 1	1,40	0,00	0,17	0,18
45 mm	1	83,20	HV 1	0,20	0,00	0,17	0,17
	2	84,50	HV 1	1,40	0,00	0,17	0,16

3.3. Tensile Test Results

Test report

Customer	: Casting Sample Result	Material	: Aluminum Profile
Job no.	: 1	Specimen type	: EN AW-6063
Test standard	: 755-2	Machine data	: Zwick/Roell
Type and designation of	: Tensile Test		

Pre-load	: 2	MPa	Speed in the yield range :	0,00025	1/s
Speed, E-Modulus	: 60	MPa/s	Test speed :	0,008	1/s
Speed, yield point	: 60	MPa/s			

Test results:

Nr	E GPa	R_{eH} MPa	R_{eL} MPa	A_e %	$R_{p0.2}$ MPa	R_m MPa	F_m kN	$A_{t\,(corr.)}$ %	$A_{gt\,(corr.)}$ %	A_{50} %	L_0 mm	L_c mm	a_0 mm	b_0 mm
3	47	-	-	-	193	223	4,50	11,5	8,05	11,2	34,97	50,45	1,61	12,55

Series graph:

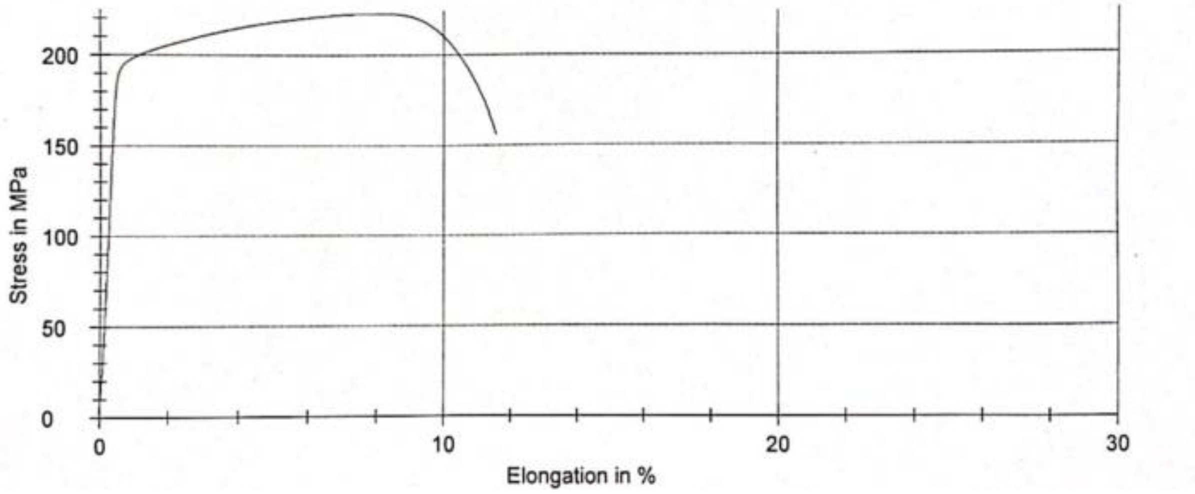
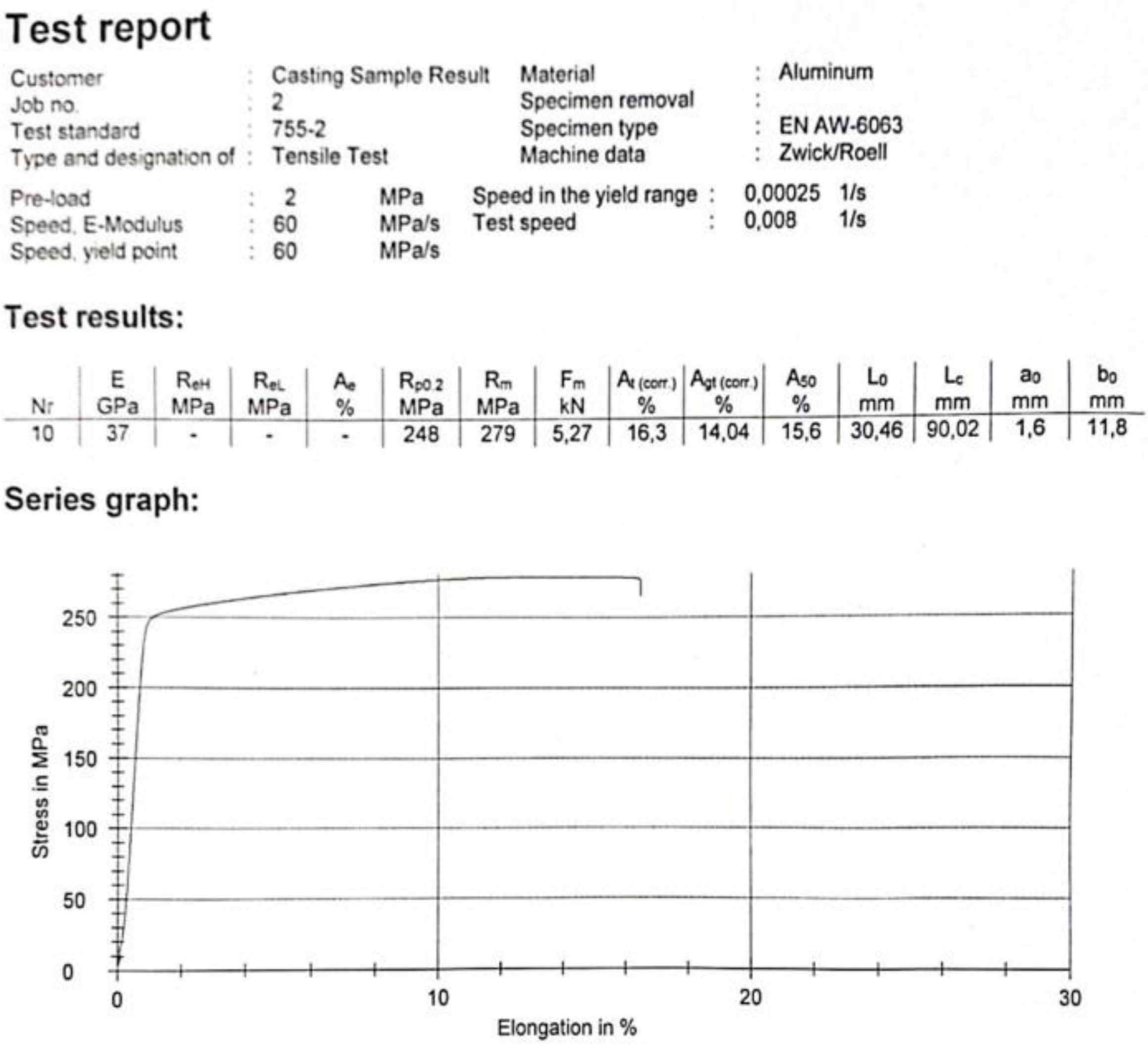


Figure 8. Cast-3 110mm/min tensile test sample images,



Test report

Customer : Casting Sample Result
Job no. : 2
Test standard : 755-2
Type and designation of : Tensile Test
Material : Aluminum
Specimen removal :
Specimen type : EN AW-6063
Machine data : Zwick/Roell

Pre-load : 2 MPa
Speed, E-Modulus : 60 MPa/s
Speed, yield point : 60 MPa/s
Speed in the yield range : 0,00025 1/s
Test speed : 0,008 1/s

Test results:

Nr	E GPa	R_{eH} MPa	R_{eL} MPa	A_e %	$R_{p0.2}$ MPa	R_m MPa	F_m kN	$A_{t\ (corr.)}$ %	$A_{gt\ (corr.)}$ %	A_{50} %	L_0 mm	L_c mm	a_0 mm	b_0 mm
10	37	-	-	-	248	279	5,27	16,3	14,04	15,6	30,46	90,02	1,6	11,8

Series graph:

Figure 9. Cast-1 690^{0}C tensile test sample image

Table 8. Tensile Test Results

Sample Name	Tensile Strength R_m (MPa)	Yield Strength $R_{po,2}$ (MPa)
Cast-1 690^{0}C	279	248
Cast-2 700^{0}C	244	215
Cast-3 710^{0}C	233	205
Cast-1 100mm/min	219	191
Cast-2 105mm/min	270	223
Cast-3 110mm/min	223	193
Cast-1 25mm	239	214
Cast-2 35mm	263	228
Cast-3 45mm	211	188

Solidification occurs very quickly in the vertical continuous casting method. Therefore, the metal temperature should be kept low for solidification to proceed rapidly [7]. During solidification, the liquid metal that comes into contact with the mold wall immediately solidifies and forms a crust. This shell formed is actually the first nuclei formed during solidification. If the casting temperature is high enough, the liquid in the center of the billet will stay above the liquidus temperature for a long time. As a result, most of the crystals will remelt soon after they are removed from the mold wall. Only these remaining crystals will be able to grow near the mold wall to form the cooling zone and will form a thin crust of randomly oriented small coaxial grains on the billet surface. On the other hand, if the casting temperature is low, all of the liquid in the mold will cool rapidly below the liquidus temperature and the crystals will rapidly migrate into the melt, known as "bing-bang" nucleation[2]. Then a fully coaxial billet structure will be produced [8]. In aluminum castings, the metal temperature should be kept as low as possible in order for the solidification to progress rapidly [7]. Therefore, it is thought that the mechanical properties of the castings with a metal temperature of 690^{o}C are measured as high.

4. CONCLUSION

The following general results were obtained from this study, which was carried out by changing the m parameters during the production of AA 6063 aluminum alloy billet with a diameter of 203 mm by vertical continuous casting method.

1. It is thought that the microstructure of AA6063 aluminum alloy produced by vertical continuous casting method consists of aluminum solid melt (matrix) and α+Mg2Si eutectic phase. After the applied homogenization heat treatment, a finer grained and homogeneous microstructure was obtained compared to the casting state.
2. It was observed that the size of the grains in the microstructure increased as the casting temperature increased.
3. The increase and decrease in casting speed did not give positive results, and the optimized speed became more effective.
4. When the metal height on the casting table is 35 mm, a better microstructure value was achieved compared to other height values.
5. It has been observed that the cooling rate of 200^{0}C/hour is more appropriate in the cooling process after the homogenization process.
6. The best hardness results were 84-85 HV, tensile strength of 263-279 MPa and yield strength of 223-248 MPa at 690 ^{o}C temperature, casting speed of 105 mm/min and liquid metal height of 35 mm.

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