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Full Length Research Paper

The improvement of the mechanical properties of AA 6063 aluminum alloys produced by changing the continuous casting parameters

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This study aims to improve manufacturing parameters of the AA 6063 aluminum alloy produced with the vertical continuous casting method. For this purpose, the billets were manufactured at different metal temperatures and different casting speeds, using the vertical continuous casting method. Billet specimens were prepared at two different conditions: casting and homogenization heat treatment. The homogenization heat treatment was applied at 580°C for 4 h. Specimens at each group were exposed to microstructure analyses and hardness and tensile tests in order to determine their mechanical properties. As a result of the applied experiments, it was determined that the mechanical properties varied depending on metal temperature and casting speed; and the optimum casting parameters were 690°C metal temperature and 100 to 110 mm/min casting speed.

Key words: Aluminum alloys, AA 6063, DC casting, mechanical properties.

INTRODUCTION

With the development of industry and technology, the use of aluminum and its alloys is also increasing. Due to the many advantages of its technical properties, aluminum is used more and more in the world (Turbalıoglu, 2009).

In recent years, aluminum and its alloys have had high rate of consumption compared to iron-steel products and are being used more in industries such as electrical, chemical, medicine, construction, automotive and aviation and their sub-industries, increasing their importance the more (Arun et al., 2010; Sun et al., 1999; Altenpohl, 1986).

AlMgSi alloys, apart from their importance in the aluminum industry and being called 6000 series, are also known for their good extrudeability, high corrosion resistance, and having lower costs of processes in order to obtain clear surface and moderate level of strength after hot deformation (Turbalioglu, 2008). Due to their high strength, good workability and high corrosion resistance, AlMgSi alloys are used in various areas including automotive and aviation, transportation, architecture industries, construction sector and decoration applications (Sun et al., 2011; Birol, 2004; Gavgali et al., 2003).

The first step of manufacturing in the 6000 series aluminum alloys starts with the casting method, and the initial casting structure has an important effect on the success of thermo-mechanical methods. Therefore, it is very important to define and distinguish the casting state of the AlMgSi alloy billets in their hot processability. In defining their casting state structures, it is possible to benefit from three variables controlling the microstructure:

(1) Rate of solidification or rate of diffusion at the solid-liquid interface.
(2) Temperature gradient at the diffused solid-liquid interface.
(3) Diffusibility of the soluble at the liquid and the solid interface (Cai et al., 2007; Cavazos, 2001; Siddiqui et al., 2000).

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Table 1. Chemical compositions of billets according to their casting number.

Casting number	Fe	Si	Mg	Zn	Ti	Mn
1416	0.19	0.42	0.49	0.008	0.014	0.002
1420	0.18	0.43	0.50	0.008	0.022	0.002

Table 2. The casting parameters were changed in the production of aluminum billets.

Casting Number	Temperature of metal (°C)	Flow rate of the cooling water (m^3/h)	Casting speed (mm/min.)	Temperature of casting water (°C)
1420	690			
1416	700			
1416	710		110	
1420	720	160		21
1438			100	
1438	710		110	
1438			120	

This study aims to investigate the effect of parameters of metal temperature and casting speed on the mechanical properties of the AA 6063 aluminum alloy produced with the vertical continuous casting method (Turbalıoglu, 2008). By this means, the determined production parameters will make it possible for enterprises to gain time and energy in billet production with the vertical continuous casting method and the production costs will be decreased.

MATERIALS AND METHODS

In this study, the AA6063 aluminum alloy billets, whose composition is given in Table 1, were produced with the vertical continuous casting method by using the casting parameters given in Table 2. During the casting, casting water flow and casting water temperature were kept constant and the casting was carried out at the values of 4 different metal temperatures between 690 to 720°C and at 3 different casting speeds between 100 to 120 mm/min. These alloys were exposed to mechanical experiments both in casting state and in homogenization heat treated state. The applied homogenization heat treatment was conducted at 580°C for 4 h.

The microstructures of the AA6063 aluminum alloys produced with the vertical continuous casting method were analyzed at the optical microscopy (LOM), scanning electron microscope (SEM) and energy dispersive spectrometer (EDS). The metallographic analysis was conducted by exposing the specimens to grinding at up to 1200 mesh and then polishing with Al_2O_3 paste. After the polishing process, the specimen surfaces were etched with the Keller solution (95 ml H_2O, 2,5 ml HNO_3, 1,5 ml HCL and 1 ml HF) for 2 min. Then the surfaces of the specimens were washed with pure water and alcohol, dried, and then analyzed in the optic microscope.

The mechanical property characterization was carried out with hardness and tensile tests. The hardness tests were carried out at room temperature and under 62.5 N load with Frank brand Brinell hardness test device in the metallographic laboratory of the ETI Aluminum Company. While the hardness test was being applied, 5 different points at equal intervals from the outmost point of the specimen, where measurements can be carried out, to the center of the specimen were determined. The hardness measurement was carried out at 3 different places of these determined points and the average of these values was calculated.

The tensile tests were carried out at 1/20 mm/s tensile speed conditions at YMM-5 brand test device in the metallographic laboratory of the ETI Aluminum Company. The tension bars were prepared from the produced casts at 5 different places of the billet in accordance with the ASTM E8M standard. The tensile strength and the elongation % values were determined by taking the average of the results.

RESULTS

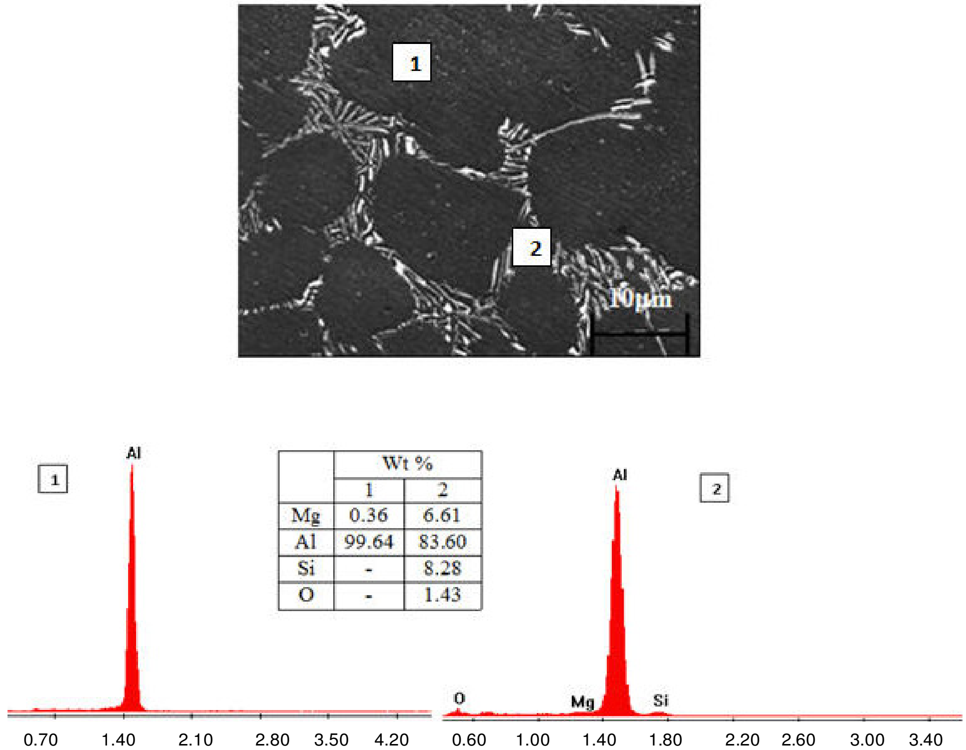
Microstructure examinations

SEM micrographs and EDS of the homogenized AA6063 specimens (710°C and 110 mm/min) are given in Figure 1. Microstructures consisted of a matrix (dark region) and eutectic phase (lamellar region). The matrix was aluminum and the eutectic phase was α+Mg_2Si in the investigated AA6063 alloys (Onurlu, 1987).

Experimental results of billets produced by changing the metal temperature

The change occurring in the hardness of the alloys cast by changing the metal temperature is shown in Figure 2. In the hardness tests conducted on the specimens prepared from the billets produced by changing the metal temperature values, the highest hardness value was obtained from the specimen produced at 690°C and then exposed to the homogenization heat treatment. The hardness value tends to decrease with the increase of the metal temperature.

Depending on the metal temperature, the change of the tensile strength and the elongation % values, obtained after the tensile test, of the billets produced by changing the metal temperature with the continuous casting method



	Wt %	
	1	2
Mg	0.36	6.61
Al	99.64	83.60
Si	-	8.28
O	-	1.43

Figure 1. SEM photographs and EDS analysis of the homogenized AA 6063 alloy.

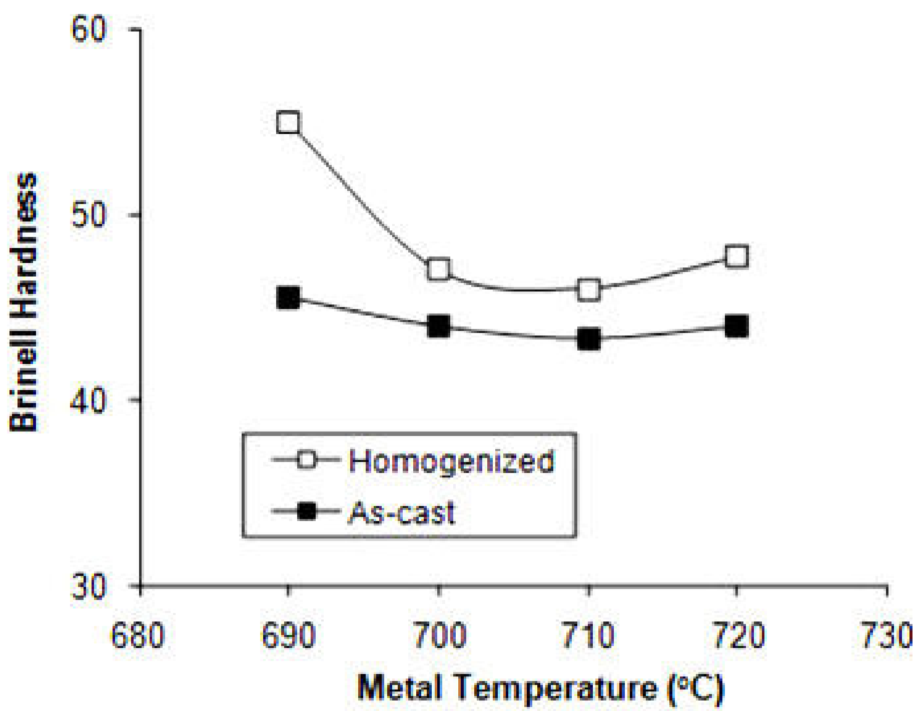


Figure 2. The changing of hardness values according to the metal temperature.

is shown in Figure 3a and b respectively. As it is seen from the results of the tensile tests, the specimens exposed to the homogenization heat treatment showed higher tensile strength than the specimens in the

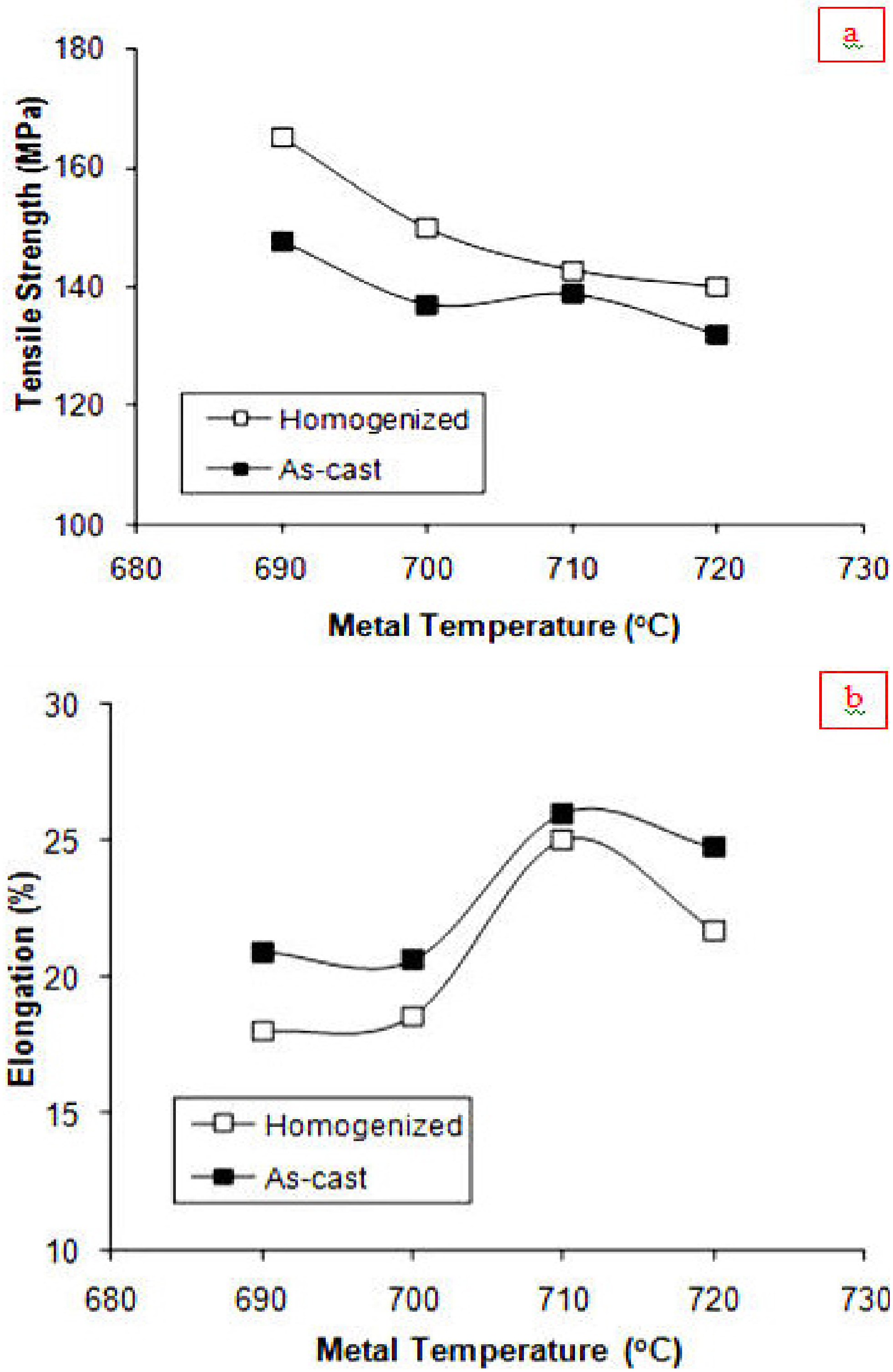


Figure 3. The changing of a) tensile strength and b) elongation % values according to the metal temperature.

casting state. The tensile strength tends to decrease with the increase of the metal temperature. In the tensile tests conducted on the billets produced at different metal temperatures, the highest tensile strength value was obtained from the billet produced at 690°C. Depending on the metal temperature, the change of the elongation % values calculated after the tensile test exposed to the billets produced by changing the metal temperature is

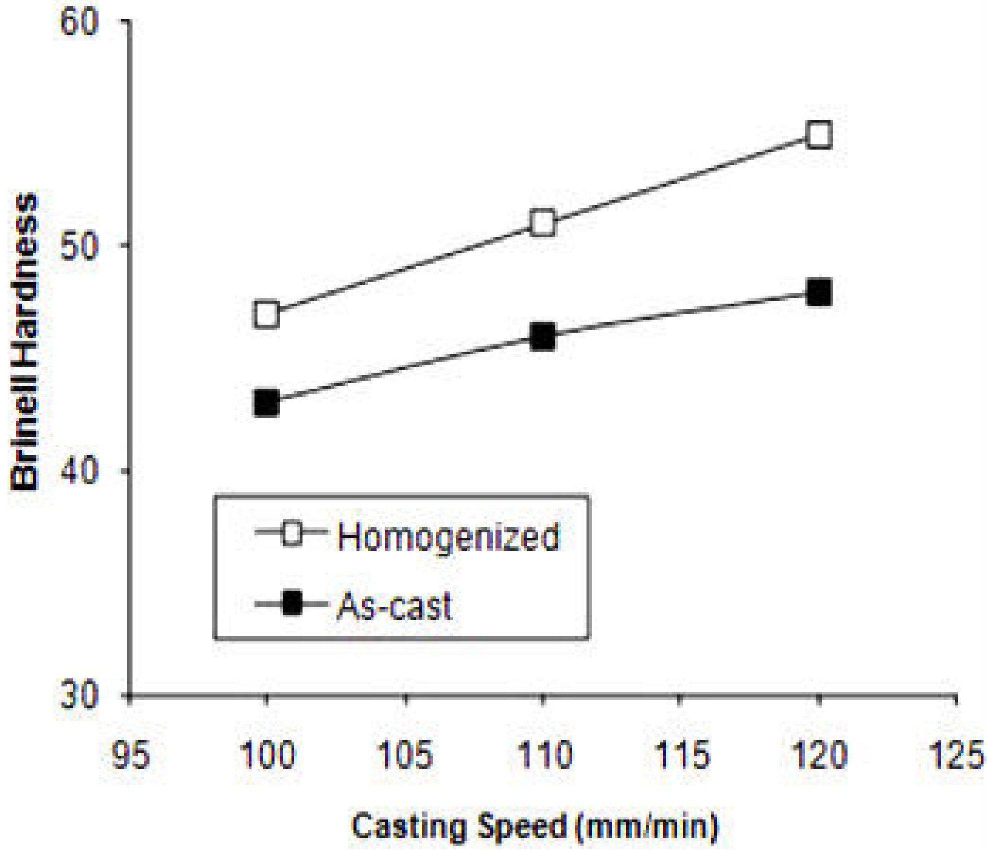


Figure 4. The changing of hardness values according to the casting speed.

given in Figure 3b. In line with the tensile strength values, with the increase of the metal temperature, the elongation % values also tend to increase. Although it is not very prominent, the elongation % values tend to decrease with the homogenization heat treatment.

Experimental results of the billets produced by changing the casting speed values

The change that occurred in the hardness of the alloys produced by changing the casting speed is shown in Figure 4. In the hardness tests applied to the specimens prepared from the billets produced by changing the casting speed values, the highest hardness value was obtained from the specimen produced at 120 mm/min speed and then exposed to the homogenization heat treatment. The hardness value tends to increase with the increase of the casting speed value.

Depending on the casting speed, the change of the tensile strength and the elongation % values of the billets, produced by changing the casting speed with the continuous casting method, obtained after the tensile test is shown in Figure 5a and b. As seen from the figure, when casting speed is increased in the continuous casting process, the tensile strength tends to decrease, although it is not prominent. The specimens exposed to the homogenization heat treatment showed higher tensile strength values than the specimens in the casting state. The highest tensile strength was observed to be in the specimen produced at 100 mm/min casting speed. Depending on the casting speed, the change of the elongation % values calculated after the tensile test applied to the billets produced by changing the casting speed is given in Figure 5b. The elongation % values tend to decrease with the increase in the casting speed values. With the homogenization heat treatment, the elongation % values decreased.

DISCUSSION

Solidification occurs very fast in the vertical continuous casting method. Therefore, it is necessary that the metal temperature be kept lower to make the solidification progress faster (Eraslan, 1999). During solidification, the liquid metal contacting with the cast wall solidifies immediately and forms a shell. These formed shells are, in fact, the first nuclei that occurred during the solidification.

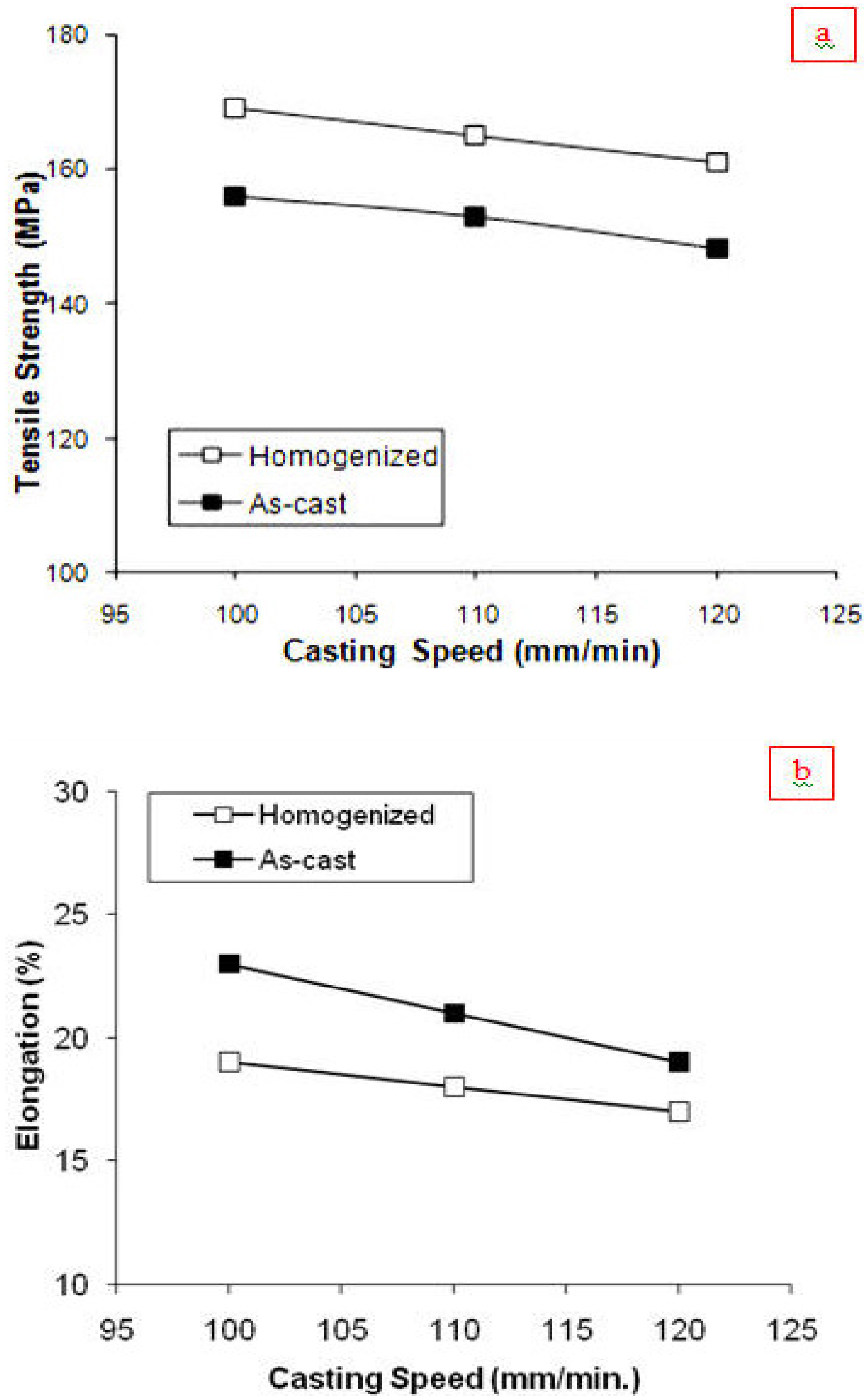


Figure 5. The changing of a) tensile strength and b) elongation % values according to the casting speed.

If the casting temperature is very high, the liquid in the center of the billet will remain over the liquid temperature for a long time. As a result of this, most of the crystals will melt again soon after they depart from the cast wall. Only these remaining crystals can extend near the cast wall to form the chill zone and a thin shell composed of randomly oriented small equiaxed grains will be formed on the surface of the billet. On the other hand, if the casting temperature is lower, all of the liquid will cool fast below the liquid temperature and the crystals will move fast into the melt, known as “bing-bang nucleation”. Then a full equiaxed billet structure will be produced (Lalli, 1987). In

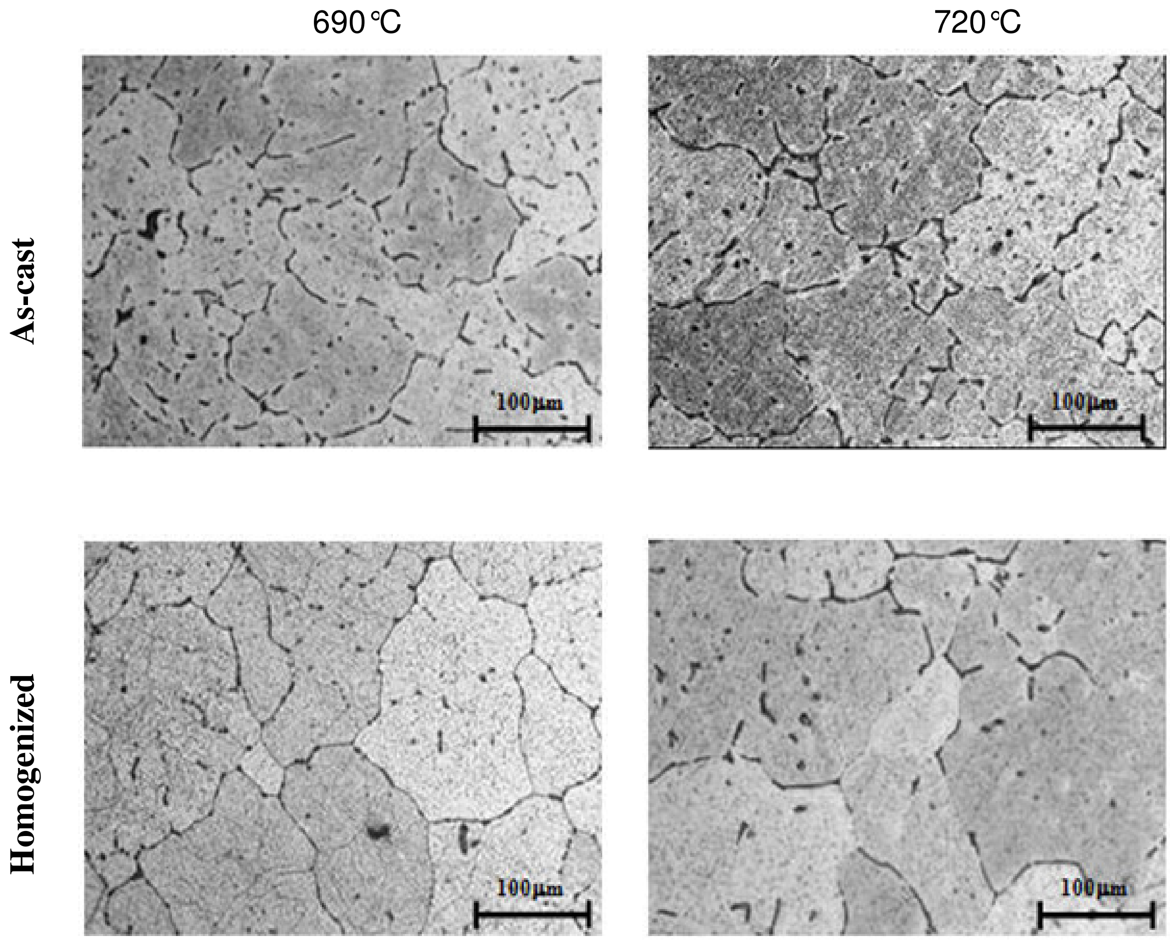


Figure 6. The optic microscope image of the billet that produced at 690 and 720 ℃, as-cast and after homogenization heat treatment.

aluminum castings, the metal temperature should be kept as low as possible for the solidification to move faster (Eraslan, 1999). Therefore, the mechanical properties of the casts whose metal temperature is 690℃ are thought to have been measured as higher.

The fact that the specimens prepared from the billets exposed to the homogenization heat treatment showed higher strength values than the specimens in the casting state in the conducted tensile tests is thought to have resulted from the fact that the microstructure is more homogenous with the homogenization heat treatment. The optic microscope images of both the billets in the casting state and the billets exposed to homogenization heat treatment are given in Figure 6.

Solidification happens very fast in the vertical continuous casting. With this fast solidification, the grain structure of the billet is made up of equiaxed grains (Eraslan, 1999). The hardness value is thought to have been higher because a faster solidification occurred at 120 mm/min casting speed than the other casting speeds and the grain structure was more equiaxed and homogenous. The change in the grain size of the microstructure with the increased casting speed is seen in Figure 7.

In the vertical continuous casting process, a great temperature decrease occurs during casting and as a result undesirable internal stresses can occur in the structure of the billet. If these internal stresses exceed a certain value, there may be cracks in the billet. One of the most effective ways to prevent cracks is to decrease the casting speed (Eraslan, 1999; Lalli, 1987). While the highest tensile strength value was seen in the billet produced at 100 mm/min casting speed in the tensile tests conducted on the billets produced at different tensile speeds, the tensile strength value tended to decrease with the increase of the casting speed. The reason for this is thought to be due to the micro cracks and internal stresses that occurred in the structure of the billet with a great temperature decrease. The cracks occurring at the shell zone of the billet can be seen in Figure 8. The change in the elongation % values also supports this view.

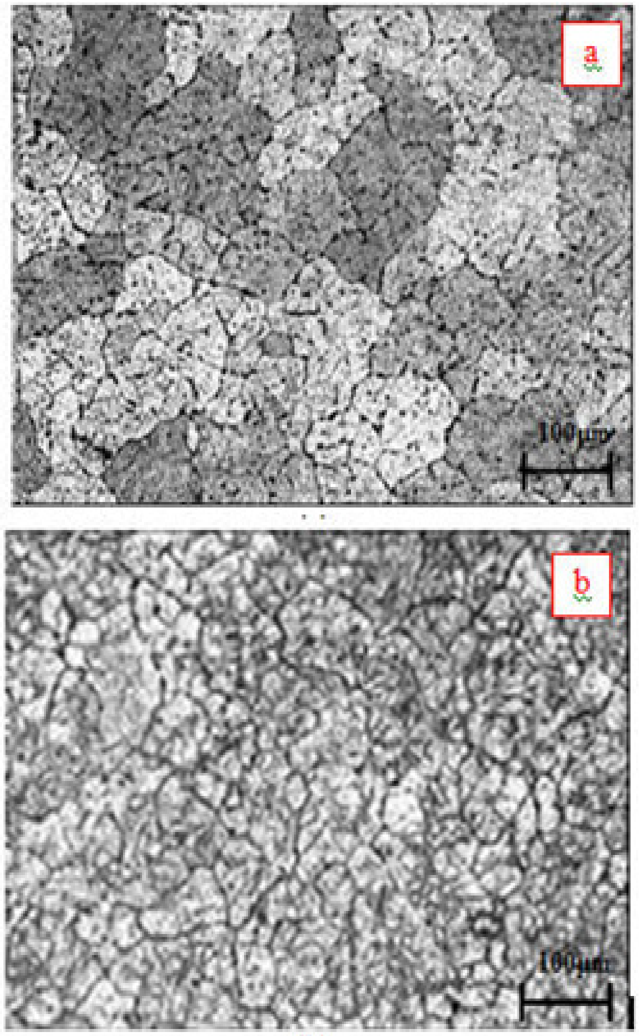


Figure 7. The optic microscope image of samples that produced at (a) 100 mm/min. (b) 120 mm/min. and the homogenization heat treatment applied.

depending on the metal temperature and the casting speed, and the optimum casting parameters had values of 690°C metal temperature, 100 to 110 mm/min casting speed and 140 m^3/h casting water flow.

Conclusion

From this study, in which the change occurring in the mechanical properties of the alloy was determined by changing the metal temperature and the casting speed during the production of the AA 6063 aluminum alloy with the vertical continuous casting method, the following general conclusions were drawn:

As a result of the experiments conducted, it was determined that the mechanical properties changed

1. The microstructure of the AA6063 aluminum alloy produced with the vertical continuous casting method is thought to have been composed of aluminum solid melt (matrix) and α+Mg_2Si eutectic phase. After the conducted homogenization heat treatment, a more homogenous microstructure was obtained than that of the casting state.

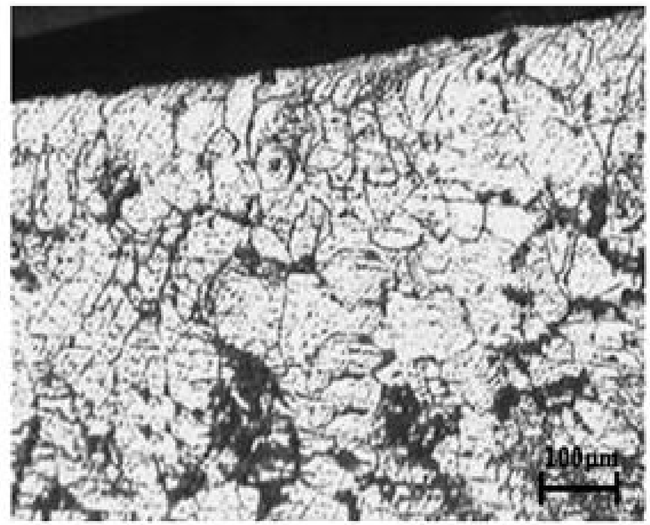


Figure 8. The optic microscope image of the samples shell zone that produced at 120 mm/min. and the homogenization heat treatment process applied.

2. As a result of the mechanical tests conducted on the aluminum billets produced by changing the metal temperature, the hardness value and the tensile strength tend to decrease with the increase of the metal temperature. On the contrary, the elongation % value tends to increase.

3. As a result of the mechanical tests conducted on the aluminum billets produced by changing the casting speed, while the hardness values increase with the increase of the casting speed, the tensile strength and the elongation % values tend to decrease. In both of the changed parameters, the homogenization heat treatment increased the mechanical properties of the analyzed alloys.

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