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AA6063 and AA6951 Aluminum Alloy Billet Casting Parameter and Heat Treatment Optimization

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ABSTRACT

In this study; The properties of billets of 3 different diameters of AA6063 and AA6951 aluminum alloys were investigated by trying different methods. In line with this study, the properties of the alloys were investigated by comparing the casting and homogenization parameters of alloys of different sizes. The metallographic and mechanical analyzes of the samples were made and presented in the tables. Casting and homogenization parameters providing the most suitable parameter were determined according to the values.

Keyword: Aluminum, Billet Casting, Homogenization, 6xxx Alloys, Microstructure

1. INTRODUCTION

Due to the fact that aluminum is the most common metal in nature and its metallic and mechanical properties, its use is widely used in daily life [1] . In order to reduce production costs in new industrial moves, trying to produce products with the same features at a lower cost has been the main target of companies in the global market. Aluminum alloys, which can be produced at lower cost, have begun to replace durable but costly materials such as iron and steel, which are used in many parts of the sector. Aluminum is easy to be shaped and its reserves are high, allowing aluminum to be used more than other metals. It is carried out as a result of obtaining an alloy by mixing with elements such as magnesium and silicon in order to increase its industrial use and to carry the metal's own properties to better dimensions [2] . These alloys are classified according to the metal ratios they contain and series are formed. 6xxx series Aluminum alloys are used more than other series due to both their mechanical properties and the width of their usage areas [3]. 6xxx series Aluminum alloys are used in different sectors such as electrical/electronics, machinery manufacturing, exterior products and automotive industry, thanks to their mechanical properties and heat treatment capabilities [4]. Producing the alloys used in different parameters enables them to improve their mechanical properties. Production parameters generally include casting, homogenization and cooling parameters. In this study, it was aimed to determine the most suitable parameters in the production by preparing samples of 6063 and 6951 alloys in 3 different sizes (6,7 and 8 inches) and examining the mechanical and microstructure properties of the alloy with different homogeneous parameters.

The most appropriate parameters to be determined are aimed to meet the purposes of the alloy in the consumption area and to decide in which parameters the most suitable material can be produced in this direction.

2. EXPERIMENTAL STUDY

2.1. Production Process

In this study, 2 different alloys, AA6063 and AA6951 alloys, and 3 different billet diameters, 6"-7"-8", were produced. Direct cooled casting method (DC Casting) was used in casting the billets to be produced and the parameters were adjusted. 3 different castings were made from the billet cast in 3 different diameters and 2 different alloys; casting parameters, homogenization parameters and chemical compositions are different. Different parameters of these castings were made by metallographic examinations and mechanical tests.

The liquid metal travels through the runners and passes through the ceramic filter first. Then it reaches the molds and casting begins. When liquid metal is filled into molds, pressurized water is given and the starting heads move. There is sudden solidification with the help of graphite ring in the mold and no damage occurs on the billet surface. It is continuously cooled with water passing through the mold and used to cool the liquid metal. The outer part of the metal is solidified, while the inner core is still liquid. As the whole of the ingot continues to cool, water is sprayed directly from the mold onto the ingot and the temperature of solidification is reached [7].

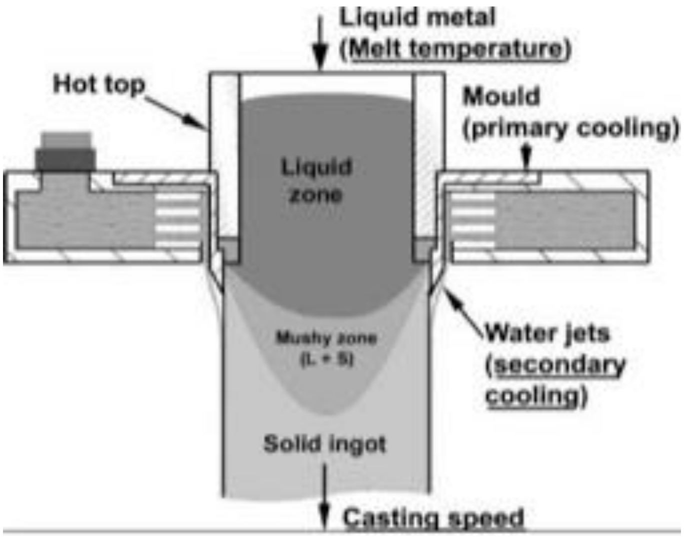


Figure 1. DC casting şematik gösterimi [5]

During the solidification of the molten metal, the alloying elements redistribute on the liquid and solid phase. In most of the solidification processes, inhomogeneities and macro segregations occur in the composition. This event occurring in the flow direction affects the metal behavior during heat treatments and is the most important problem in the direct chill casting method since it causes the appearance of non-uniform mechanical properties [6].

Hsu et al. have shown that in most 6xxx Al alloys, solidification takes place via the formation of primary Al followed by secondary eutectic and peritectic reactions leading to the formation of small amounts of intermetallic particles in interdendritic regions. At a typical cooling rate for DC casting, a cubic AlFeSi phase has been observed to form mainly via two reactions: (i) equilibrium peritectic reactions L + Al13Fe4 → α-Al + AlFeSi; and (ii) non-equilibrium eutectic reaction L → α-Al + AlFeSi. [8]

In this study, K. Uttarasak et al. showed that ex situ techniques can be used as an analytical technique to characterize the microstructural evolution of intermetallics, which strongly influences the abnormal grain growth mechanism in 6063 aluminum alloys during homogenization. It showed that the volume fraction and shape of the β-Al5FeSi particles changed during homogenization, resulting in abnormal grain growth when the particle fixation parameter of 6063 aluminum sample was in the range of 0.25–1.00. [9]

2.1.1. Casting and Homogenization Parameter

Liquid metal casting temperature, cooling water temperature, casting speeds and homogenization times are given in the tables below. Table 1 and Table 2 give the tables separated according to the alloy differences of 6" diameter billet. In Table 3 and Table 4, 7" diameter billet and 8" billet are given in Table 5 and Table 6. It is undesirable for the liquid metal temperature to be too high. The reason is that it is slow during solidification.It will be better if the liquid metal temperature is low, the cooling water is low and the casting speed is high.In this study, 3 different castings from each diameter and alloy will be examined and a specific recipe will be created according to these diameters.

Table 1. 6" dimension and AA6063 alloy parameters

Cast No	Alloy	Molten Metal Temperature(^{0}C)	Cooling Temperature(^{0}C)	Casting Speed(mm/s)	Homogenization Time(hour)
CS-1	AA6063	685	34	110	10,58
CS-2	AA6063	668	31	110	11,5
CS-3	AA6063	690	33	110	10,75

Table 2. 6" dimension and AA6951 alloy parameters

Cast No	Alloy	Molten Metal Temperature(^{0}C)	Cooling Temperature(^{0}C)	Casting Speed(mm/s)	Homogenization Time(hour)
CS-4	AA6951	680	31	112	10
CS-5	AA6951	678	30	118	12
CS-6	AA6951	675	30	110	14

Table 3. 7" dimension and AA6063 alloy parameters

Cast No	Alloy	Molten Metal Temperature(^{0}C)	Cooling Temperature(^{0}C)	Casting Speed(mm/s)	Homogenization Time(hour)
CS-7	AA6063	688	31	100	11,33
CS-8	AA6063	671	30	110	12,25
CS-9	AA6063	677	33	110	10,25

Table 4. 7" dimension and AA6951 alloy parameters

Cast No	Alloy	Molten Metal Temperature(^{0}C)	Cooling Temperature(^{0}C)	Casting Speed(mm/s)	Homogenization Time(hour)
CS-10	AA6951	681	30	100	10,67
CS-11	AA6951	669	29	110	11,75
CS-12	AA6951	690	32	110	11,33

Table 5. 8" dimension and AA6063 alloy parameters

Cast No	Alloy	Molten Metal Temperature(^{0}C)	Cooling Temperature(^{0}C)	Casting Speed(mm/s)	Homogenization Time(hour)
CS-13	AA6063	671	29	109	13,00
CS-14	AA6063	682	30	105	10,08
CS-15	AA6063	684	28	106	11,33

Table 6. 8" dimension and AA6951 alloy parameters

Cast No	Alloy	Molten Metal Temperature(^{0}C)	Cooling Temperature(^{0}C)	Casting Speed(mm/s)	Homogenization Time(hour)
CS-16	AA6951	686	33	112	11
CS-17	AA6951	685	35	105	9,75
CS-18	AA6951	675	30	114	12,50

The homogenization process generally takes place in 4 stages;

1. First Stage heating; The heating process takes place until the furnace reaches 580^o C. This process takes approximately 3.5-4 hours.
2. Second Stage hold; The oven, which has reached 580 0C, waits between 20-30 minutes for the temperature to stabilize.
3. Third Stage ceiling; The annealing process is carried out between 6-8 hours.
4. The fourth stage is cooling; After the annealing process is finished, the billet is removed from the homogenization furnace and taken from the cooling cabinet. In the cooling cabinet, air cooling is performed with the help of fans. The process here varies between 2-4 hours depending on the ambient temperature and billet diameter.

What we want to examine here; are the changes in the grain size of the billet at different homogenization times according to diameters and alloys.

2.1.2. Chemical Compositions

Chemical analyzes of 18 different billet castings with different diameters and different alloys are given below. The chemical compositions of 6” diameter AA6951 and AA6063 billets are given in Table 7. The chemical compositions of 7” diameter billets and 8” AA6951 and AA6063 billets in Table 9 are given in Table 8.

Table 7. 6” dimension AA6951 and AA6063 alloy parameters

Cast No	Dimension	Alloy	Fe%	Si%	Cu%	Mn%	Mg%	Zn%	Ti%	Al%
CS-1	6”	AA6063	0,23	0,42	0,071	0,013	0,48	0,039	0,016	98,6
CS-2	6”	AA6063	0,17	0,44	0,017	0,008	0,48	0,011	0,015	98,7
CS-3	6”	AA6063	0,18	0,44	0,027	0,006	0,44	0,009	0,021	98,8
CS-4	6”	AA6951	0,59	0,48	0,15	0,035	0,51	0,11	0,009	98,3
CS-5	6”	AA6951	0,63	0,44	0,15	0,047	0,5	0,14	0,013	98
CS-6	6”	AA6951	0,53	0,41	0,15	0,046	0,51	0,15	0,014	98

Table 8. 7” dimension AA6951 and AA6063 alloy parameters

Cast No	Dimension	Alloy	Fe%	Si%	Cu%	Mn%	Mg%	Zn%	Ti%	Al%
CS-7	7”	AA6063	0,19	0,48	0,029	0,005	0,51	0,017	0,011	98,7
CS-8	7”	AA6063	0,18	0,44	0,052	0,023	0,48	0,058	0,026	98,7
CS-9	7”	AA6063	0,22	0,45	0,042	0,012	0,46	0,019	0,031	98,7
CS-10	7”	AA6951	0,60	0,43	0,15	0,042	0,55	0,15	0,015	98,1
CS-11	7”	AA6951	0,57	0,4	0,15	0,041	0,54	0,11	0,011	98,1
CS-12	7”	AA6951	0,59	0,42	0,15	0,047	0,57	0,15	0,012	98

Table 9. 8” dimension AA6951 and AA6063 alloy parameters

Cast No	Dimension	Alloy	Fe%	Si%	Cu%	Mn%	Mg%	Zn%	Ti%	Al%
CS-13	8”	AA6063	0,17	0,46	0,015	0,016	0,5	0,024	0,025	98,7
CS-14	8”	AA6063	0,24	0,43	0,01	0,006	0,46	0,009	0,022	98,7
CS-15	8”	AA6063	0,22	0,4	0,021	0,018	0,47	0,027	0,022	98,7
CS-16	8”	AA6951	0,54	0,47	0,15	0,074	0,51	0,08	0,012	98
CS-17	8”	AA6951	0,6	0,42	0,15	0,033	0,54	0,074	0,012	98,1
CS-18	8”	AA6951	0,53	0,41	0,15	0,035	0,55	0,067	0,014	98,2

2.2. Metallographic Process

Metallographic examination was carried out by sanding the samples up to 2500 mesh and then polishing with dimond suspansition paste. After polishing, the sample surfaces were etched with Keller’s Solution (95 ml H_2O, 2.5 ml HNO_3, 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 as a final process is drying, and the samples were examined under an optical microscope.

2.3. Mechanical Tests

2.3.1. Hardness Tests

Samples were taken from all of the samples and measured with the Leeb Hardness Tester hardness device. Hardnesses are given in HB.

2.3.2. Tensile Tests

Spoon samples were taken from the samples in a suitable size for the tensile test. The tensile tests of the samples were made with the Zwick/roell device.

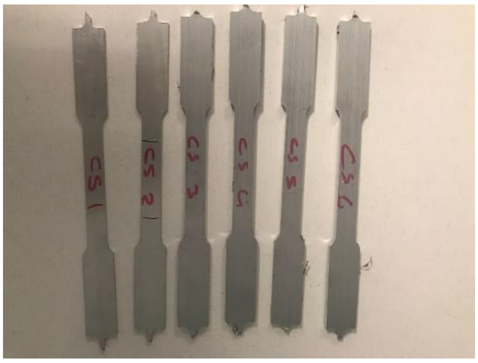


Figure 2. Spoon samples

3. RESULTS AND DISCUSSION

3.1. Microstructure Analysis

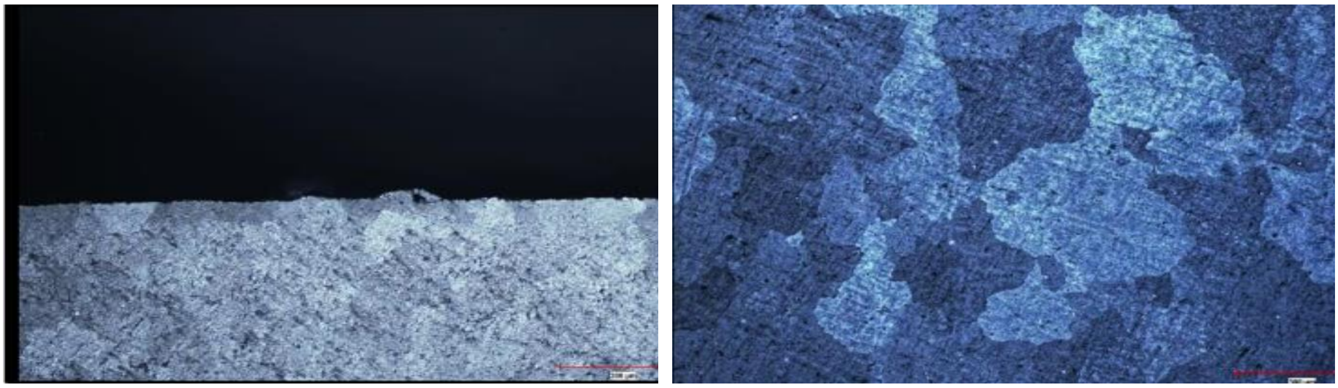
The grain and shell structures of the samples, the microstructure of which were examined under the optical microscope, were measured in 'µm' and given with casting numbers in the tables below.

In Table 10, grain sizes and shell thicknesses of 6 inch diameter and AA6063 alloy billet are given.

Table 10. Shell thickness and grain sizes of 6 inch 6063 alloy billets

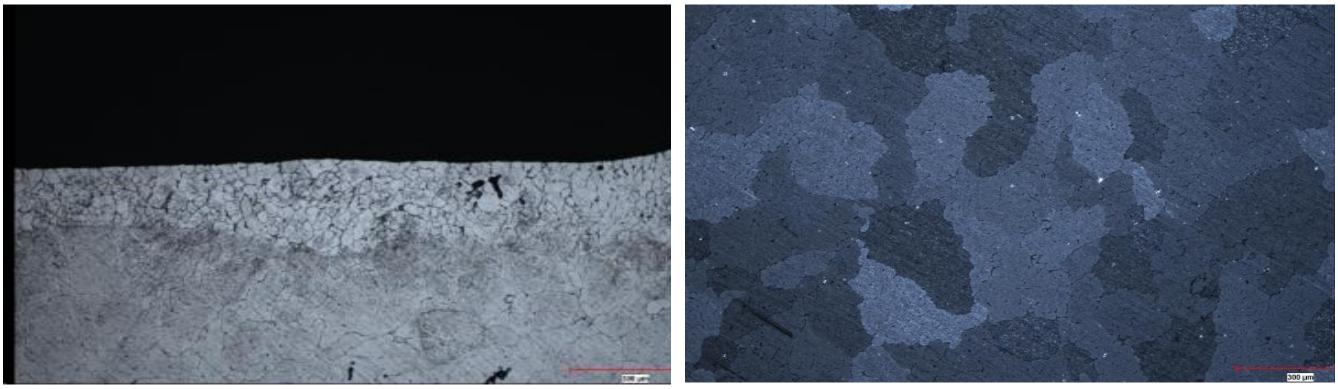
Cast No	Alloy	Shell Thickness(µm)	Grain Size(µm)
CS-1	AA6063	239	195
CS-2	AA6063	216	140
CS-3	AA6063	309	150

Shell thicknesses and grain sizes of 6 inch diameter AA6063 alloy billet are shown in Figure 3, Figure 4 and Figure 5.



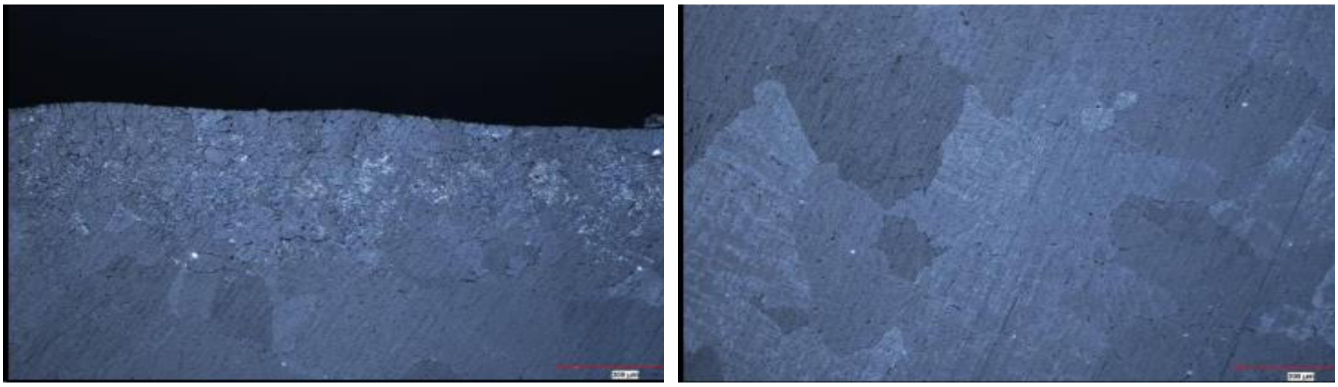
(a) (b)

Figure 3. Casting number CS-1 (a) shell thickness, (b) grain size



(a) (b)

Figure 4. Casting number CS-2 (a) shell thickness, (b) grain size



(a) (b)

Figure 5. Casting number CS-3 (a) shell thickness, (b) grain size

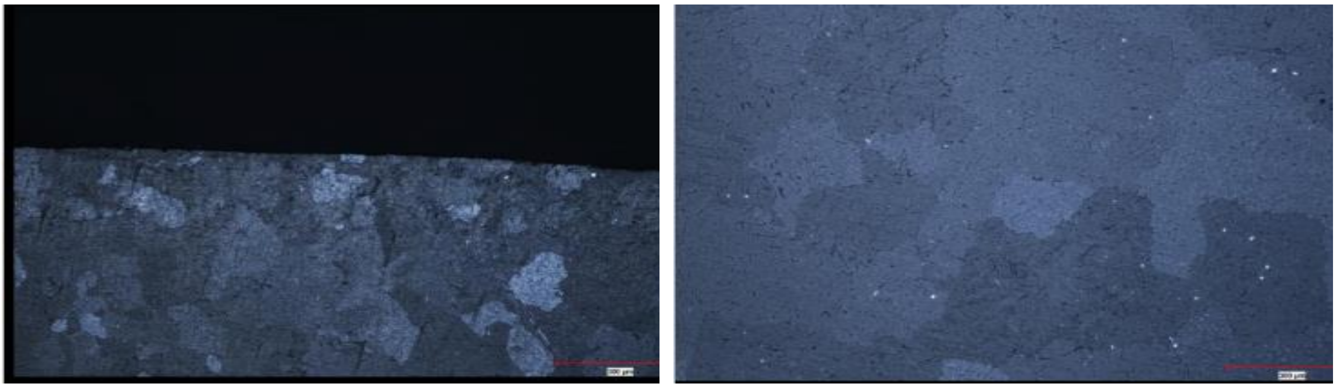
Castings with 6 inch diameter AA6063 alloy appear to have the best/lower shell thickness and grain size as casting number CS-2.

In Table 11, grain sizes and shell thicknesses of 6 inch diameter and AA6951 alloy billet are given.

Table 11. Shell thickness and grain sizes of 6 inch 6951 alloy billets

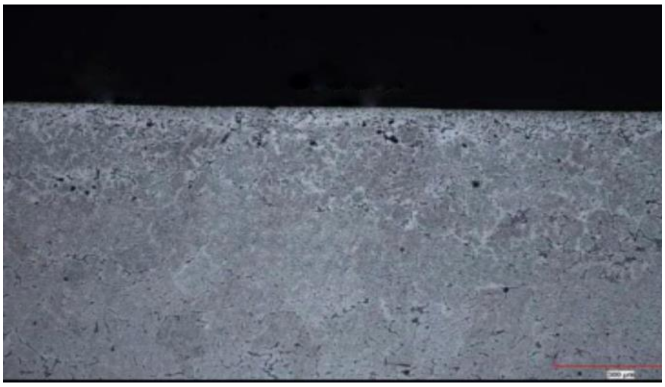
Cast No	Alloy	Shell Thickness(μm)	Grain Size(μm)
CS-4	AA6951	208	177
CS-5	AA6951	248	167
CS-6	AA6951	179	114

Shell thicknesses and grain sizes of 6 inch diameter AA6951 alloy billets are shown in Figure 6, Figure 7 and Figure 8.



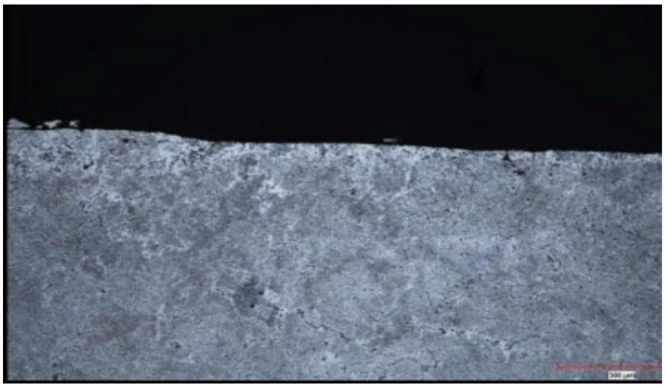
(a) (b)

Figure 6. Casting number CS-4 (a) shell thickness, (b) grain size


(a)


(b)

Figure 7. Casting number CS-5 (a) shell thickness, (b) grain size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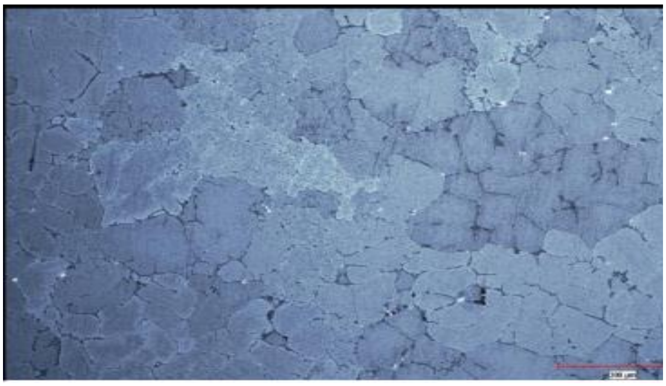

(b)

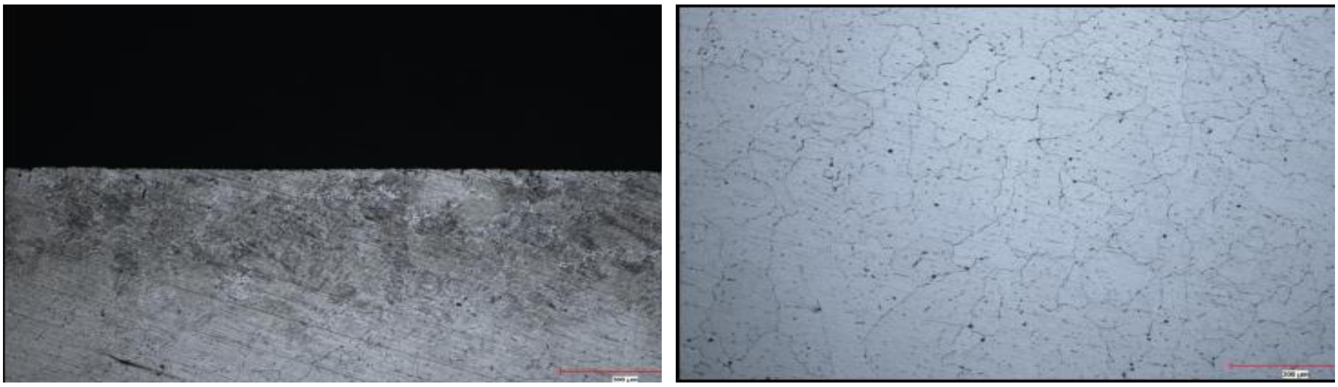
Figure 8. Casting number CS-6 (a) shell thickness, (b) grain size

Castings with 6 inch diameter AA6951 alloy appear to have the best/lowest shell thickness and grain size as casting CS-6. In Table 12, grain sizes and shell thicknesses of 7 inch diameter and AA6063 alloy billet are given.

Table 12. Shell thickness and grain sizes of 7 inch 6063 alloy billets

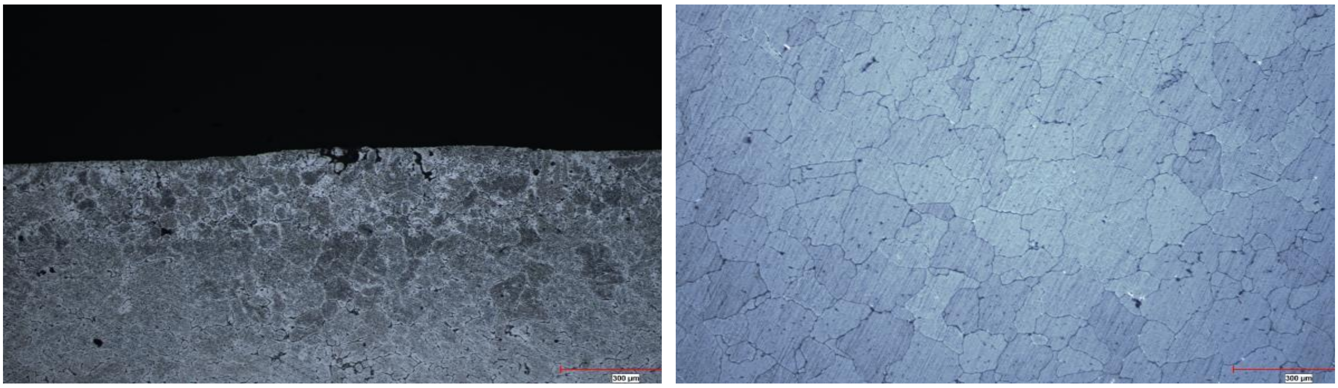
Cast No	Alloy	Shell Thickness (μm)	Grain Size (μm)
CS-7	AA6063	231	140
CS-8	AA6063	214	129
CS-9	AA6063	269	159

Shell thicknesses and grain sizes of 7 inch diameter AA6063 alloy billet are shown in Figure 9, Figure 10 and Figure 11.



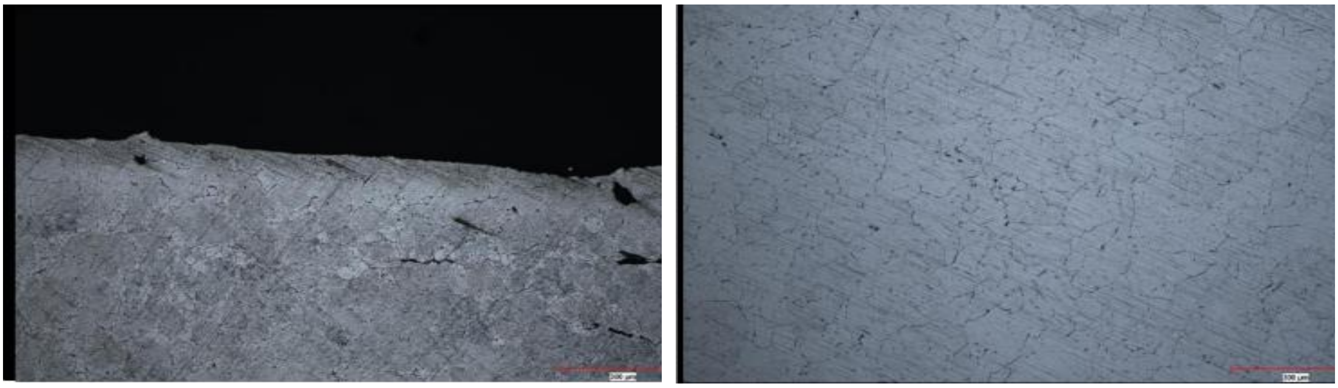
(a) (b)

Figure 9. Casting number CS-7 (a) shell thickness, (b) grain size



(a) (b)

Figure 10. Casting number CS-8 (a) shell thickness, (b) grain size



(a) (b)

Figure 11. Casting number CS-9 (a) shell thickness, (b) grain size

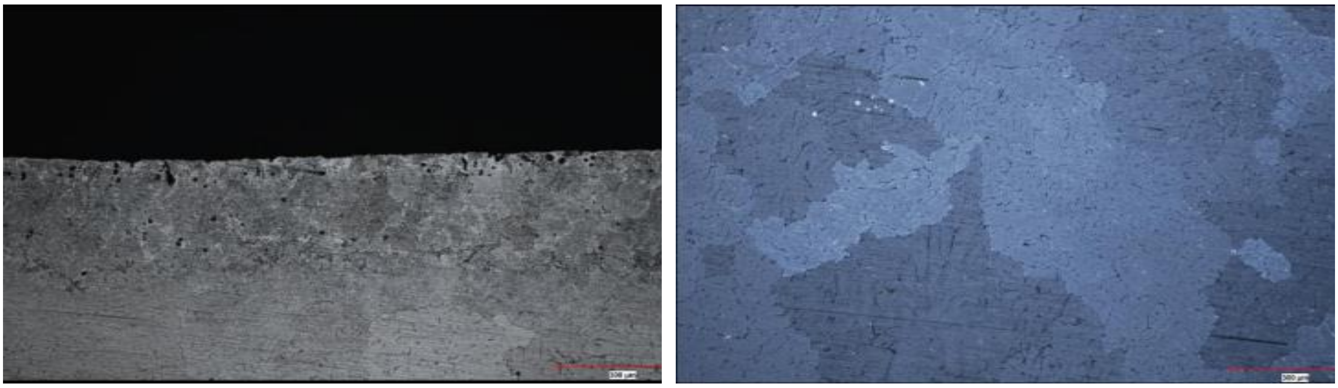
Castings with 7 inch diameter AA6063 alloy appear to have the best/lowest shell thickness and grain size as casting CS-8.

In Table 13, grain sizes and shell thicknesses of 7 inch diameter and AA6951 alloy billet are given.

Table 13. Shell thickness and grain sizes of 7 inch 6951 alloy billets

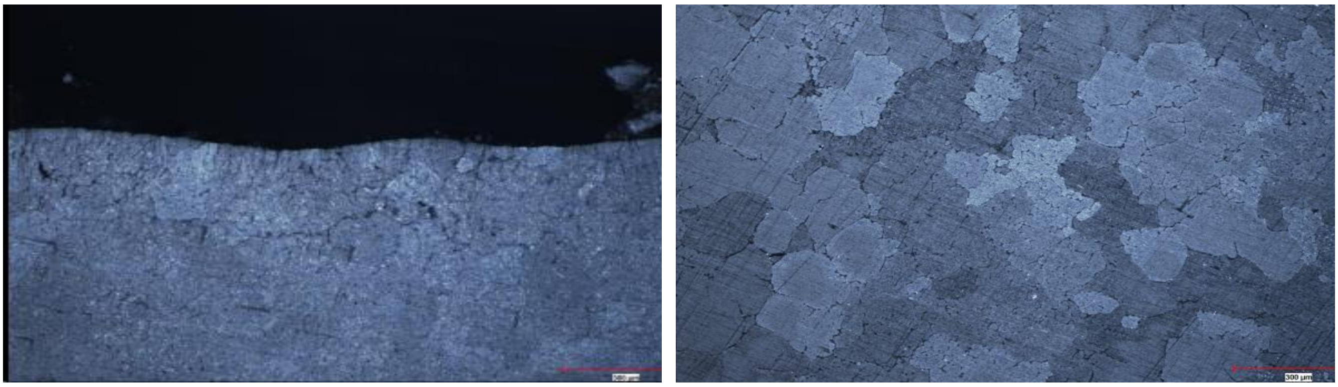
Cast No	Alloy	Shell Thickness(µm)	Grain Size(µm)
CS-10	AA6951	281	172
CS-11	AA6951	226	120
CS-12	AA6951	261	222

Shell thicknesses and grain sizes of 7 inch diameter AA6951 alloy billets are shown in Figure 12, Figure 13 and Figure 14.



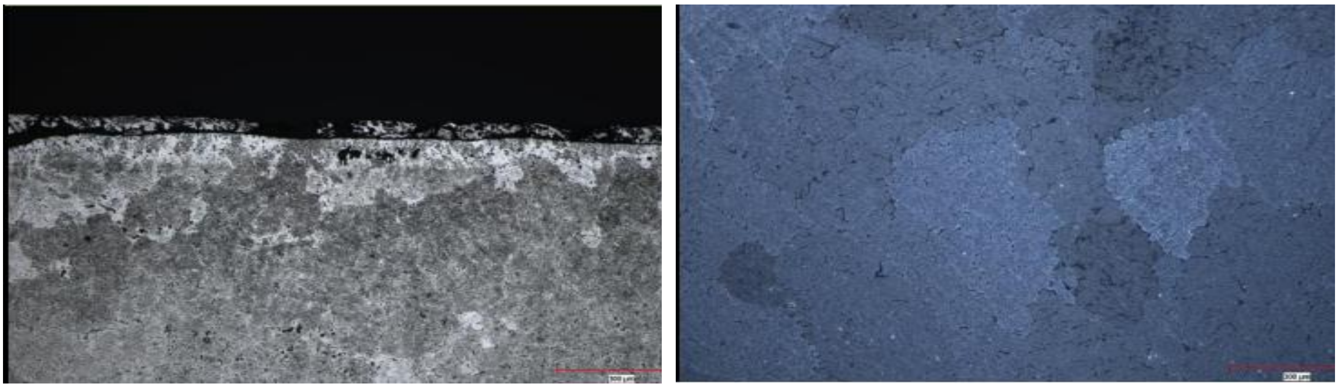
(a) **(b)**

Figure 12. Casting number CS-10 (a) shell thickness, (b) grain size



(a) **(b)**

Figure 13. Casting number CS-11 (a) shell thickness, (b) grain size



(a) **(b)**

Figure 14 Casting number CS-12 (a) shell thickness, (b) grain size

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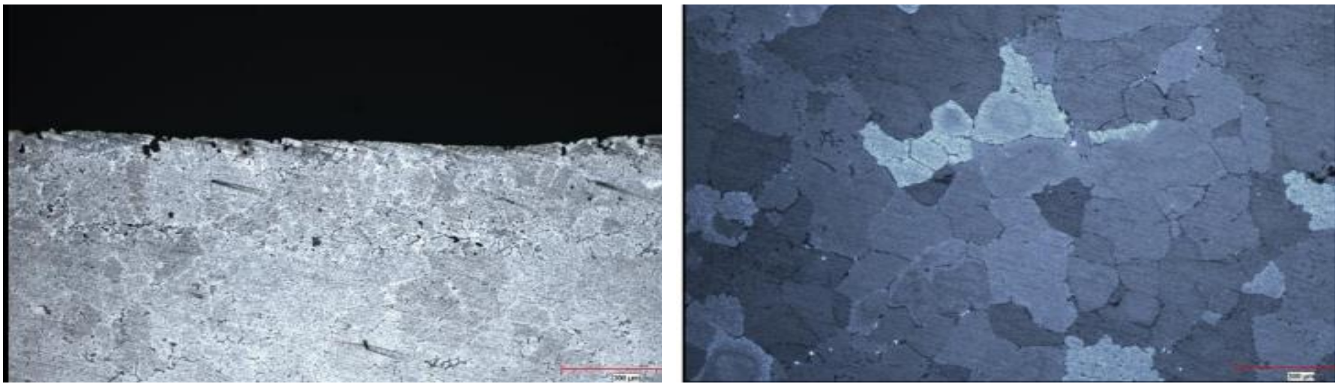
Castings with 7 inch diameter AA6951 alloy appear to have the best/lowest shell thickness and grain size as casting CS-11. In Table 14, grain sizes and shell thicknesses of 8 inch diameter and AA6063 alloy billet are given.

Table 14. Shell thickness and grain sizes of 8 inch 6063 alloy billets

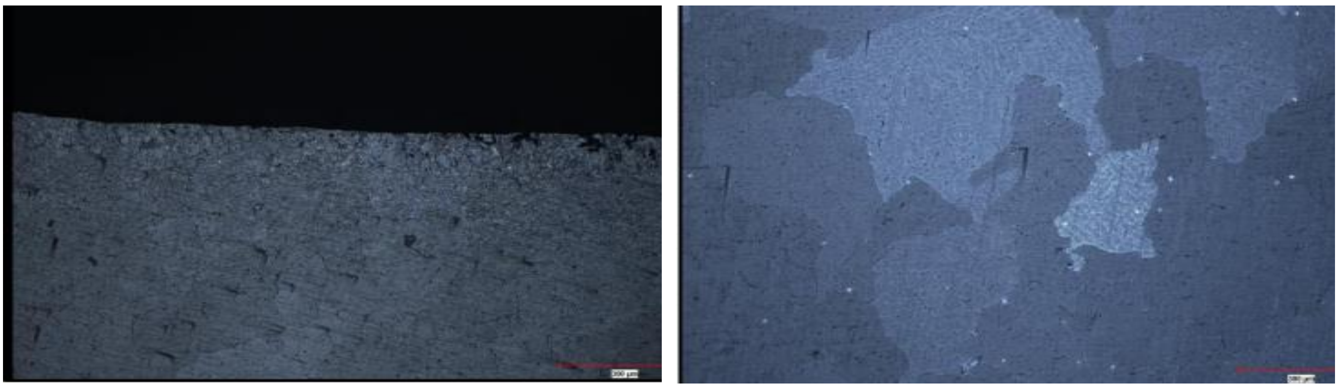
Cast No	Alloy	Shell Thickness(μm)	Grain Size(μm)
CS-13	AA6063	221	132
CS-14	AA6063	248	222
CS-15	AA6063	256	161

Shell thicknesses and grain sizes of 8 inch diameter AA6063 alloy billet are shown in Figure 15, Figure 16 and Figure 17.



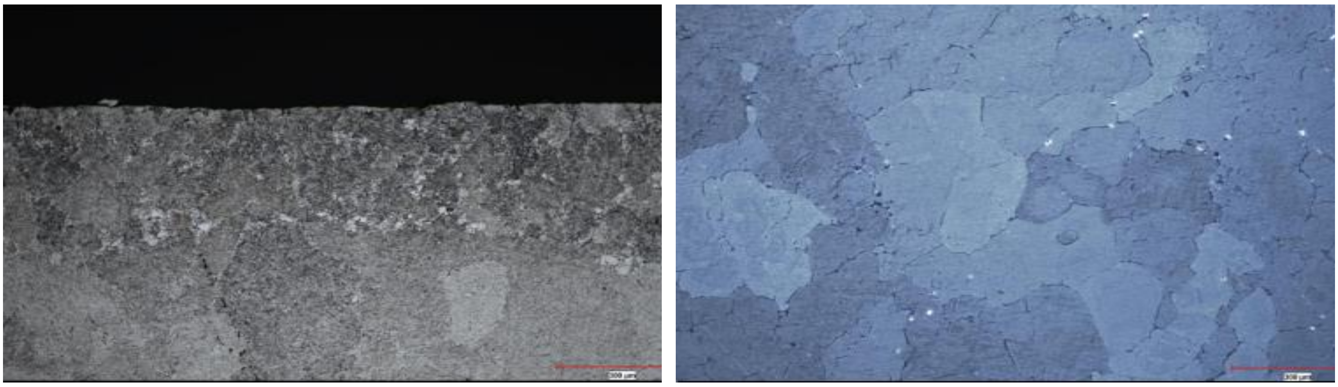
(a) (b)

Figure 15. Casting number CS-13 (a) shell thickness, (b) grain size



(a) (b)

Figure 16. Casting number CS-14 (a) shell thickness, (b) grain size



(a) **(b)**

Figure 17. Casting number CS-15 (a) shell thickness, (b) grain size

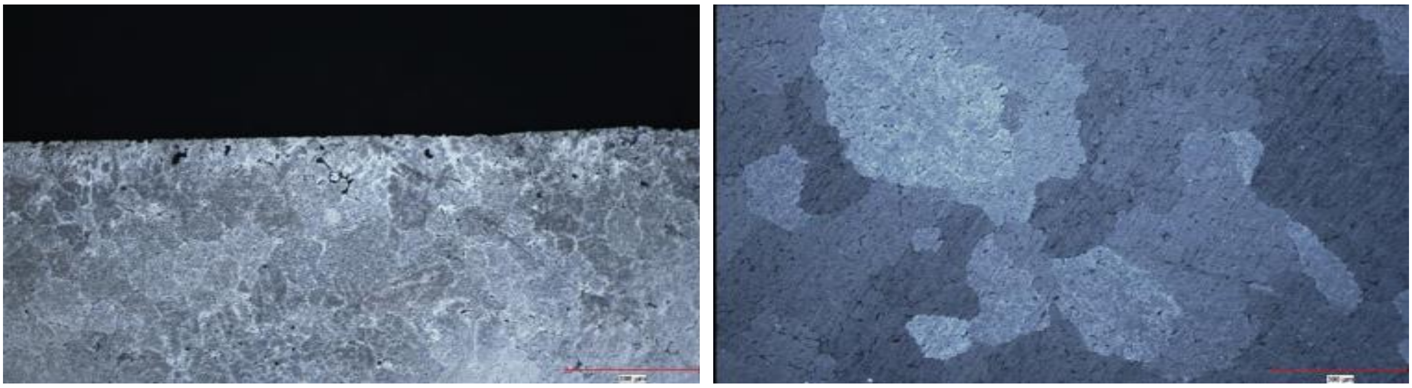
Castings with 8 inch diameter AA6063 alloy appear to have the best/lowest shell thickness and grain size as casting CS-13.

In Table 15, grain sizes and shell thicknesses of 8 inch diameter and AA6951 alloy billet are given.

Table 15. Shell thickness and grain sizes of 8 inch 6951 alloy billets

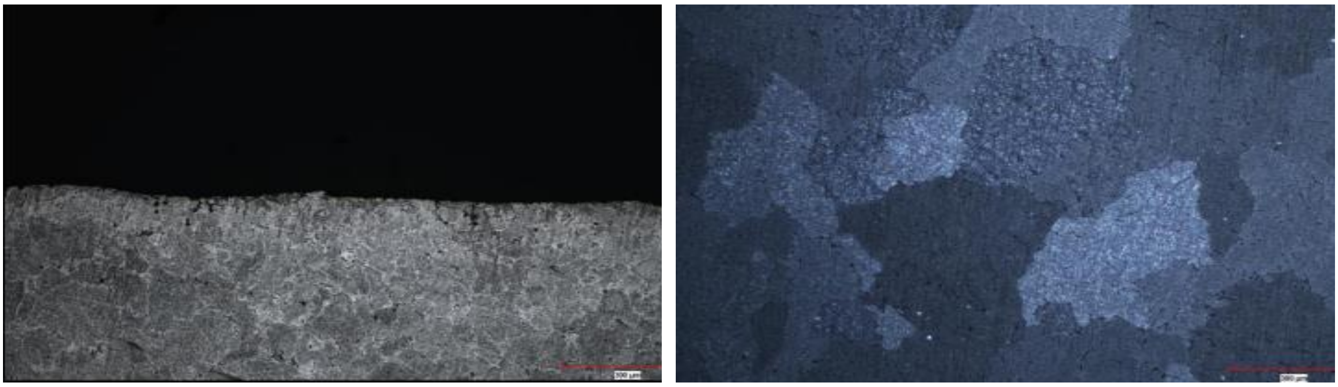
Cast No	Alloy	Shell Thickness(μm)	Grain Size(μm)
CS-16	AA6951	239	168
CS-17	AA6951	252	259
CS-18	AA6951	209	141

Shell thicknesses and grain sizes of 8 inch diameter AA6951 alloy billets are shown in Figure 18, Figure 19 and Figure 20.



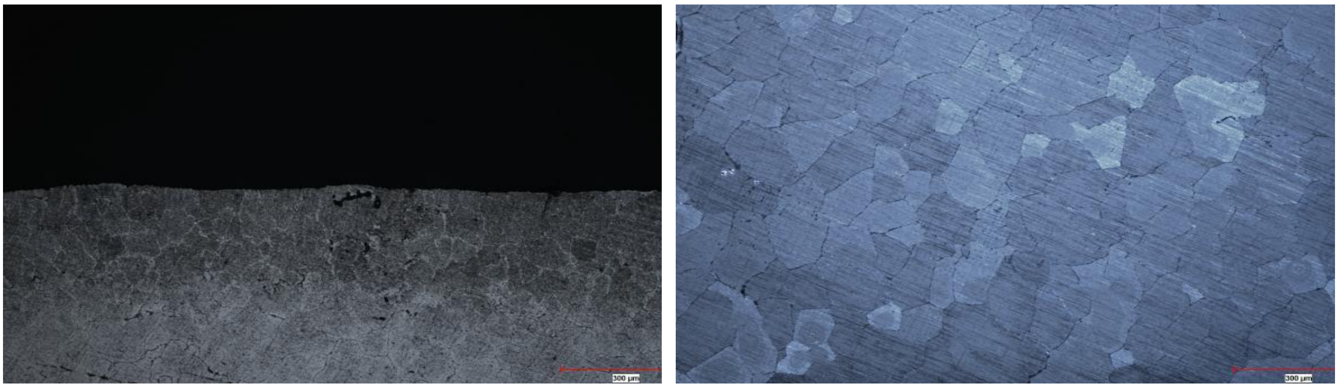
(a) **(b)**

Figure 18. Casting number CS-16 (a) shell thickness, (b) grain size



(a) **(b)**

Figure 19. Casting number CS-17 (a) shell thickness, (b) grain size



(a) **(b)**

Figure 20. Casting number CS-18 (a) shell thickness, (b) grain size

Castings with 8 inch diameter AA6951 alloy appear to have the best/lowest shell thickness and grain size as casting CS-18.

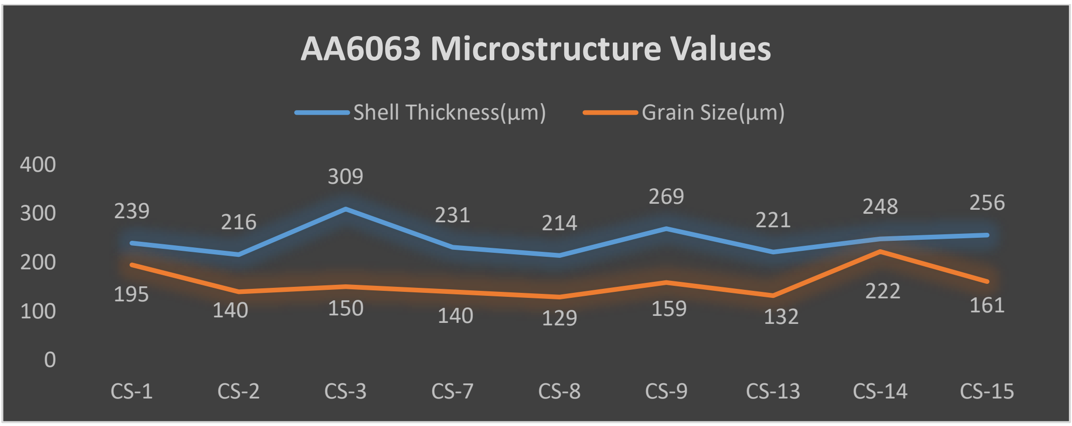


Figure 21. Graph of AA6063 microstructure values

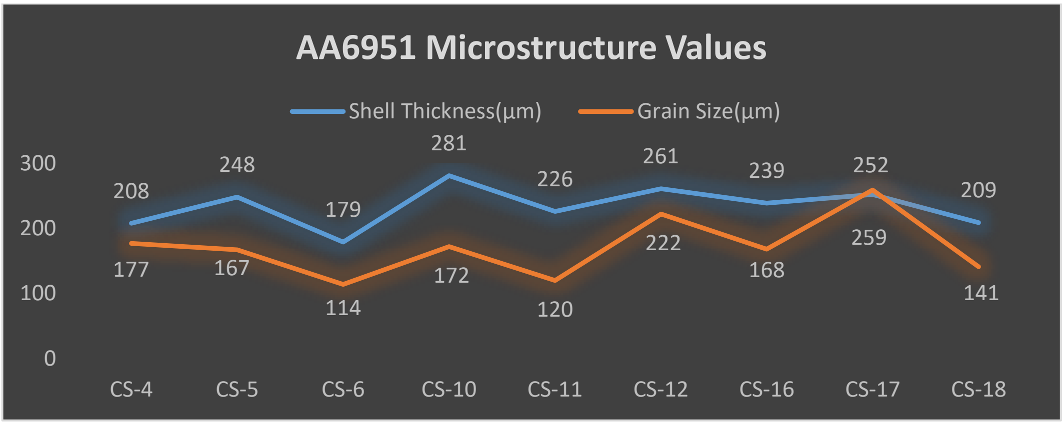


Figure 22. Graph of AA6951 microstructure values

3.2. Mechanical Test Results

After the extrusion processes of the cast billet were completed and the aging processes were completed, hardness measurements were made from the produced profiles. The hardness measurements were made with the Leeb Hardness Tester and the values according to their diameters are given in Tables 16, 17 and 18.

Table 16. Hardness values of profiles produced from 6 inch billet

Cast no	Alloy	Value	Method
CS-1	AA6063	79,10	Brinell Hardness(HB)
CS-2	AA6063	84,70	Brinell Hardness(HB)
CS-3	AA6063	81,90	Brinell Hardness(HB)
CS-4	AA6951	82,20	Brinell Hardness(HB)
CS-5	AA6951	84,80	Brinell Hardness(HB)
CS-6	AA6951	85,50	Brinell Hardness(HB)

Table 17. Hardness values of profiles produced from 7 inch billet

Cast no	Alloy	Value	Method
CS-7	AA6063	79,80	Brinell Hardness(HB)
CS-8	AA6063	84,70	Brinell Hardness(HB)
CS-9	AA6063	80,90	Brinell Hardness(HB)
CS-10	AA6951	82,10	Brinell Hardness(HB)
CS-11	AA6951	86,00	Brinell Hardness(HB)
CS-12	AA6951	84,40	Brinell Hardness(HB)

Table 18. Hardness values of profiles produced from 7 inch billet

Cast no	Alloy	Value	Method
CS-13	AA6063	83,10	Brinell Hardness(HB)
CS-14	AA6063	81,90	Brinell Hardness(HB)
CS-15	AA6063	80,50	Brinell Hardness(HB)
CS-16	AA6951	79,70	Brinell Hardness(HB)

CS-17	AA6951	82,30	Brinell Hardness(HB)
CS-18	AA6951	86,10	Brinell Hardness(HB)

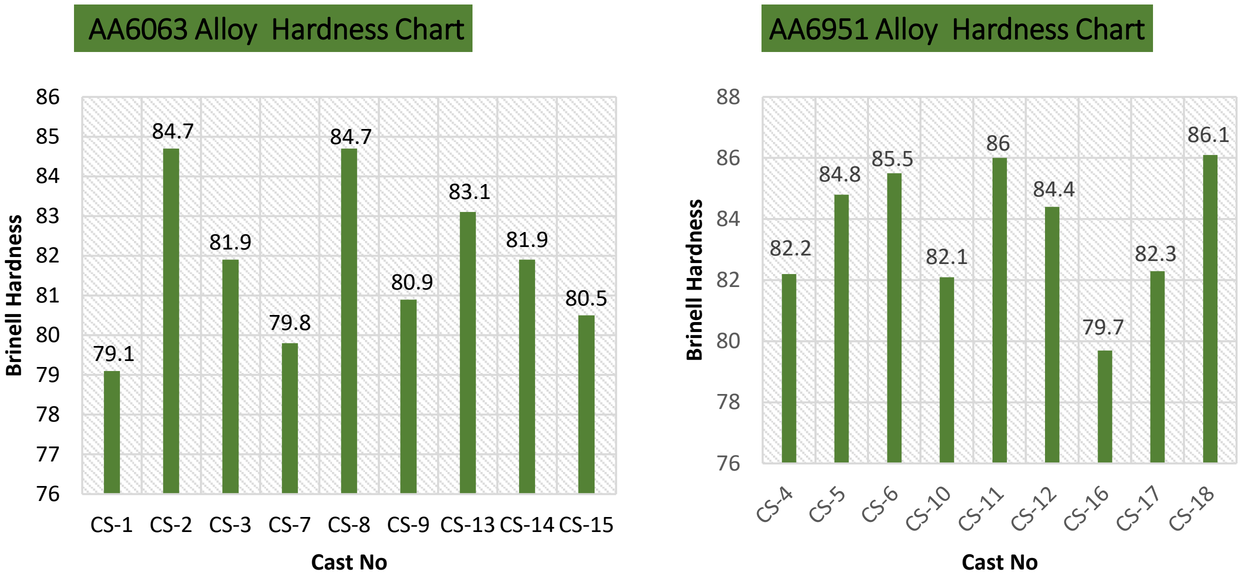


Figure 23. AA6063 and AA6951 Alloys hardness charts

Hardness tables of AA6063 and AA6951 alloys are given in Figure 21, and the highest value was 84.7 HB in AA6063 alloy. The highest hardness of 86.1 HB was observed in the profiles produced from AA6951 alloy.

3.3. Tensile Test Results

Samples were taken from the profiles produced after the extrusion processes of the examined billet. Spoon sample was cut from these samples for tensile test.

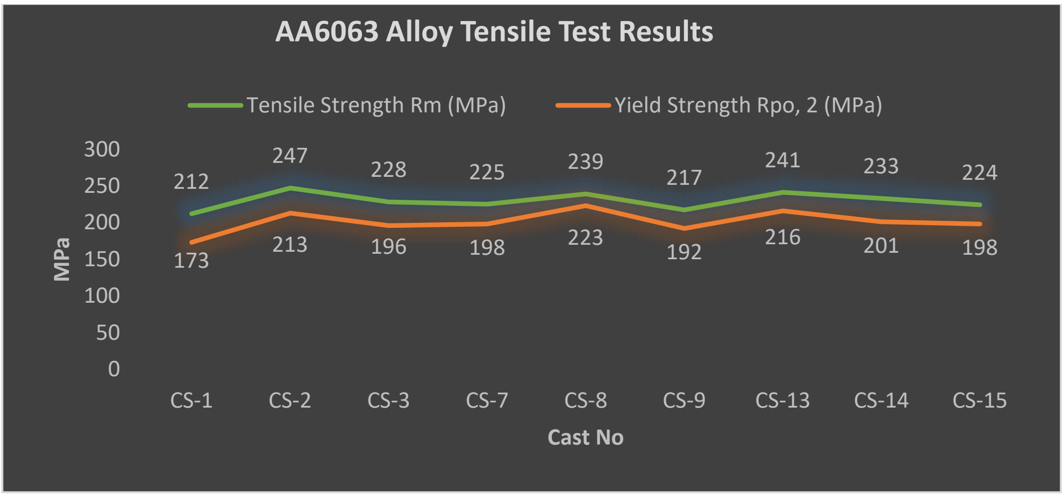


Figure 24. AA6063 Alloys tensile test result charts

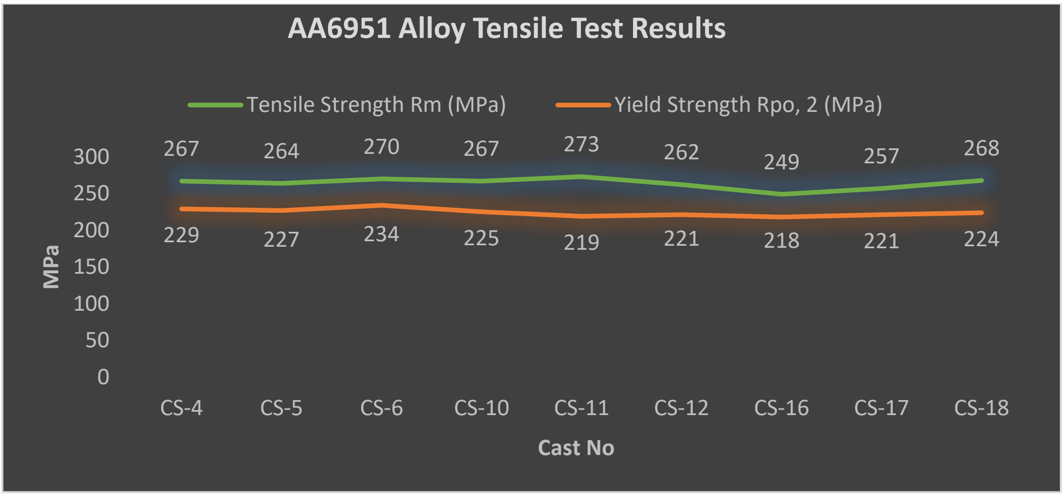


Figure 25. AA6951 Alloys tensile test result charts

In the tensile test graph taken from the AA6063 alloy in Figure 24, it was observed that the tensile strength reached the highest 247 MPa and the yield strength reached 213 MPa. In the tensile test graph taken from the AA6951 alloy in Figure 25, the highest tensile strength was found to be 273 MPa, while the yield strength was 234 MPa.

4. CONCLUSION

The following results were obtained as a result of examining the parameters and homogenization process time differences during the production of 6, 7 and 8 inch diameter 6063 and 6951 aluminum alloy billets by vertical continuous casting method.

1- The shell size range for 6063 Alloy was determined as 309 µm, the lowest value was 214 µm, and the highest grain size for the grain size was 222 µm and the lowest grain size was 129 µm.
2- The hardness value of 6063 alloy was between 79.1-84.7 HB, and the highest value was determined as 84.7 HB. In the tensile test results; The highest tensile strength was 247 MPa and the highest yield strength was 223 MPa.
3- The shell size range for 6951 Alloy was determined as 281 µm, the lowest value was 209 µm, and the highest grain size for the grain size was 252 µm and the lowest grain size was 114 µm.
4- The hardness value of 6951 alloy was determined between 79.7-86.1 HB and the highest value was determined as 86.1 HB. In the tensile test results; The highest tensile strength was 273 MPa and the highest yield strength was 234 MPa.
5- According to these results, the best microstructure, hardness and tensile test results; low molten metal temperature, low cooling water temperature, high casting speed and homogenization process time is more than 11.5 hours.

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