REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF NANOTECHNOLOGY AND ENGINEERING SCIENCE

8 INCH AA6063 BILLET FOR DC CASTING PROCESS WITH SIMULATION PROGRAM CASTING BILLET MOLD DESIGN AND PRODUCTION

BİLGEHAN TUNCA
MASTER OF SCIENCE

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I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]

Bilgehan TUNCA

ABSTRACT

8 INCH AA6063 BILLET FOR DC CASTING PROCESS WITH SIMULATION PROGRAM CASTING BILLET MOLD DESIGN AND PRODUCTION

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This study is to aim to develop of the casting quality of the 6XXX aluminium billet, which is one of the most important parameters for the extrusion of the studied aluminium alloy series as well as increasing the profile quality reducing the quality errors. In billet casting, many different parameters affect the billet quality at both macro and micro levels. Physical parameters such as the physical condition of the billets, the surface quality, the smoothness of the surface, the micro-structure features, the shell thickness, the grain size, the start-up of solidification at the right place and time play crucial role as well as the cooling and the design of the casting molds The production of 8 inch diameter billets have some severe problems so this thesis focused to design suitable mold geometry with the support of the simulation in order to improve the billet quality.

Keyword: Aluminium Billet, AA6063, DC Casting, HotTop

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1. ALUMINIUM

1.1 . Aluminium and General Properties

The symbol of aluminium is Al. The atomic weight and density of the aluminium are 27 gr/mol, 2.7 gr/cm, respectively. The melting point is 660 ˚C and the boiling point is 2300 ˚C. thermal conductivity (K) is 2,37 W/cm k (at 25 ˚C) while the electrical conductivity is 64,94% ACS (for pure aluminium and 25 ˚C temperature). The tensile strength of pure aluminium is about 49 Megapascal (MPa), this value increases to 700 MPa when it was alloyed [2]. It can be easiy shaped (high machinable capacity), malleable, easy to cast, soft, silvery color, not toxic, magnetic flammable metal. It has very superior corrosion properties due to oxide layer formed on the surface. Thats make the material more resistant to moisture, sudden temperature changes and other chemicals. Since it is resistant to atmospheric conditions, itsalloys are used in the automobile and aviation industry as well as construction materials such as doors, windows and lightness.

With the development of industry and technology, the use of aluminium and its alloys have been increasing in our country and all over the world. Since the metal cools easily and absorbs heat, it has wide application in cooling industry and is preferred compare to copper due to easy processing high thermal and electrical conductivity as well as having low density hense the light metal [1].

The application area can be widened as followings; spot lights, electronics industry, kitchen equipment, and lightweight vehicles and vehicles parts. Since having low density property it makes them to use them lighting parts and vehicles. It has widely been used in the automotive and aerospace industry to reduce consumption of the fuel. Moreover, there are application for the health, food and climbing industries as well as, marine vehicles, underground cables, electrical pipes and motor coil winding [1].

1.1.1. Atomic Structure

Aluminium, is group 3A element with, atomic number 13 having theatomic radius 1.43A˚ and ion diameter is 0.86 A˚. Its atomic weight is 27 g-mol. Since each aluminium ion is surrounded by neighboring 12 ions, the coordination number is 12 [3].

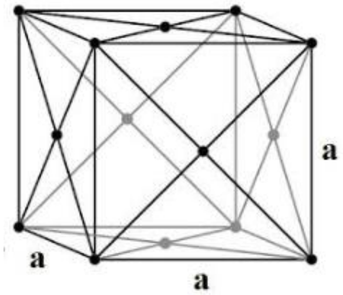


Figure 1.1 Structure of the aluminium crystal lattice [2].

The edge length a (cage distance) of an elemental cube of the aluminium cage is 4.0446- + 0.004 A˚ in 99.97% and 4.0413 + 0.001 A˚ in 99.996% metal.

1.1.2. Physical-Chemical Properties

1.1.2.1 . Density

The density of both liquid and solid aluminium decreases with increasing degree of purity as is given in Table 1.1. [1].

Table 1.1. Density values of solid aluminium metal at 20 ˚C [1].

Al, %	99.25	99.40	99.75
D, g/cm^3	2.727	2.706	2.703

The change of the density with temperature below the melting point is tabulated in Table 1.2.

Table 1.2. The density values of the aluminium at various temperature [1].

Temperature ˚C	Density g/cm^3
659	2.382
700	2.371
800	2.343
900	2.316
950	2.303
1000	2.289
1100	2.262

1.1.2.2. Thermal Conductivity

The thermal conductivity of aluminium is strongly dependent upon the purity degree of the metal. It can be given as 0.5 cal/cm.s at 200˚C for 99.49 % Al, and 0.531 cal/cms for 99.70% Al while 0.82 cal / cms for 99.9% Al at 190˚C [3].

1.1.2.3. Electrical Conductivity

The impurities in aluminium adversly affects the electrical conductivity. Adding the vanadium, titanium and manganese in the structure reduce the electrical conductivity of, If one of these metals is present in the range of 0.25-3.30%, every 0.01% reduces rate the electrical conductivity of pure aluminium by 1-1.2%. The effect of iron and on the electrical conductivity is weaker. The reduction in the electrical conductivity by adding 1.5% Fe or Si and copper are 5% and 20% respectively. However, he effect of Gold(Au), Beryllium(Be), Nickel(Ni), Silicon(Si), Iron(Fe) and Zinc(Zn) on the electrical conductivity of the alloy is extremely small [3].

Table 1.3. shows the specific electric resistance as a function of the temperature.

Table 1.3. Temperature and specific electrical resistance values.

Temprature ˚C	658	686	715	745	774	816	925
P, Ω mm^2/m	25.5	26	26.4	26.8	26.8	27.6	29.2

1.1.3. Mechanical Properties

Mechanical properties of the aluminium and its alloys is also stronglydepended on the degree of purity. When the purity is high aluminium starts to decrease, that is, when the alloy ratios increase, its hardness and strength begins to increase. Pure aluminium has 19-20 Brinell hardness and can reach up to 140 Brinell in its alloys. Tensile strength can increase from 9 MPa to 65 MPa in some recumbent alloys [1]. Table 1.4. compares the aluminium with other metals.

Table 1.4. Comparison of some properties of aluminium with other metals [1]

PROPERTY	**Al**	**Mg**	**Fe**	**Cu**	**Zn**
Specific Weight (gr/cm3)	2.71	1.74	7.87	8.94	4.1
Electric Resistance (Ohm. mm^2).10	2.66	4.46	9.8	1.68	6.0

Thermal Conductivity (Cal/ cm^2/cm ˚C)	0.52	0.37	0.19	0.92	0.27
Thermal Expansion Coefficient (mm/mm˚C). 10-6	24.0	25.7	11.9	16.7	33.0
Melting Temperature ˚C	658	651	1535	1083	420
Burning Heat (kcal/kg)	6970	6000	1600	-	1270
Extension(%)	43	-	48	50	-
Hardness (Brinell)	19	-	70	25	-

1.2. Aluminium and Alloys

Mechanical, physical and chemical properties of aluminium alloys vary depending on alloy elements and their contens as well as their microstructure. The most important alloying elements involved in aluminium are copper, manganese, silicon, magnesium and zinc.

Aluminium alloys are divided into two groups as forged and cast alloys. Forging alloys have good plastic deformation ability and can be easily shaped. Heat treatment can be applied to a large part of aluminium forging and casting alloys.

Pure aluminium is a soft material that is easy to process and has a low strength and is alloyed with elements such as magnesium, silicon, copper, zinc, manganese to increase its strength. It is possible to produce alloys that can be used in different sectors by adding these alloying elements into the to pure aluminium in different proportions. With the effect of some alloying elements, precipitation hardening can be applied in Al alloys. heat treatment is applied causing the increment in the strength of the aluminium alloy [1].

Theuse of extrusion industry has been developng to the easy forming of the billets. Among the aluminium alloy series, 6xxx series has a big market. It is also known as AlMgSi alloys having good extensibility, high corrosion resistance, clean surface after hot deformation and low cost of the processes applied with medium strength.

Casting method and parameters play important role in AlMgSi alloys. The mechanical structure formed during the casting stage directly affects the extrusion process. For the formation of microstructures that will affect the mechanical structure during casting, the solidification rate, the liquid-solid interface diffusion rate, the temperature gradient at the emitting liquid-solid interface, the diffusivity of the liquids and solids. It is desired that the solidification rate is high during casting. For diffusing alloy elements, a shorter diffusion path is desired, thus allowing the grain structure to be more homogeneous.

The homogenization of the casting structure before the thermomechanical process is extremely important to improve hot workability. The development of hot processability with the homogenization process depends on the diffusion of solutes and the distribution and condition of other secondary phase particles. The first target after solidification is to resolve the imbalance of the secondary phase and then equalize the concentration differences. During the homogenization simultaneously with structural stabilization and dissolution of unstable phases, the homogenization time and temperature, the grain roughness depending on the alloy type and diffusion, the precipitation of excessively saturated elements, the roughness of stable intermetallic metals, the precipitation of excessive saturated elements, surface oxidation, formation of porosity, segregation and events such as regional melting can also occur [1].

The mechanical strength of aluminium may be enhanced by cold work and alloying; however, both processes tend to diminish resistance to corrosion. Major alloying elements include copper, magnesium, silicon, manganese, and zinc. Nonheat-treatable alloys consist of a single phase, for which an increase in strength is achieved by solid-solution strengthing. Others are rendered heat treatable (capable of being precipitation hardened) as a result of alloying. In several of these alloys precipitation hardening is due to the precipitation of two elements other than aluminium, to form an intermetallic compound such as $MgZn_2$ [2].

1.2.1. Aluminium Alloy Series

According to the American Aluminium Association, aluminium forged alloys are classified by four letters. This classification is as follows:

1XXX : Unalloyed aluminium
2XXX : Aluminium alloy with copper
3XXX : Aluminium alloy with manganese
4XXX : Aluminium alloy with silicon
5XXX : Aluminium alloy with magnesium

6XXX : Aluminium alloy with silicon and magnesium
7XXX : Aluminium alloy with zinc
8XXX : Aluminium alloy with iron and silicon
9XXX : Newly found alloys (Example: Lithium alloys) [4].

1XXX, 3XXX, 4XXX and 5XXX series forged aluminium alloys can be hardened by deformation, and are not heat treated. 2XXX, 6XXX, 7XXX and 8XXX series alloys can be hardened by heat treatment.

Table 1.5. General classification of aluminium and its alloys according to their composition and usage areas [1].

Alloy	**Major Alloy Element**	**Important Features**	**Main Uses**
1XXX	Fe and Si are the main elements. Aluminium is more than 99.0%.	High wear resistance, high electrical and thermal conductivity, exceptional machinability, low mechanical properties.	Electricity transmission cables, electronic devices, chemical industry, packaging material and deep drawing applications
2XXX	Cu	High tensile strength, elongation, hardness, low corrosion resistance	Screws, bolts, aircraft construction, rivets, forged cylinder heads and pistons operating at high temperatures, aircraft propellers, as well as aircraft and other components that are exposed to tension.
3XXX	Mn (1.5% and lower)	Good machinability and medium strength	General applications requiring good processability and moderate strength, beverage box, bus bodies and roof coverings
4XXX	Si	Low melting temperature, sufficient ductility and decorative appearance.	Solder wire, hard soldering, architectural applications, radiator slices
5XXX	Mg	No process can be applied, high tensile	In pressure tanks, capillaries, applications requiring high

		strength, hardness, weldability and abrasion resistance	strength/weight ratio, marine vehicles and automobile industry; aircraft fuel and oil lines, fuel tanks, architectural applications.
6XXX	Si and Mg	Good formability, heat treatment susceptibility, corrosion resistance, moderate mechanical strength	Packaging in pharmaceutical and chemical industry, machine parts, architectural applications, automotive industry, bridge, crane and roof beams
7XXX	Zn	Very high strength and mechanical property	Ceiling cranes, dump truck crates, wagons and aircraft constructions

1.2.2. Icon Basic Operations

F : After fabrication

O: Annealed - Process alloys only

H: Hardness and strength increase as a result of plastic forming performed at temperatures below the recrystallization temperature.

W: Solid melting heat treatment applied

T: Heat treated to produce effects other than F, O, and H

The subdivisions and their meanings are as follows;

O is used for annealed, recrystallized alloys, indicating the softest condition..

F is the state after fabrication. This state indicates the physical structure after it is manufactured without any additional treatment in order to change its strength or hardness. There is no guarantee of the mechanical properties of the formed aluminium alloys. For the casting case; For example, the 43-F mark is used.

H is applies only to alloys that can harden with cold work hardening and symbolizes this situation. It is generally used for flat products (plate/sheet). It refers to the increase in strength and hardness obtained in the formed aluminium alloys despite the cold forming result and whether additional heat treatment is performed to obtain a partial softening.

W refers to the non-permanent structure after solid melting heat treatment. This state is indicated by the aging period due to natural aging. For example; The 2246-W-8 icon is used for the properties that the 2246 alloy will bear after an 8-hour aging.

T is used for heat treated alloys. The alloy may have been cold treated or not. If the aging process does not match the properties obtained after the operations indicated by a number followed by the letter T, a second number is used. Different types of heat treatments are expressed as follows.

T1 means hot processed, cooled and naturally aged. Cast alloys and hot extrusion alloys are applied for alloys that increase their resistance with aging at room temperature.

T2 stands for annealed (cast alloys only) alloy. After hot processing, it is cooled, cold treated and stabilized with natural aging.

T3 is used for the cold-hardening process of process alloys that have been subjected to solution heat treatment. We can also call this process an aging process.

T4 stands for the solution heat treatment and the natural aging applied alloy.

T5 stands for fabricated temperature and artificially aged alloy.

T6 stands for solution heat treatment and artificial aging (thermal) applied alloy.

T7 the solution heat treatment symbolizes the balanced alloys.

T8 solution heat treatment applied; stands for cold-worked and artificial-aged alloys (for process alloys).

T9 stands for successive solution heat treatment, symbolizes artificial aging (thermal) and cold treatment processes.

T10 artificially aged and cold worked (for machining alloys) [1].

Generally, aluminium alloys are classified as either cast or wrought. Composition for both types is designated by a four-digit number that indicates the principal impurities, and in some cases, the purity level. For cast alloys, a decimal point is located between the last two digits. After these digits is a hyphen and the basic temper designation a letter and possibly a one- to three-digit number, which indicates the mechanical and/or heat treatment to which the alloy has been subjected. For example, F, H, and O represent, respectively, the as-fabricated, strainhardened, and annealed states; T3 means that the alloy was solution heat treated, cold worked, and then naturally aged (age hardened). A solution heat treatment followed by artificial aging is indicated by T6 [2].

Recent attention has been given to alloys of aluminium and other low-density metals (e.g. Mg and Ti) as engineering materials for transportation, to effect reductions in fuel consumption. An important characteristic of these materials is specific strength, which is quantified by the tensile strength–specific gravity ratio. Even though an alloy of one of these metals may have a tensile strength that is inferior to a more dense material (such as steel), on a weight basis it will be able to sustain a larger load [2].

1.2.3. Effect of Elements on Aluminium Alloy

Aluminium can easily mix with many metals in liquid form. In the solid state, the solubility of metals in aluminium is only a few percent. In many alloys intermetallic compounds are formed and significantly affect the properties of the alloys. No solid state element (100%) can be dissolved completely in aluminium. The intermetallic compounds mentioned above consist mostly of high alloy additions. Since they are very hard and crunchy, they affect the mechanical properties negatively. Generally, the total ratio of alloying elements should not exceed 15%. The most important and common among alloys consist of 2XXX, 3XXX, 4XXX, 5XXX and 7XXX series [1].

The fact that there is such a difference in the values between the high solubility and room temperatures causes precipitation of these elements in their alloys. This is the underlying reason for the aging process [1].

1.2.3.1. Effect of Silicon (Si)

Silicon added to aluminium increases the fluidity of aluminium but reduces the tendency of aluminium to hot cracking. Alloys containing more than 13% silicon are very difficult to process. In addition, silicon increases the corrosion resistance of the aluminium alloy [5].

1.2.3.2. Effect of Magnesium (Mg)

Magnesium provides the Al-Mg alloy with high strength, ductility and excellent corrosion resistance. With that; allows 1-6% Mg forming ease in its alloys [5].

1.2.3.3. Effect of Copper (Cu)

Copper used as an alloying element in aluminium is used at a rate of 3-12%. It is the main element that gives hardness to alloys. It increases the tensile strength of the alloy when it is heat treated or not. It is used between 3-5% in forged alloys. If more than 5% is used, it creates mechanical processing difficulties. It also reduces electrical conductivity and corrosion resistance.

The solubility of copper in aluminium increases with increasing temperature. For this reason, it is possible to harden aluminium alloys containing copper by precipitation hardening by heat treatment. The time required for precipitation depends on the composition of the alloy and the temperature. The effect of precipitation on mechanical properties depends on the amount, size and distribution of the deposited phase [6].

1.2.3.4. Effect of Manganese (Mn)

Manganese is used with iron (Fe) to increase the casting ability in aluminium alloy. It also changes the properties of intermetallic compounds. It reduces shrinkage in the structure. It increases the ductility and toughness properties of alloys [5].

1.2.3.5. Effect of Zinc (Zn)

Although it increases the manganese casting ability in aluminium alloy, zinc makes castability difficult. Likewise, while silicon reduces the tendency to crack, high zinc alloys produce hot cracking and cooling. Although alloys higher than 10% Zn show stress cracking, it increases the strength if it is found with other alloy elements. There is no significant effect on binary aluminium alloys containing less than 3% Zn [5].

1.2.3.6. Effect of Titanium (Ti)

Titanium has a grain-thinning effect. It provides increased mechanical properties. It is desired to be between 0,02-0,05% in alloys to be cast into sand and metal mold. It can be found at a maximum of 20% in AI. It is best seen when used with boron. Titanium increases tensile strength and ductility, reduces thermal conductivity [6].

1.2.3.7. Effect of Iron (Fe)

Iron is found naturally in ore in aluminium. In small proportions, it increases the hardness and strength of some alloys. It plays a role in reducing the tendency of castings to crack hot [5]. High rates of iron(Fe) create problems during surface coating processes.

1.2.3.8. Effect of Transition Metals

Transition metals in aluminium are chrome, zirconium, titanium, etc. The transition metals in the solid melt significantly reduce the strength of the zinc and magnesium solid melt in aluminium. For example; Increasing the presence of zirconium in electron microscopy showed that. It significantly reduced the strength of zinc and magnesium solid melt in aluminium. In addition, transition metals in solid melt reduce the stable solubility of the main alloying elements in aluminium. Therefore, the strength of the transition metals solid solution should be increased. Meanwhile, there are opinions that argue that transition metals in solid aluminium melt strengthen atomic bonds and reduce the diffusion motion of atoms [7]. According to this view, transition metals should increase the strength of the melt. However, the strength of the zinc and magnesium solid melt in aluminium has been seen by experiments and researches that have been reduced when alloyed with transition metals. In this case, the first view, which defends the increase in resolution, turns out to be more accurate. The same can be said about chrome and zirconium [7].

Table 1.6. Important uses of aluminium and alternative materials [7, 8].

Sector	**Place of use**	**Alternative Materials**
MACHINE	Beds Heat exchangers Hydraulic systems	Casting materials Copper, stainless steel Steel
ELECTRICITY ELECTRONIC	Transformer Generator Conductors	Copper Copper Copper

	Telephone cables	Copper
MARINE VEHICLES	Boat hull	Wood, glass fiber, steel
CONSTRUCTION	Wall covering Roofing Window and door frames	Wood, steel, plastic Wood, galvanized steel, lead plate Wood, PVC hard plastic
AIRPLANE AND SPACE VEHICLES	Structural elements Aircraft body	Steel, plastic, magnesium Carbon fiber and other composite materials
TRANSPORTATION	Radiators Engine parts Body plate	Copper, brass Cast iron Black galvanized or other coated steel sheet
WHITE GOODS	Refrigerator Air conditioners Cooking tools	Special steel, plastic, copper Special steel, plastic copper Steel, stainless steel, copper

1.2.4. Al-Mg-Si Alloys (6XXX Series)

Among the elements in the 6XXX series alloys, the silicon ratio ranges between 0.2-0.7% and the magnesium ratio ranges between 0.35-0.9%. For the iron, which is the most important impurity element in the AA 6000 series aluminium alloys, lower and upper limits have been determined in some standards, while only the upper limit has been given in others. Although it is desired that the amount of titanium and zinc, one of the impurity elements, is generally below 0.1-0.2%, they are included in the group of "other impurity elements", which in some standards should total less than 0.15%. While the weight of copper and chromium in the impurity elements is desired to be below 0.05-0.12%, the difference between the lower and upper limits of the amount of manganese in the alloy is wide and varies between 0.1-0.3% [1].

Alloys of 6xxx series are divided into 3 subgroups among themselves according to the place of use. These;

1) Those that will be used as construction material in applications where strength is important; The percentage of this group is high in magnesium and silicon.

2) Alloys that have high extrusion ability; Balanced or some excess silicon alloys are included

in this group. The magnesium and silicon content of this group is of medium value.

3) Alloys with high anodization ability; Their magnesium content is high. %Si is at medium level in Mg_2Si. Elements such as Fe and Zn that can be considered as impurity are very low [1]. (Fe<%0,15, Zn<0,001)

1.2.5. Physical, Chemical and Mechanical Properties Of Al-Mg-Si Alloys

The main components of Al-Mg-Si alloys are magnesium and silicon, and these elements form the Mg_2Si intermetallic compound in the structure. Generally, elements such as iron, manganese and chromium are found as regulators. A small amount of zinc or copper may induce increasing strength without causing big change in corrosion resistance. The elements such as boron, titanium, vanadium, and zirconium contribute to control the grain size wherelead or bismuth make the workability is much easy [9]. The Mg_2Si intermetallic compound stoichiometric Mg:Si ratio is 1.73. The Mg and Si contents of the 6063 alloy are selected to form Mg_2Si and are considered as balanced alloys.

There are mostly free Mg and Si in the structure. Some of the silicon is involved in the formation of the Al-Fe-Si phases. Although very limited, in some cases free or excess silicon is allowed to improve castability. Free or excess magnesium is absolutely undesirable as it negatively affects extrudability. The compound Mg_2Si (63.2%Mg, 36.8%Si) has a cubic structure; There are 12 atoms in the unit cell. The lattice parameter is $a=6.35\text{-}6.40x10^{-10}$m. Its density is 2,70 gr/cm^3. Its thermal conductivity is 234 W/m˚C and its modulus of elasticity is 69GPa [9].

Regional segregation tendency is observed due to change in balance conditions such as rapid cooling. In these cases, silicon can be seen in the form of Mg_2Si in the alloy composition For single-phase alloys in equilibrium conditions, cluster Mg_2Si or Mg_2Al_8 may be present, but completely inbalance conditions do not create significant differences [10].

Excessive magnesium increases corrosion resistance while reducing the strength and deformation ability. On the other hand, excessive silicon provides higher strength without effecting much the deformation ability. Hence, the lattice parameter of alloys is adjusted by the addition of magnesium and silicon. Copper, manganese, zinc and chromium are mostly present in very low amounts in the alloy, so they have no measurable effect (less than 1%). The elements such as iron, titanium and boron do not have a significant effect on the lattice parameter. The physical properties such as surface tension, density, thermal expansion, specific heat, and self-drawing of alloy play important role in solidification compared to pure aluminium. For instance, the thermal conductivity between 0-100˚C temperature is 200 W/m˚C which is 10-20% lower than that of pure aluminium [11]. The electrical resistance is in the range of 3.0-3.5 μ**Ω**cm (50-55% IACS) in 0.4-0.5% Mg alloys artificially aged low amount of excess silicon. More magnesium, manganese and copper reduce this conductivity. This conductivity is even lower in naturally aged alloys. But it can reach 55-60% IACS value in annealed condition [10]. Physical properties of Al-Mg-Si alloys are given in Table 1.8 [11].

Table 1.7. Chemical compositions of Al-Mg-Si alloys [12].

Alloy	Si(%)	Fe(%)	Cu(%)	Mn(%)	Mg(%)	Cr(%)	Zn(%)	Ti(%)
AA6082	0.7-1.3	0-0.50	0-0.10	0.40-1.0	0.6-1.2	0-0.25	0-0.20	0-0.10
AA6063	0.20-0.6	0-0.35	0-0.10	0-0.10	0.45-0.9	0-0.10	0-0.10	0-0.10
AA6061	0.40-0.8	0-0.7	0.15-0.40	0-0.15	0.8-1.2	0.04-0.35	0-0.25	0-0.15

Table 1.8. Physical properties of Al-Mg-Si alloys [11].

Alloy Type and Tempers	Density (gr/cm^3)	Melting Range (^oC)	Linear Expansion Coefficient (20-1000) (10-6/^oC)	Thermal Conductivity (0-100 ^oC) (W/m^{0}C)-(%IACS)	Electrical Resistance Conductivity (20^{o}C)(20^{o}C) (μΩcm)-(%IACS)
6082 - TF	2.70	570-660	23	184 – 43.7	3.7 – 46.6
6063 - TF	2.70	580-660	23.5	201 – 51.1	33 – 52.2
6061 - TF	2.70	570-600	24	156 – 39.6	4.0 – 43.1

Tests on alloys made from 99.99% aluminium, 85% of light reflectance has been observed after electro polishing and anodization (anodizing). The mechanical properties of the Al-Mg-Si alloys most used in the industry are given in Table 1.9 and the stress-strain diagrams are given in Figure 1.2 [11].

Table 1.9. Mechanical properties of Al-Mg-Si alloy [11].

Alloy Type and Tempers	0.2% Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Abrasion Resistance (MPa)	Fatigue Strength $50x10^6$cev (MPa)	Hardness Brinell	Elastic Module (GPa)
6082-TF	270	310	9	218	124	90-100	69
6063-TF	180	210	8	155	85	75	69
6061-TF	265	305	11	205	95	90-100	69

Among the temper symbols shown in the table above, TB (T4), TE (T5), TF (T6) are equivalent. Here;

T4(TB): Stabilization after solution heat treatment and natural aging.

T5(TE): Artificial aging after high temperature forming and then cooling.

T6(TF): Refers to solution heat treatment and then artificial aging [11].

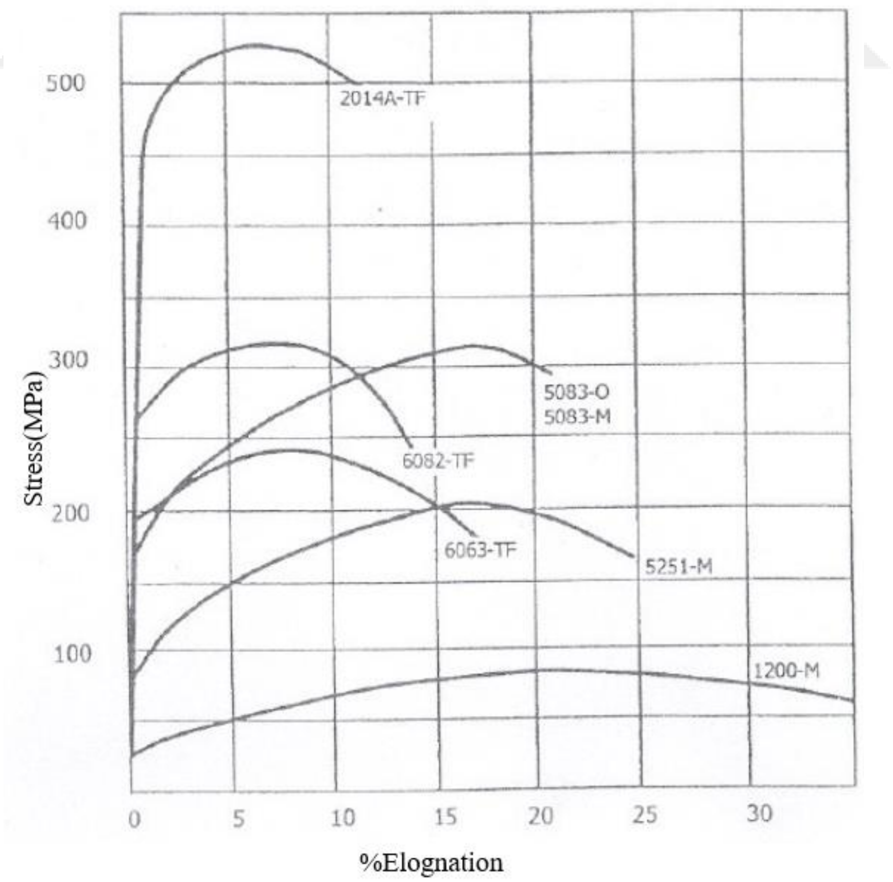


Figure 1.2. Comparative stress-elongation% diagram of Al-Mg-Si alloys with other

aluminium alloys [11].

It is known that Al-Mg-Si alloys change in strength with changing temperature. The resistance increases at low temperatures, for example: At -200˚C, the material increases by 80% compared to its value at room temperature without losing its ductility and fracture toughness values. In Figure 1.3, resistance of Al-Mg-Si alloys with other aluminium alloys are shown comparatively with varying temperature [11].

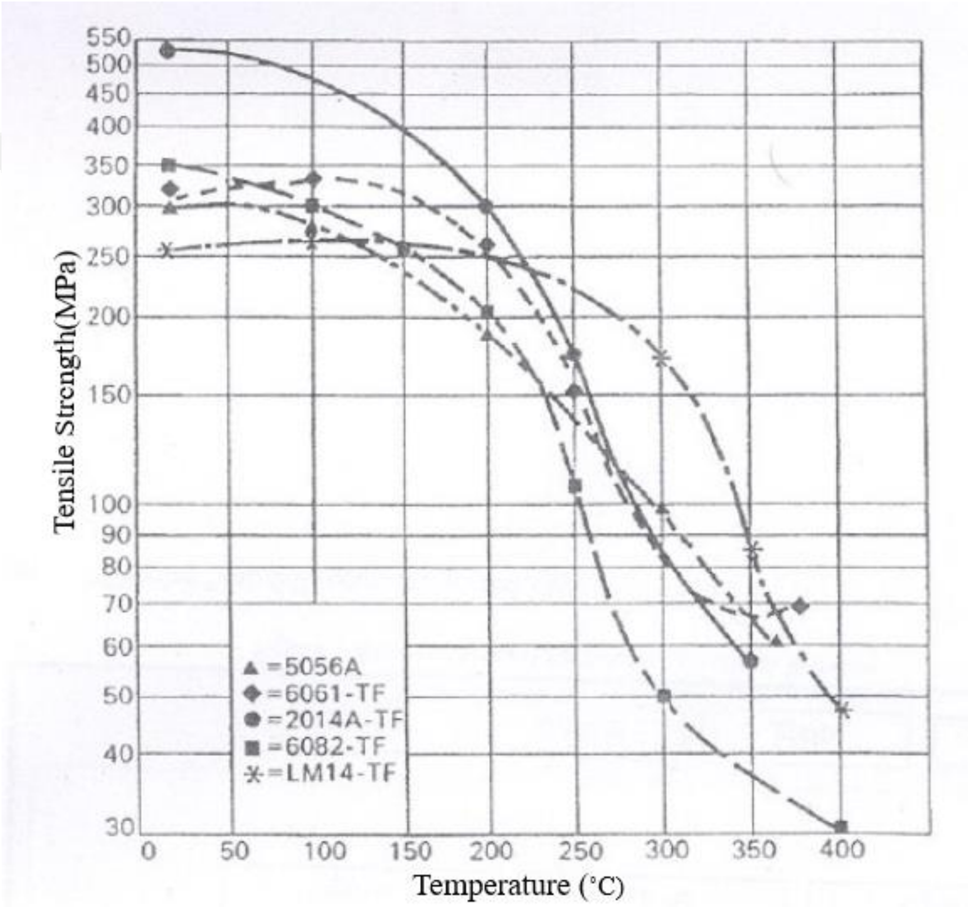


Figure 1.3. Resistance differences of Al-Mg-Si alloys with other aluminium alloys according to temperature changes [11].

1.2.6. The Effect of the Chemical Composition of the AA 6063 Alloy on the Properties

The AA 6063 alloy makes up the vast majority of extruded aluminium products and is an alloy suitable for anodic coating. AA 6063 extrusion products are corrosion resistant materials as well as good surface appearance and have good mechanical properties. Because of these features, they are widely used in architectural applications.

It is known that the mechanical properties of AA 6063 depend on the amount of Mg_2Si. Mechanical properties improve with increasing amount of Mg_2Si, whereas extrudability decreases [14]. Figure 1.4 shows the change of tensile strength of AA 6063 with the amount of Mg_2Si in the alloy [15]. As can be seen from the figure, when the amount of Mg_2Si drops below 65%, the strength of the material decreases rapidly.

In AA 6063 series aluminium alloys, magnesium and silicon combine at 1.73:1 ratio stoichiometrically and form Mg_2Si precipitate which is stable α phase in the balance diagram. If silicon is more than enough to form stoichiometric compound in the alloy, the strength increases. In contrast, when there is an increase of amount of magnesium in this ratio, the strength decreases. In addition, extrudability is also negatively affected by the magnesium increase [16],[17].

However, it should be taken into consideration that if the amount of silicon in the alloy is increased in order to obtain high strength values, the so-called “black spots” defects may occur on the surface as a result of sedimentation of the silicon. Figure 1.3 shows the effect of Mg_2Si and excess silicon on the tensile strength of AA 6063 [18].

Excess silicon regulates sediment morphology by increasing the nucleation rate during the aging process, so it provides increasing of the strength. The amount of Mg_2Si required for hardening of solid solution in AA 6063 alloy is minimum 0.3%. In Figure 1.4, the variance of AA 6063 alloy with Mg_2Si amount is given [14].

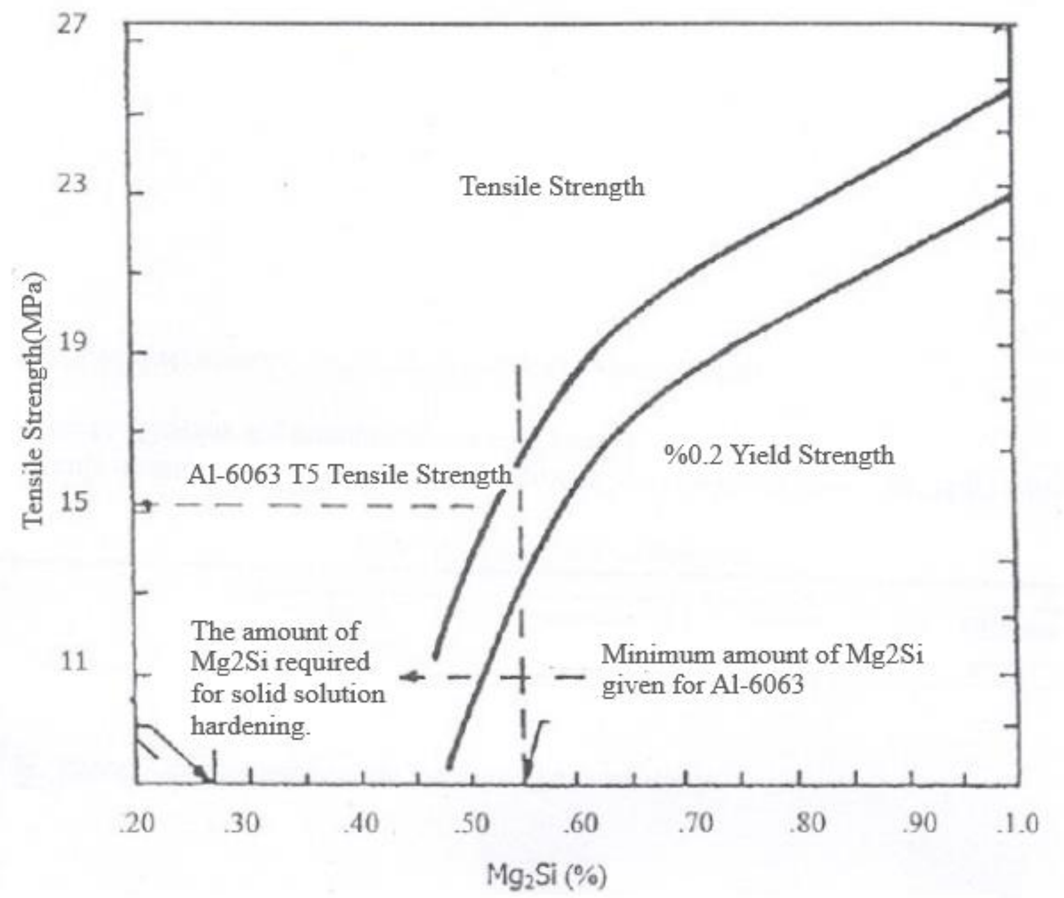


Figure 1.4. The change of tensile strength of AA 6063 with Mg_2Si amount [14].

Iron, which is in the material as a controlled impurity, combines with some silicon and changes the magnesium/silicon ratio. For this reason, the material must have enough silicon to combine with both iron and magnesium. Otherwise, all of the magnesium will not combine with silicon to form the Mg_2Si precipitates, and as a result, the alloy strength will be below the strength values set for AA 6063 [1].

Iron, which is found as the most important impurity in aluminium alloys during cooling after casting, cooling after homogenization or during subsequent thermal and mechanical processes; By combining with aluminium and silicon, it creates various phases that affect the properties of the material such as recovery, recrystallization, structure, formability, surface cleaning and electrical resistance. These Al-Fe and Al-Fe-Si intermetallic compounds, which are formed in aluminium alloys, are intensely researched as they will determine the mechanical properties, corrosion resistance and surface quality of the product [1].

1.3. Vertical Continuous Casting

The basic reactions occurring in all casting processes are also theoretically valid for aluminium alloy tickets and ingots. The solidification rate that completes the amount of heat loss makes the main difference between different techniques. The form of heat flow that affects the structure of the billets varies from one technique to another. In general, the process alloys are poured with high solidification speeds, which suppress some degree of reverse billet segregation. That is, the alloying elements are enriched near the billet surface and the secondary phases are rough. In slow solidification, reverse billet segregation is found in sub-eutectic alloys [19]. In other words, rapid solidification and rapid cooling can result in over saturation, grain segregation and high residual stresses as a result of shrinkage in the most recent solidified regions. However, if the entire casting is cooled homogeneously, these stresses can be significantly reduced and eliminated by stress relieving annealing.

It is clear that if the alloying elements added in order to obtain unique properties are distributed uniformly, they can give the desired effects. All types of segregation are undesirable, whether it is microscopic scale grain segregation or long distance billet segregation [20]. Ingot segregation and shrinkage can be avoided by solidification that can be achieved by continuous casting technique or minimized. A completely clean smelting is required before good quality castings can be produced regardless of the casting technique used. Some other important measures can be summarized as follows;

a) Careful selection of the material to be melted,
b) During the melting process, attention should be paid to the furnace temperature,
c) Slag such as oxides, nitrides etc. should not remain in the liquid metal,
d) Gas removal should be done at the highest level,
e) Effective grain reduction, fine grains not only increase tensile strength and part performance, but also minimize shrinkage and hot cracking [20].

Arrangement of gating systems in molds is also important in the production of quality castings. Due to aluminium high thermal conductivity and susceptibility to oxidation, the air-contacting surface of the molten metal should be kept as small as possible. For this, the melt must be poured into the mold by means of a sprue that is aligned with the lower edge of the casting and perpendicular to the casting cavity. In addition, in aluminium castings, the casting temperature should be kept as low as possible for the solidification to proceed rapidly [10].

As it is known, aluminium melts undergo a volumetric shrinkage of approximately 5% to 7% during solidification and therefore, if preventive measures are not taken, a solidification/withdrawal gap will occur in the castings. Such voids always occur in areas where the melt remains liquid for the longest time and last solidifies, the shape of the cavity may vary depending on the type of solidification. At the shell-type solidification can occur as external or internal macro voids.

Solidification of metals and alloys occurs with the formation and growth of the core, and the solidification behavior of metals and alloys can be classified into two groups [19].

a) Internally Growing Crystallization: In this case, many nuclei are formed and their melt participation begins. This type of crystallization occurs in alloys in a wide range of solidification, in the form of ice-water type and in narrow alloys with a narrow freezing range, in the form of shell or solidification. The amount of solid phase increases during solidification, and the liquid remaining thereafter remains solid, eventually completely solidifying [19].
b) Externally Growing Crystallization: In this case, solidification always starts on the mold wall where there are enough nuclei and continues from here to the melt by showing columnar growth. It also ends with the last solidification of the molten metal in the spaces between the dentrites. Sponge type, rough wall type and wall type solidifications are also the result of this type of crystallization [19].

Figure 1.5. The crystallization forms occurring in billet produced by vertical continuous casting method are given in [10].

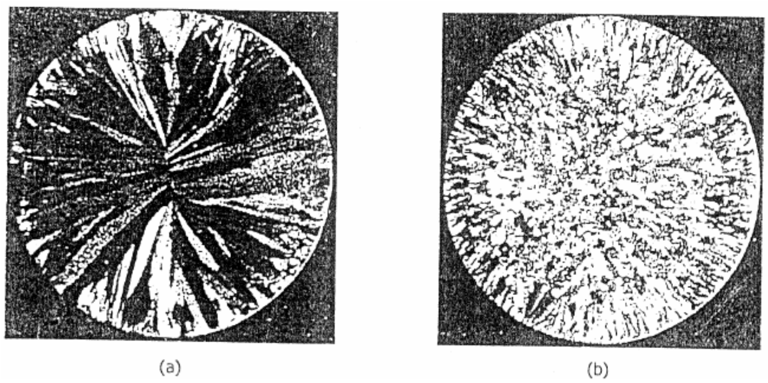


Figure 1.5. a) Internally growing crystallization, b) Externally growing crystallization [10].

Solidification is a common step in the production of metals and alloys. Casting structure is important as it determines the working life and properties of the products in service [1].

1.3.1. Directly Cooled Casting Method

Ingot and billets are produced to be used in rolling, extrusion or forging manufacturing methods by direct cooling casting (DC casting) method. This method, which has been used for more than 70 years, was discovered by W.T.Error [21]. Ingots and billets play an important role in the production of all aluminium products. Plate, sheet, foil, wire and pipe can be produced by pressing or rolling ingots and billets [5].

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.

Figure 1.6. Aluminium filled molds (Zahit Aluminium, 2019)

After the casting is finished, the frozen aluminium parts on the mold are cleaned and the vertical position is brought by lifting the mold with the help of the piston, and the billets are taken out of the well for the homogenization process with the help of a crane.

Figure 1.7. Extraction of billets from the casting well (Zahit Aluminium, 2019)

In this process, the cross-sectional shape of the casting product is determined by the shape of the mold, generally rectangular molds for extruded and forged products, circular cross-sectional molds for extrusion billets and square-sectional molds for rod wires. The base is pulled downwards either by steel rope or hydraulic system at certain speeds. The liquid metal that contacts the water-cooled mold wall immediately solidifies and forms a shell. Due to the shrinkage caused by the liquid-solid transition, the shell contracts inward and forms an air gap that prevents heat transfer. Later, due to the shrinkage formed in solidification, this shell is separated from the mold wall. In this way, the formation and shrinkage of the shell allows the billet to be continuously removed (continuous casting) from the mold. The rate of solidification slows down, meanwhile, a rich fluid flow begins outward from the intergranular and interdentritic facades with the pressure of the liquid mass in the center of the billet and the capillary effect caused by solidification. With this fluid flow, alloying elements (reverse segregation) are deposited into the shell and even come out to the billet surface and begin to contact the mold again, and then immediately solidify and shrink again. Solidification by heat transfer in the mold through the mold wall is called “primary cooling”. Solidification is very complex due to the presence of many mechanisms in this region [20].

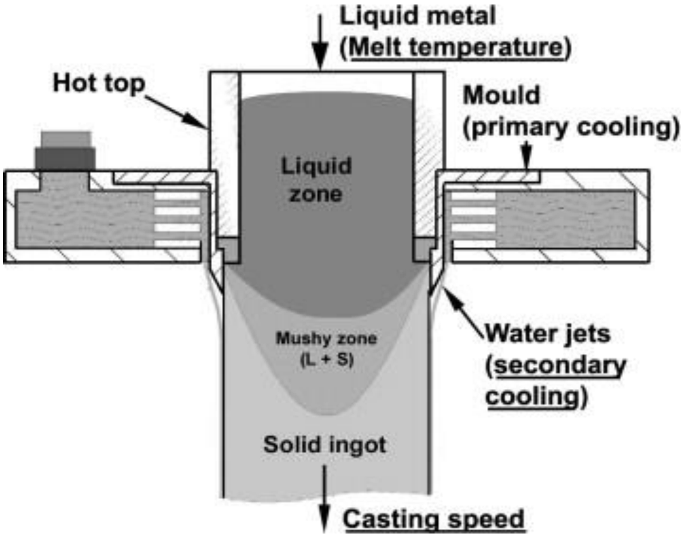


Figure 1.8. Direct Chill Casting Process(DC Casting) [22].

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 [23].

1.3.2. Segregation

The deviation from the uniform distribution of alloying elements in the structure is called “segregation”. This irregularity in the distribution of the alloy elements is called “microsegregation” if it is in the dentrit arm spacing or micro distances as in the grains [24].

Since segregation has negative effects on mechanical properties, it is undesirable and tried to be kept as low as possible. Micro segregation amount is minimized by the process with a very slow cooling during solidification or homogenisation [10].

In commercial casting techniques, there is not enough time for broadcasting, which will perform the uniform distribution of foreign atoms within a grain. In addition, since the alloy generally cools as quickly as possible to the solidus temperature, the relations obtained in the new solidified structure are maintained widely. Structural changes that may occur by keeping the solid phase material at high temperatures for long enough times can be eliminated by such rapid cooling [10].

Crystals that initially solidify in the solidification of an alloy will have a lower solute content than the melt they solidify. For example, the first growing crystals in solidification of an Al-0.5Mg alloy contain only about 1%Mg. In the subsequent cooling process, the melt will be enriched with Mg. The Mg content of the crystals also increases as growth continues. As can be seen in Figure 1.9, a second type of crystal enriched with Mg occurs at this point with a heterogeneous structure at grain boundaries. The amount of microsegregation essentially depends on the rate of solidification. The slower an alloy hardens, the lower the amount of microsegregation [1].

The effect of solidification rate or homogenization process on microsegregation is shown in Figure 1.9b. Since the foreign atom content changes from the center outwards in the same centered rings, the grains containing segregation show separation [20].

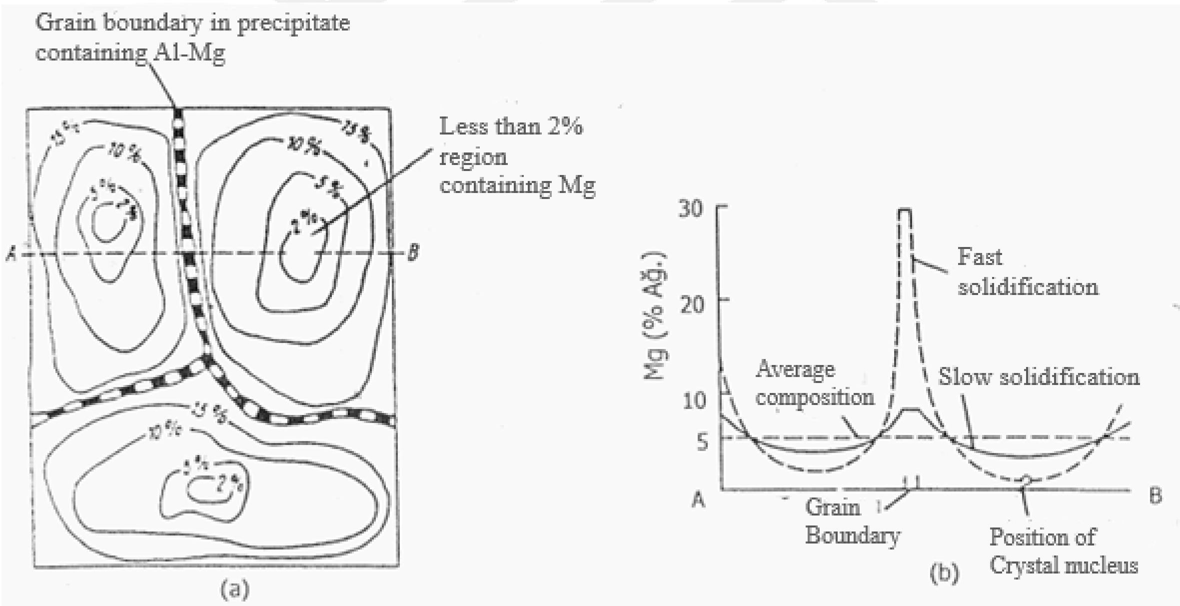


Figure 1.9. a) Schematic section of the casting structure with grain segregation in Al- 5% Mg alloy (rings indicate regions with equal Mg content). b) Effect of solidification rate or homogenization on grain segregation [20].

There are four important factors that cause segregation in billets due to mass flow to large distances during solidification;

a) Shrinkage resulting from solidification and thermal contraction,
b) Density differences between the dendrites,
c) Density differences between liquid and solid,
d) Migrations resulting from density differences caused by temperature changes in the liquid.

Another segregation type frequently seen in Al-Mg-Si alloy billets produced by continuous casting method is reverse segregation. According to the classical mechanism, the billet shell solidification results in the formation of channels occupied with low melting point phases. An air gap is formed between the mold wall and the shell due to the shrinkage when liquid is still present between the dentrite facades of the coral crystals. The growth of the shell, which maintains and surrounds the central liquid mass, and whose thickness increases linearly over time, slows down and partially melts with the formation of an air gap with high heat transfer resistance. At this point, the high fluid fluid in the spaces between the dendrites moves outward and reaches to the surface both by feeding the volumetric withdrawal and by the effect of the hydrostatic pressure of the central fluid. Reverse segregation is constantly evolving and depends on nutritional characteristics. In Figure 1.10, exudation/bleeding can be seen as a result of segregation created by hydrostatic pressure on the billet surface of the components with low melting point through the channels between the dentrites. Channels between dentrites are indicated by arrows [25].

Figure 1.10. Formation of reverse billet segregation [25].

Formation that occurs at the mold-billet interface are extremely complex and include a variety of mechanisms of this complex procedure. In cases where reverse segregation is low, it is seen that surface segregation is dependent on reverse solidification theory. According to this assumption, a developing shell or protrusion moves away from the actual surface to the liquid metal surface (meniscus) and the alloying element (solute) is pushed towards the surface. Reverse surface segregation can therefore be considered as normal segregation as a result of reverse solidification [25].

1.3.3. Homogenization

Homogenization, the high temperature annealing step preceding extrusion, is an essential process in aluminium extrusion technology and is aimed at making the as-cast billet capable of undergoing extensive plastic deformation without cracking or local melting. A homogenisation treatment is required for all aluminium alloys produced by direct chill or by other conventional casting processes. The metallurgy of the homogenisation process is highly complex as a multitude of processes takes place. The exact nature of these processes depends on the chemistry of the alloy but for AA6XXX (Al Mg–Si) extrusion alloys the most relevant reactions are phase transformations of Al(Fe,Mn)Si-intermetallics and dissolution of Mg– Si particles into the aluminium matrix which increases its Mg and Si solute content [26].

As far as the resistance to plastic deformation at the high temperatures encountered during extrusion is concerned, the condition of the principal alloying elements Mg and Si is most significant. Here, the condition of Mg and Si is defined as the presence of Mg and Si as Mg-Si particles, in solid solution in the aluminium matrix, or in a combination of these conditions. For a given alloy composition a (desirable) low flow resistance is obtained when a significant fraction of the alloying elements is taken up in large, incoherent precipitates. For the Al–Mg-Si-alloys these would be the β precipitates. However, the Mg and Si atoms taken up in these precipitates are not available to contribute to precipitation hardening during artificial ageing of the extruded material and the product would fall short in tensile strength. Alternatively, by bringing all alloying elements into solid solution during the homogenisation treatment, a high extrusion pressure will result but all alloying elements can contribute to the strength of the extruded product by precipitation in the form of fine coherent β precipitates during artificial ageing [26].

During homogenization, the β-AlFeSi phase turns into a global α phase, which is poorer in Si and is more preferred in the extrusion process. The α phase increases the ductility of the material due to its morphology, which causes less micro-fractures than the planar β- AlFeSi phase. The α phase leads to a decrease in pickup errors on extruded surfaces [27].

The higher the cooling rate in homogenized billets, the better efficiency is obtained. Sudden cooling (150°C/hour) from the homogenization temperature ensures that the Mg_2Si particles, which can be seen with a normal microscope, remain in the solid solution without precipitation [28].

After homogenization, Mg_2Si grows by nucleation with a slow cooling. It precipitate on the surfaces of iron-rich particles along the grain and grain boundaries. The growth of these sediments is prevented by reheating by induction; more time is needed for large Mg_2Si precipitates to pass into solution in the extrusion process. Otherwise, it causes unacceptable decreases in strength properties [29].

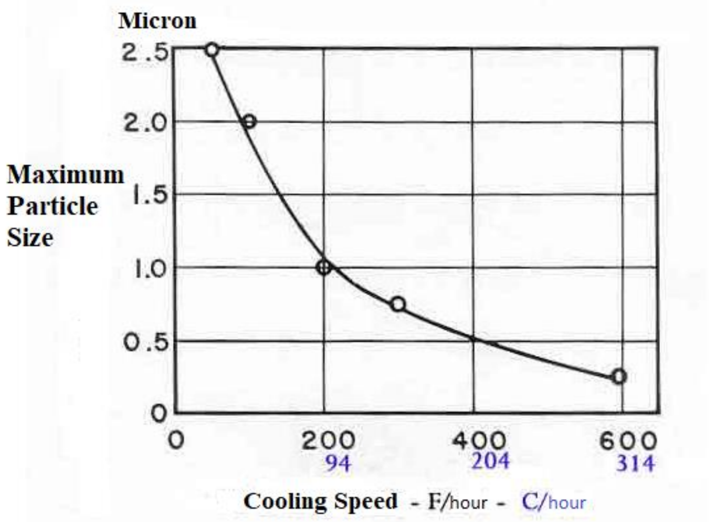


Figure 1.11. Effect of cooling rate from homogenization temperature on the size of precipitated Mg_2Si particles [30].

By using different rapid coolings of 6063 billets after homogenization a number of properties of this material can be decisively influenced. Thus, with direct extrusion, the extrusion and frictional loads depend on the size and distribution of the Mg_2Si precipitates as do the surface quality of the extruded section and the maximum extrusion rate achieved, and also the mechanical properties achieved after artificial aging after extrusion [31].

Depending on the cooling rate after homogenization, different amounts of Mg and Si remain in the solid solution. These amounts can be from 100% solution to 100% Mg_2Si. Excessively uniform structure can cause large cracks during extrusion. At an undetermined value below the maximum tensile strength value, frequent breakage of the material during operation is a serious condition encountered in 6000 series alloys. The effect of Mn, Cr, Zr and Cu on the notch impact strength of Al-Mg_2Si binary alloys was investigated. However, the homogenization temperature of the balanced Al-Mg-Si alloy (1%, 0.5% Si) has no effect on the notch impact strength [1].

Figure 1.12. Billet loading to the homogenization furnace. (Zahit Aluminium, 2019)

In a study conducted by electron microprop analysis (EMPA), it was determined that the AlMgFeSi, Mg_2Si and AlFeSi phases show an non-equal distribution in the microstructure. The concentration of Mg_2Si is different from the stoichiometric ratio of 1.73:1. It provides co-distribution between magnesium and silicon dendritic arms by homogenization. The rate of AlFeSi phases does not change much as a result of heat treatment, but does not break down [32]. It was found that the unbalanced AlMgSi and AlMgFe phases dissolved within 30 minutes during the homogenization process above 500˚C with EMPA and electrical resistance experiments. However, the magnesium and silicon concentration gradient in the dendrites are equalized at 570˚C after 2.5 hours of standby time. During the heat treatment, the chemical composition of the AlFeSi phases changes, forming the stable AlFeSi (Fe / Si ~ 4) phase. The transformation of these phases, which are located in the grain boundaries, into shapes to be rounded from thin lengths, slows down at the end of the same period [33].

Homogenization of aluminium alloys is an expensive component of the entire manufacturing process because of the high temperatures and long times involved. Specific cycles vary, but actual practices for 6xxx alloys are typically performed between 530-590^{o}C with 6-8 hour soak times. Therefore, reductions of homogenization time or temperature are attractive ways of lowering expenditures [34].

2. LITERATURE REVIEW

1. Simulation of macrosegregation in direct-chill casting -A model based on meshless diffuse approximate method (2020)

In this study of Vanja Hatič, Boštjan Mavrič and Božidar Šarler, A multiphysics numerical model has been developed for prediction of macrosegregation in direct-chill casting. The model uses volume averaged mass, momentum, energy, and species conservation equations to simulate the solidification of axisymmetric aluminium alloy billets. The automatic adaptive generation of computational node arrangement decreases the calculation time and in a straightforward way enables investigation of the complex flow for geometrically different inflow structures, including sharp and curved edges. The model is used for casting simulation of an Al-5.25wt%Cu alloy billet with a 120 mm radius for various inlet designs. The effect of inlet geometry on the temperature, solid fraction, melt flow, and macrosegregation is investigated. The described developments represent a first meshless numerical approach for simulation of macrosegregation of an important industrial process.

2. Modeling of Ingot Distortions During Direct Chill Casting of Aluminium Alloys(1996)

İn this study of J.-M. DREZET and M. RAPPAZ, A comprehensive three-dimensional (3-D) mathematical model based upon the ABAQUS software has been developed for the computation of the thermomechanical state of the solidifying strand during direct chill (DC) casting of rolling sheet ingots and during subsequent cooling. Based upon a finiteelement formulation, the model determines the temperature distribution, the stresses, and the associated deformations in the metal. For that purpose, the thermomechanical properties of the alloy have been measured up to the coherency temperature using creep and indentation tests. The 3-D thermomechanical model presented here has been validated using ingot distortion measurements. This model is able to predict with accuracy the butt curl of the ingot during the starting phase and the transient and steadystate rolling faces pull-in as a function of the casting conditions (casting speed, ingot size, and mold shape). The input data, thermophysical and thermomechanical properties as well as boundary conditions, have been paid particular attention because the final ingot shape is the result of several interplaying phenomena. With the help of this model, it is shown that a nearly steady-state thermomechanical regime is reached after about 1-m cast length.

3. Microstructure Control and Extrudability of Al-Mg-Si Alloys Microalloyed with Manganese (1994)

According to Zajac S., Hutchinson B., Johansson A. And Gullman L., there is a close relationship between grain size and billet diameter. According to this relationship; With the increasing diameter of the billet, the grain size is also growing. This statement is in line with the views; With the rapid cooling of small billets at high temperatures, the nucleation rate of the phase increases during solidification and the precipitation of alloy elements is prevented. As a result, the grain size of AA 6063 is 50% larger in big billets than in small billets. This rapid cooling in small billets causes the formation of small AlFeSi and this resulting uniform distribution of AlFeSi. They also found that these small AlFeSi particles are found not only within their boundaries, but also within the grain and even between the dentrites..

4. Precipitation in a heat-treatable aluminium alloy cooled at different rates(2001)

Jose Luis Cavazos and Rafael Colas, in their study; They were produced from AA 6063 alloy for extrusion with vertical continuous casting method, extruded and heat treated, and they were cooled to room temperature at different speeds for 4 hours at 520 ˚C. Samples were taken from this stick and aged at different temperatures and times. After the aging process, precipitation hardening was observed in the rods. At the cooling speed below 10˚C / second, the highest hardness values were obtained at the aging temperatures given in the cooled samples. Selected samples were examined in Xray Diffraction (XRD) and Transmission Electron Microscope (TEM). It was observed that no precipitation occurred in the non-aged samples cooled at a speed of 60 ˚C/second. They observed that the lattice parameter of the matrix structure was approximately 4.055 A˚ and the lattice structure was the surface center cubic structure. This lattice structure and lattice parameter is slightly larger than the lattice structure specified for pure aluminium. In contrast, small deposits were observed in samples that were not cooled at a slower rate but aged. They showed that when the cooling rate decreases, the cage intervals in aged and non-aged samples change.

5. Improvement of Casting Speed and Billet Quality of Direct Chill Cast Aluminium Wrought Alloy with Combination of Slit Mold and Electromagnetic Coil(2007)

In this study of Hai Hao, Xingguo Zhang, Shan Yao and Junze Jin, a mold with slits and external cooling water channels was designed for the direct chill casting processing. By imposing a high frequency magnetic field, the surface quality and microstructure of the direct chill cast billets are improved. The casting speed could be improved by the simultaneous use of mold and electromagnetic coil. In the case of one kind of Al-Cu-Mg alloy with a wide freezing range, the critical casting speed to break-out can be improved 60%. The microstructure of the billet cast with electromagnetic field is more fine and uniform than that of the conventionally cast billet, and the subsurface segregation usually observed in the conventional billets is eliminated.

3. TEST AND EXPERIMENTAL STUDIES

3.1. Status Before Starting the Project

The main purpose of the project is to eliminate the undesired and waste-causing faults on the surface of billet materials produced in Zahit Aluminium Inc.'s Billet Foundry. In addition; crack-gap fault in cross section of billet material. The high thickness of the shell (400-600 µm), which is very important for the extrusion process in the billets, is the result of the high loss of yield. The grain size, which is an important value for the extrusion and shaping process, also had a high (220-280 µm) value as the shell thickness value. The losses due to this type of problems were in the order of 15%. In order to solve these negative situations, a TÜBİTAK project was prepared within the scope of university-industry cooperation and the project was supported by TÜBİTAK. The results obtained as a result of the studies are summarized in this thesis study. These studies are briefly about mold design and optimization, liquid metal height, grain thinner, determination of cooling water pressure and determination of optimum homogenization parameters.

3.2. Experimental Study

In the method called as DC casting method in the aluminium billet casting, a mechanism that solidifies the liquid material on the solid surface and solidification proceeds towards the center of the material and is finally solid.

There are many parameters (negative-positive direction) that affect the nature of solidification in this method. Liquid metal temperature and cooling rate are the two most important parameters in solidification. The water that provides solidification does not directly contact the material. The solidification can be defined in two steps. Firstly, solidification takes place indirectly through the graphite ring in the mold. The water which circulates inside the mold travels behind the graphite and cools the graphite before reaches the mold holes. Designally, the water reaches the graphite ring before holes in the casting molds. The graphite ring first meets the liquid metal and the first solidification takes place here which in the temperature is between 70-120˚C. Then the billet is coolled by contact water with 16-24˚C comes from cooling towers. Schematic representation is given in Figure 3.1.

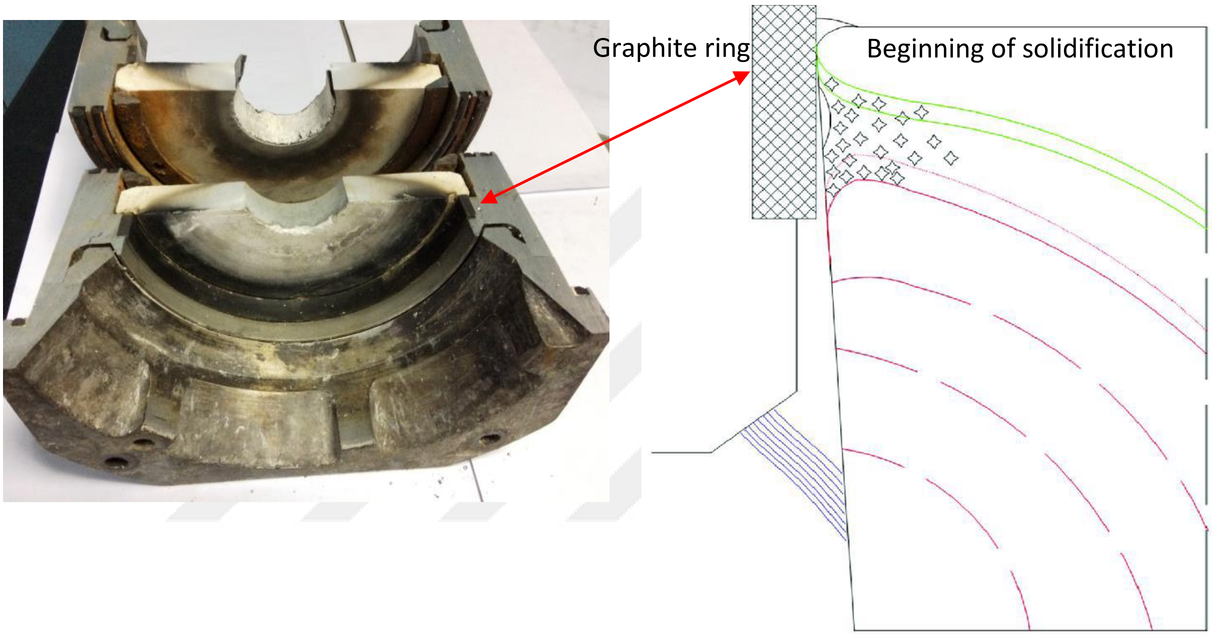


Figure 3.1. Solidification cross section view (Zahit Aluminium, 2019)

The surface quality of the billet material which is the final product directly affects the extrusion process in the billet casting. The thickness of the crust region formed during the solidification in the billet as called diffusion region – inverse (or reverse) segregation zone. The various intermetallics and/or precipitates are formed which depend on the diffusion rates of the elements in the alloy at the solidification temperature in the shell region during the solidification. And then precipitate structure is shaped. The shell thickness should not exceed 150 µm for a billet and should not contain oxide, impurity or very coarse intermetallic structure. If this structure is not formed under the qualifying conditions, quality problems (surface defects in profile, deterioration in mechanical properties and decrease in anodizing quality) may occur in extrusion.

Shell thicknesses and grain sizes in the billets affect the extrudability and wastage rates. If the grain sizes are above the desired values, it can be difficult to extrude and increase the energy cost and mold cost. Also it increases the waste per billet with changing the extrudability rate. The quality of billet is increased by means of the control of this interfacial solidification which is the most critical stage of the process.

The following parameters should be checked for the control of solidification

a) Movement of the liquid metal in the graphite area
b) Liquid-Solid phase ratio
c) Temperature
d) Cooling water control
e) Grain thinner

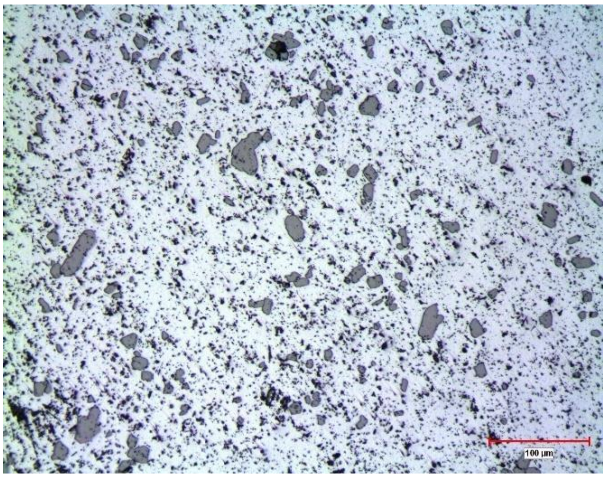
There is no metric specified for these specified parameters. As a result of the visual controls of the billet surface or the microstructure analysis of the billet is carried out.

The analysis of microstructure, shell thickness and the grain size have been obtained by using CLEMEX Vision Lite (Version 8.0) in the scope of the this thesis.

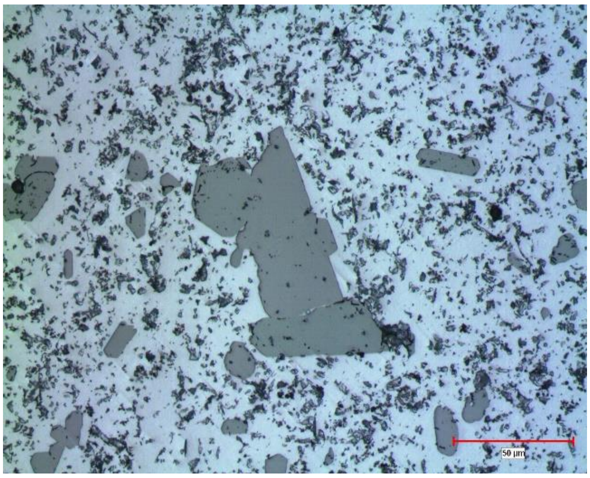
3.2.1. Grain Thinner Feature and Usage Practice

The grain thinner is one of the main parameters in determining the grain size of the produced material as is known. Although there are different types of AlTiB currently used in aluminium billet casting, the most used is the Al_5Ti_1B alloy.

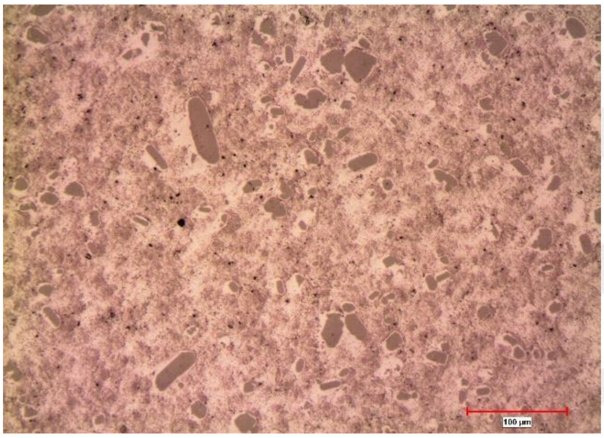
AlTiB can contain unwanted non-metallic salts in its structure due to raw materials used in production. Also there are two main factors which used to determine the quality of a grain thinner. These are Al_3Ti and TiB_2 intermetallics. The grain thinner which is expected to presence of Al_3Ti particles that is not exceeding 50 microns and the homogeneous dispersion is the non-agglomerated and TiB_2 precipitate. Al_3Ti particles which exceeding 50 microns dissolve in the liquid metal decrease the performance of the grain thinner. In this study, two different thinning materials were used and the microstructure were obtained. These microstructure are given in Figure 3.2.



1. Product (50x)



1. Product(100x)

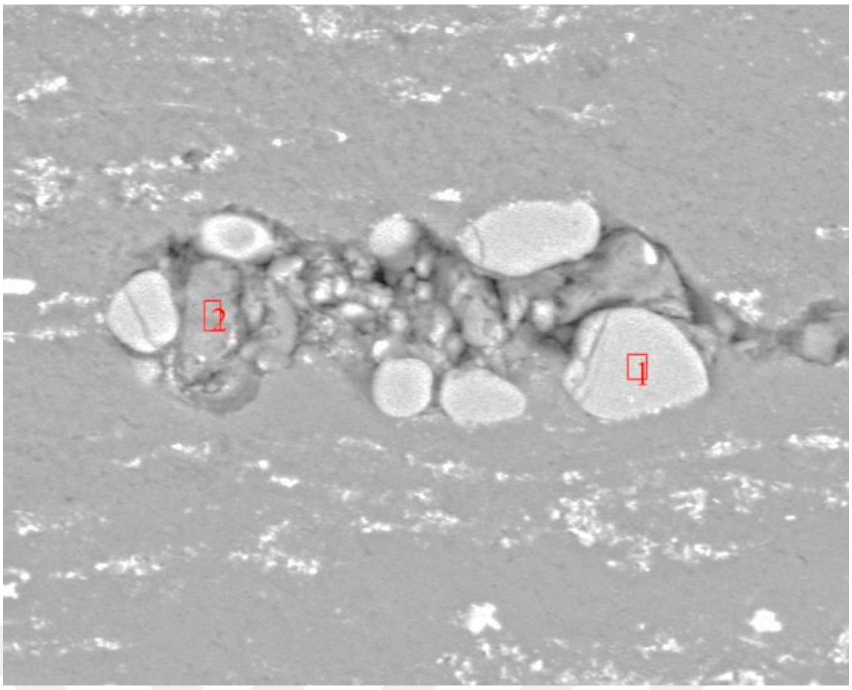


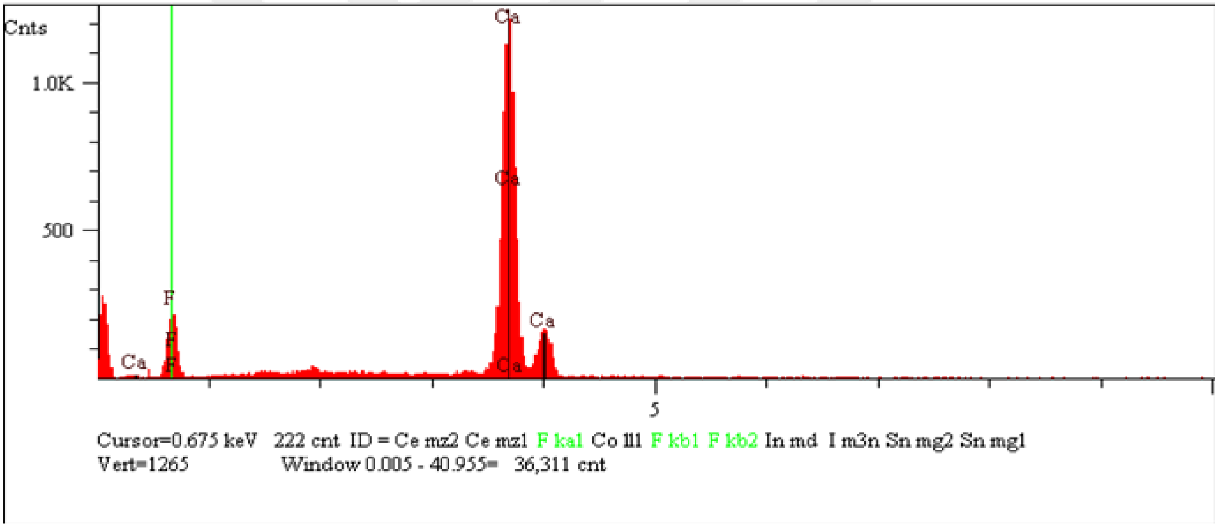
2. Product(50x)

2. Product(100x)

Figure 3.2. Microstructures of different AlTiB grain thinners. a-b) 1. Product, c-d) 2. Product

Figure 3.2 shows two different thinning microstructures. Coarse Al_3Ti particles were detected in both materials. In addition, agglomerated TiB_2 particles are also noticeable. There is a little pollution in the structure. The phases of Ca and K salts were also observed in SEM analysis. The electron microscope image (SEM) and EDS results of this study are given in Figure 3.3.

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Cursor=0.675 keV 222 cnt ID = Ce mz2 Ce mz1 F ka1 Co lll F kb1 F kb2 In md I m3n Sn mg2 Sn mg1
Vert=1265 Window 0.005 - 40.955= 36,311 cnt

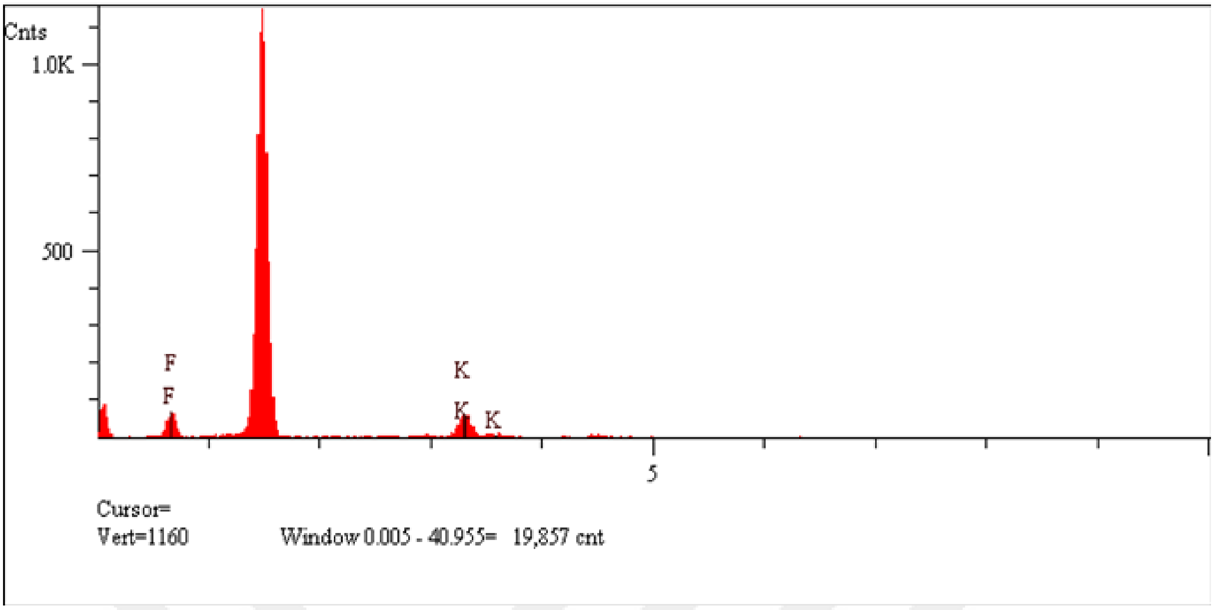


Figure 3.3. Image and EDS results of Ca and K fluoride salts seen in 2.Product

In the light of these results, it was evaluated that it would be appropriate to carry out an improvement study on grain thinner.

It is considered that the place of use exist grain thinner and feeding system are not suitable as a result of observation with grain thiner feeding technique. However, it has become compulsory to work in the current casting line design in this way. Considering the placement of 3 different melting furnaces used, this feeding has become mandatory from an optimum distance. In addition the motor has been redesigned for higher speeds and the billet quality has been improved with increasing the function of thinner.

3.2.2. Liquid Metal Heights, Temperature Measurements and Thimble Designs on Casting Table

The control of the liquid metal height is of great importance in terms of the surface to be obtained and the thickness of the shell in the HOTTOP casting technique. A typical HOTTOP casting system design is given in Figure 3.4.

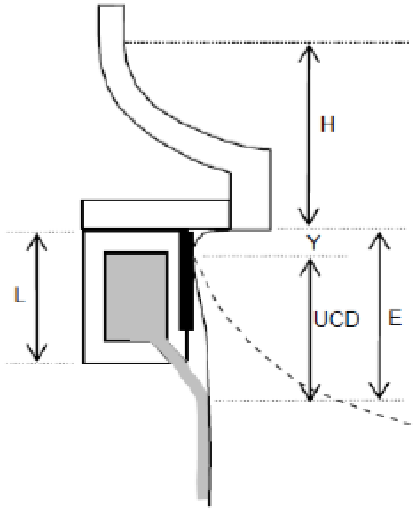


Figure 3.4. Mold design of a typical HOTTOP casting system

As shown in Figure 3.4; H: the height of the liquid metal in the table and the mold, E: the distance from the mold to the solidification point meniscus, UCD: the distance from the point where the liquid metal begins to solidify on the graphite ring, to the meniscus.

Many approaches can be applied in HOTTOP formwork systems. However, the important thing is to keep the level of liquid metal at the table and inside the mold constant and to keep it stable during casting. These parameters are important in the improvement of the surface quality of the billet and especially in the regulation of the distance of the shell thickness. However, the biggest disadvantage of the HOTTOP system is that a boundary layer cannot be formed on the graphite ring with the help of the air gas mixture used in the Airslip or Airglide methods.

Its observed that the liquid metal does not remain constant throughout the casting during examining for the behaviour of the liquid metal height. The control system of liquid metal height has not been used in Zahit Aluminium. Therefore adjusting of the liquid metal height is shaped according to the skill and experience of the operator. The height or fluctuation of the level of the liquid metal directly affects the temperature of the liquid metal in the table and accordingly the casting temperature.

The temperature with different diameters was carried out and the solidification time and curves were obtained in order to observe the change of the temperature of the liquid metal on the table. The results of this study are given in Figure 3.5.

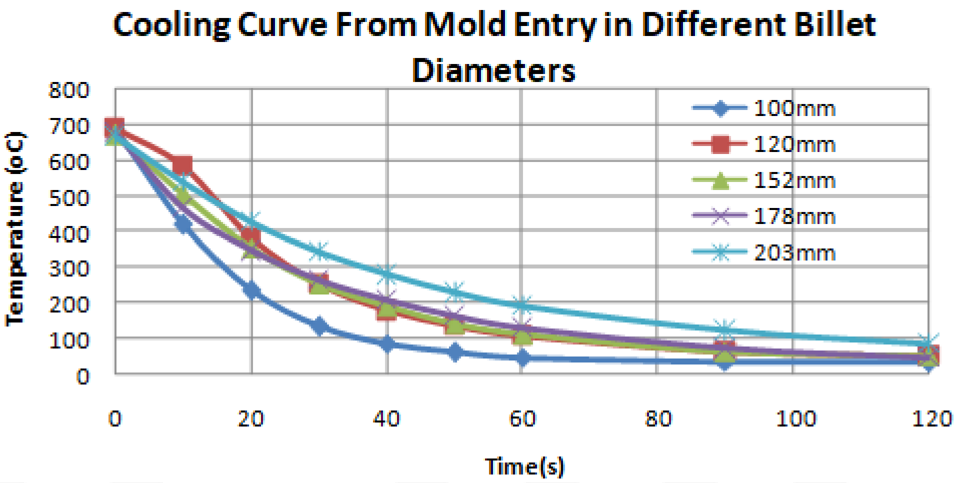


Figure 3.5. Solidification curves obtained for different diameters. (Zahit Aluminium, 2019)

The results achieved are meaningful depending on the diameter. Since the solidification of the smaller diameter billet will be faster, the time of returning the liquid metal to the solid was shorter. The achievement of this study is to review the casting speeds according to these solidification curves and to investigate the applicability of different practices. In order to examine the solidification in more detail, the region of the first 20 seconds is drawn again graphically and the hardening times of the billets are examined. Detailed results are given in Figure 3.6.

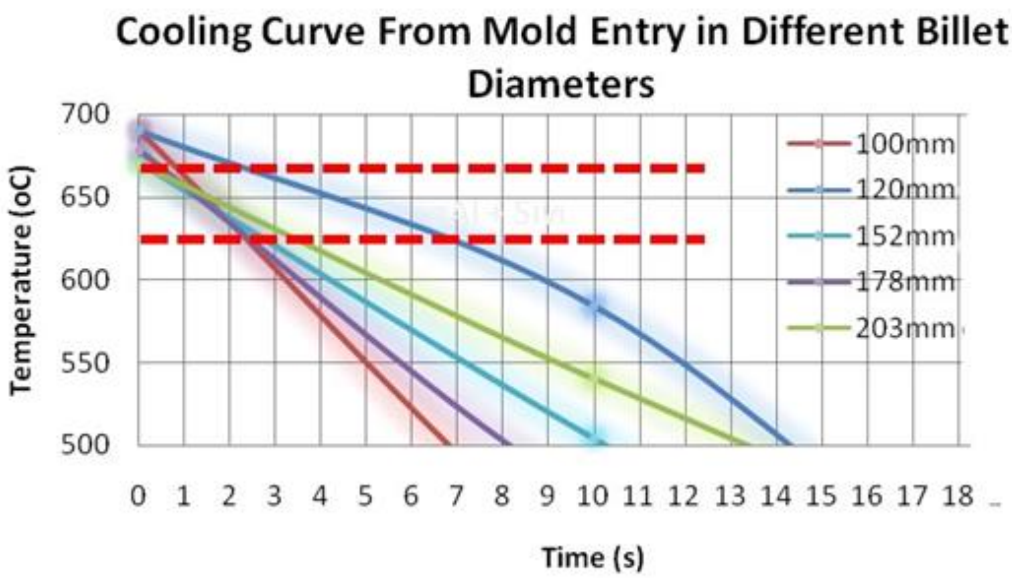


Figure 3.6. Solidification state in the first 20 seconds. (Zahit Aluminium, 2019)

The different thimble desingns were also studied to control of the liquid metal in the mold. 8 inch (203 mm) billets were emphasized in pilot experiments. Because there is an optimization problem due to the solidification distance from outer surface of the billet to center of the billet in the large diameters billet such as 8 inch.

One of the main causes of this irregular surface appearance formed around the billet is the casting temperature and liquid metal flow movements occurring in the mold wall.

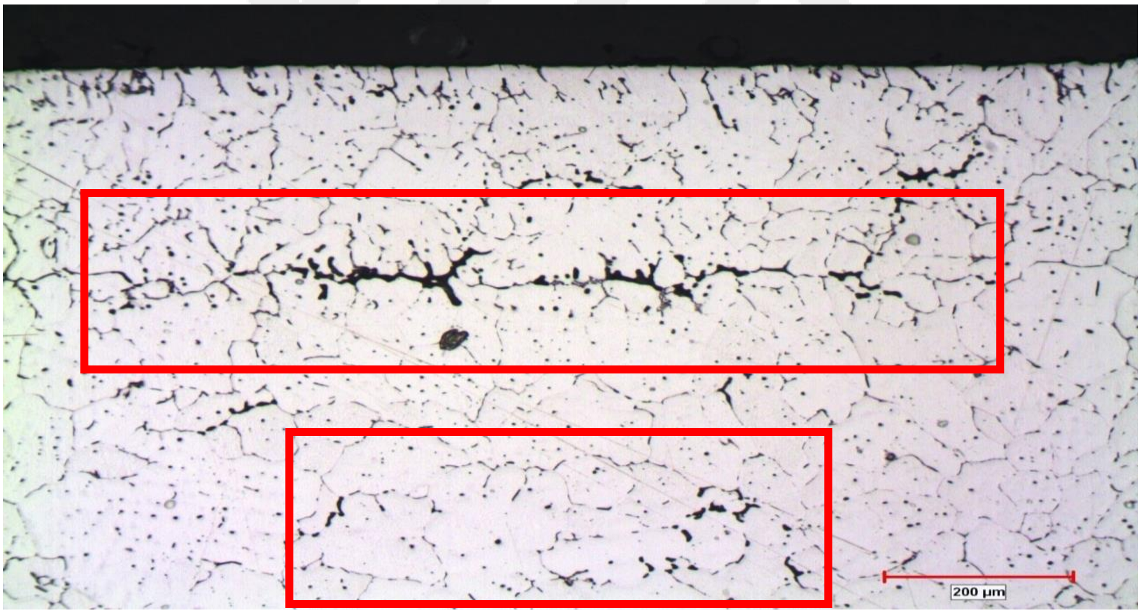
It is desirable that the water flow be regular in the molds which are used on the casting table around the mold. It was observed that water flows are given in Figure 3.7 during controls were performed on the table.

Figure 3.7. Water flow around the molds used on the casting table (Zahit Aluminium, 2019)

The water flow rate play a critial role to regulation of the solidification point. Its preferred that the water flow rate is controlled with digital counters by numerical expression in the billet casting systems. The controls have been performed by two main systems called single pump and double pump in the current system. This means that control ranges are provided in a wide spectrum. The temperature and content of the water are also important in the characteristic of solidification apart from water flow rate. Although the water cooling system is found suitable for the current casting, it is necessary to make significant improvements in the level of water pollution. It is thought that the water system used is constantly contaminated and the Ca and Mg contents vary depending on the time Because it was observed that the changes in the color of the water. The amount of solid in the water, or the high concentration of hard metals, directly affects the surface quality and thickness of the billet. For this reason, the filtering system has been revised.

Water pressure and its even distribution is a very important parameter during casting If there are blockages in the water holes and ducts in each mold, they should be cleaned.

Some experiments have been performed in the pump systems which are used in cooling in order to control the cooling behavior of the liquid metal. Microstructures of the casting in this context are given in Figure 3.8. The changes belongs to microstructure have been examined after changing of single pump and double pump.

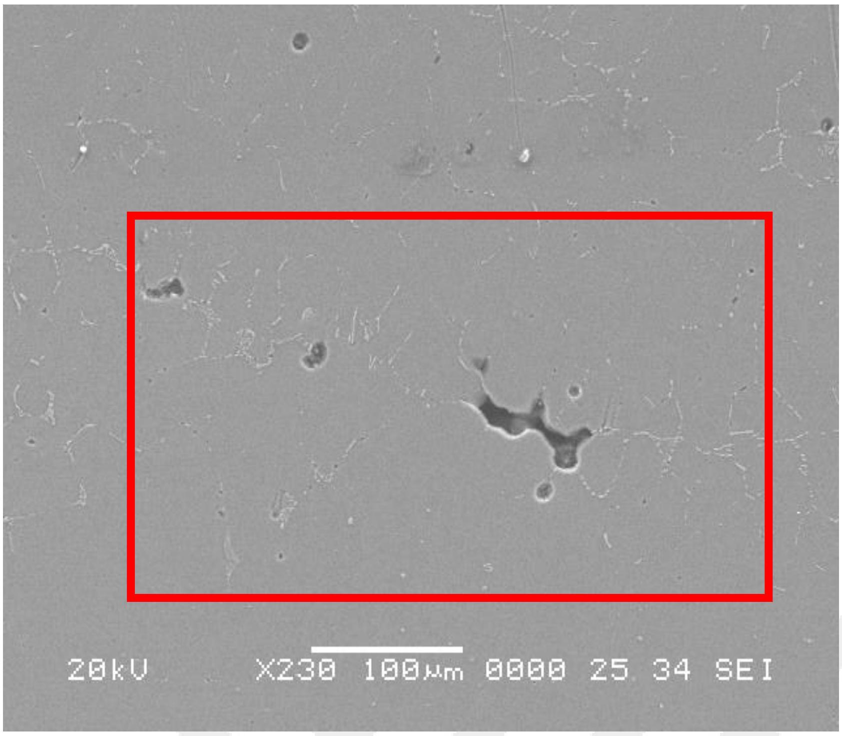


(a) Billet produced with the use of double pumps(Scale 100x)

(b) Billet produced using a single pump

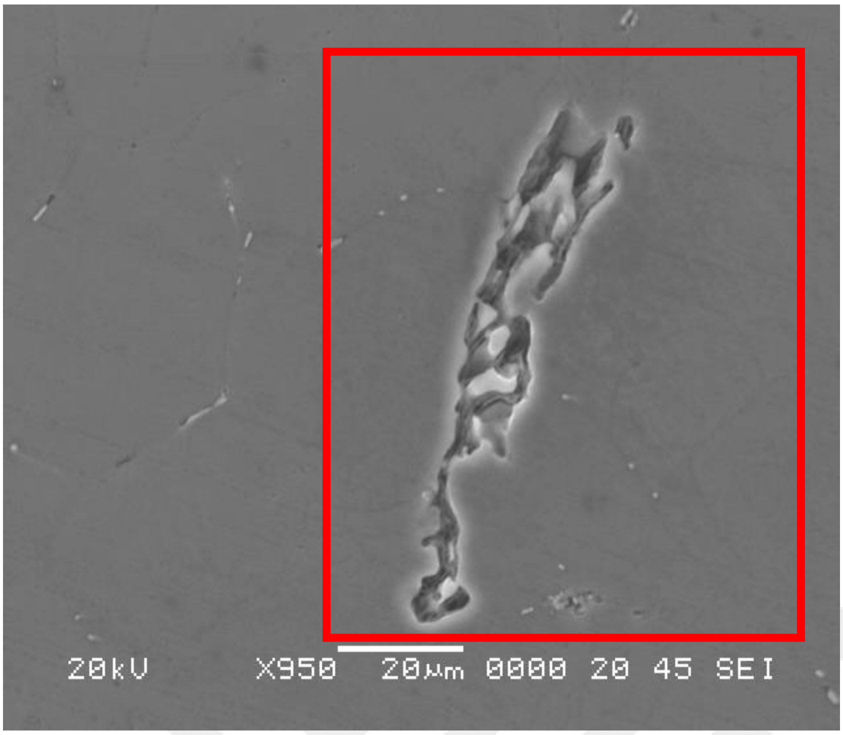
Figure 3.8. a) Double pump, b) Single pump. Microstructure of a billet produced by using double pump and single pump and with casting temperature controls.(Scale 100x)

Microporosities or early melting points seen under the surface are seen in the structure. For a more detailed analysis, Scanning Electron Microscope(SEM) study was performed. Although some of the systems seen are cavity structures, they are likely to be in AlMgO spinel phase. Images of SEM study are given in Figure 3.9.



Edge area early melting area

Edge area early melting area



Edge region AlMgO spinel phase formation

Figure 3.9. Pictures of the examination of voids in the sub-surface region

As can be seen from Figure 3.9, while the early melting points remain in the structure, the unwanted AlMgO spinel phase is also encountered. Its considered that the coarse oxide layers on the casting path somehow progress in the form of a thin film and mix into the billet microstructure.

It was examined that some region in the solidification interface and then different interpretations have been obtained. There is a schematic view of the mold interface in the Figure3.10.

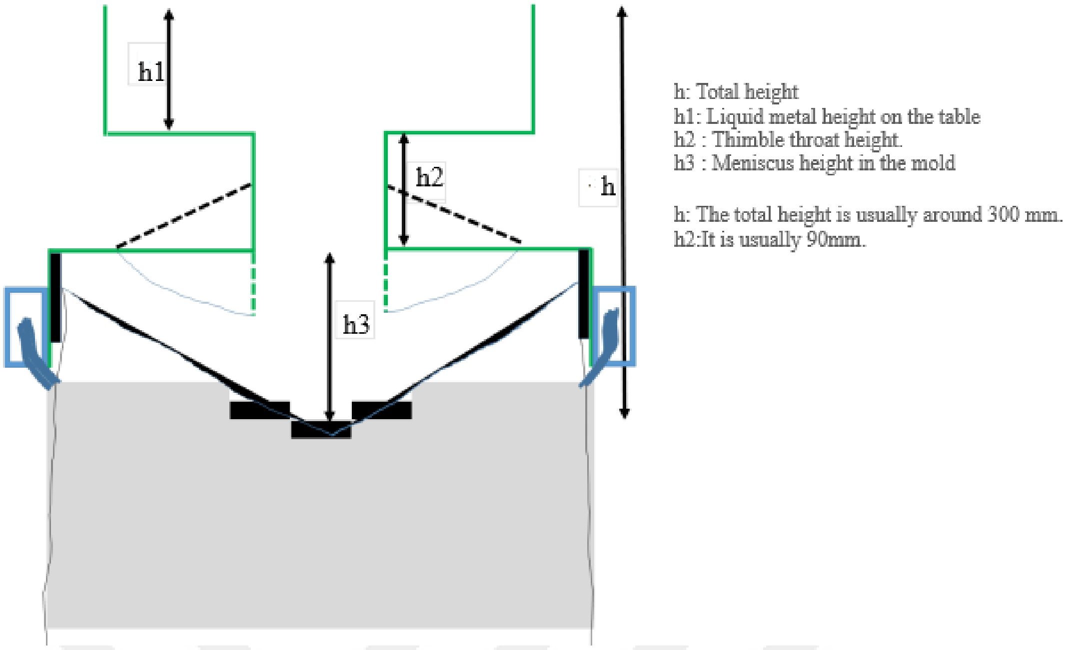
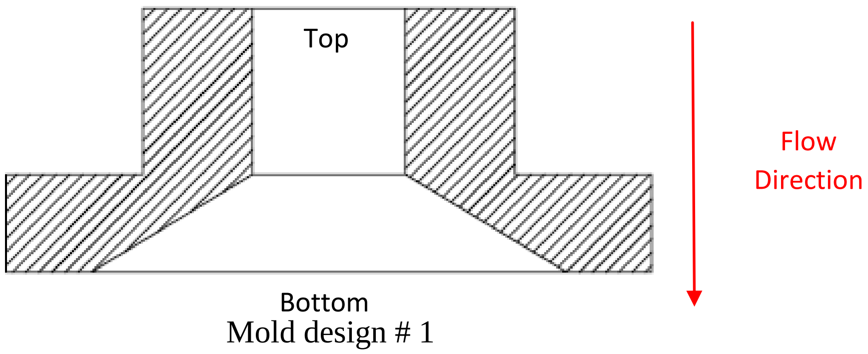
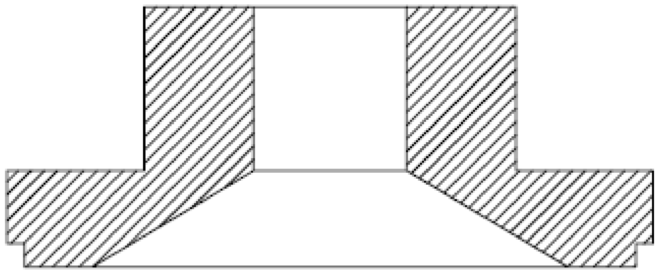


Figure 3.10. Solidification interface

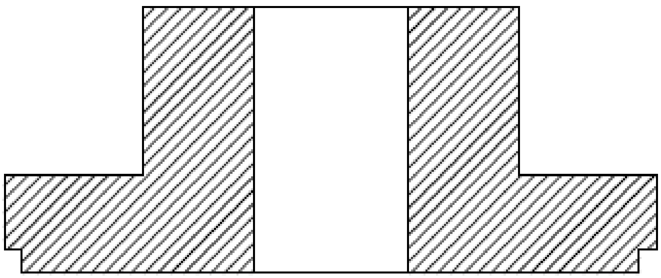
As clearly seen in Figure 3.10, the part called h3 is indicated as the height of the meniscus in the billet. Based on the thesis that if the liquid metal in h3 is controlled, a better result will be obtained in billet quality, studies have been carried out on different mold designs. It is the outline of the ceramic mold drawn in green color in Figure 3.10. Different shapes of this ceramic mold were studied in my project. Pictures of different mold designs are given in Figure 3.11.



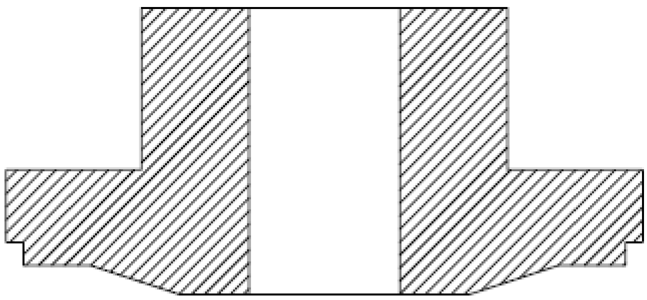
Mold design # 1



Mold design # 2



Mold design # 3



Mold design # 4

Figure 3.11. Mold designs. In the molds in the figure, the liquid metal movement is from top to bottom.

Design were performed on the lower part of the mold. It was changed on the distance L in molds and the meniscus distance which is the volume of the liquid metal in the mold was tried to be kept equal. While the interaction between the distance of L and the graphite was controlled, the distance meniscus in the mold 3 was narrowed and the distance of L was maximized. In the mold 4, the meniscus distance has been reduced and the distance L is kept close to the mold 3.

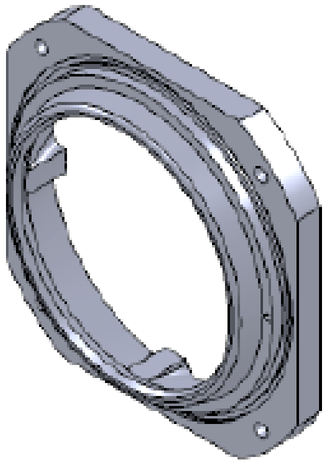
As it can be understood from the designs, the volume of liquid metal in the mold is seen as the main subject of the research. Liquid metal temperature, casting speed, water cooling temperature were kept constant in all simulation studies.

The main reason for examining the liquid volume is to control the pressure inside the mold. The pressure inside the mold will directly affect the property of the surface during the solidification of the material and consequently the formation of the crust.

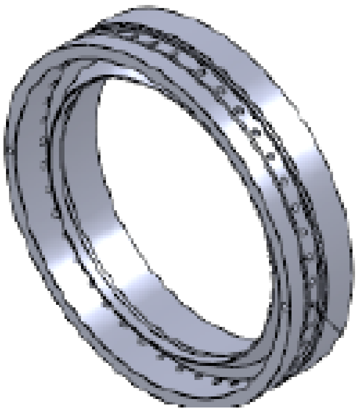
Also its considered that the pressure inside the mold aid to liquid metal flow which contacts the graphite ring walls.

A cross-sectional image of the Hot-Top Casting die was marked at critical points on the die, and similarities in die design are given on this schematic image.

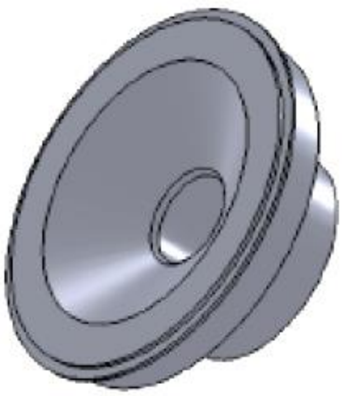
The technical drawing of the mold that working on is given in Figure 3.12.



(a)



(b)



(c)

Figure 3.12. The main parts of the mold (a) Aluminium case, (b) Aluminium case where the graphite ring sits and water flow, (c) ceramic thimble

The changes were made to the ceramic thimble, aluminium part with water flow and graphite ring in the design study. However the graphite height and the number of pores with water flow were kept constant in the simulation. Different designs are given in Figure 3.11.

Mold designs that will be input to simulation were also finalized and ProCast software was used.

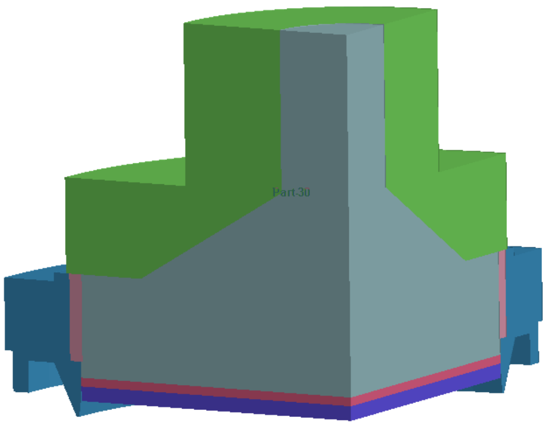
Parameters used in simulation; Some process metrics are also provided, such as casting start temperature, casting speed and cooling water temperature. With this metric, they are fixed in each simulation and do not change as the pattern changes.

It was decided to use the ProCast program perform the simulation with the molds designed for billet casting. This is because the ProCast program can simulate the die casting process of the Direct Cooled Casting Process. Technical drawing and 3D design information of 4 newly designed molds were created.

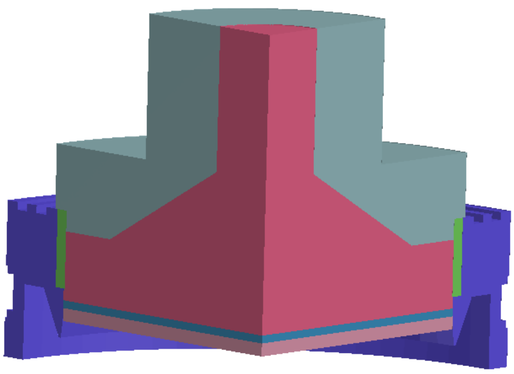
3 main topics were examined in the simulation studies,

a) Solid-Liquid Ratio
b) The movement of liquid aluminium in the mold
c) Temperature change in solidification

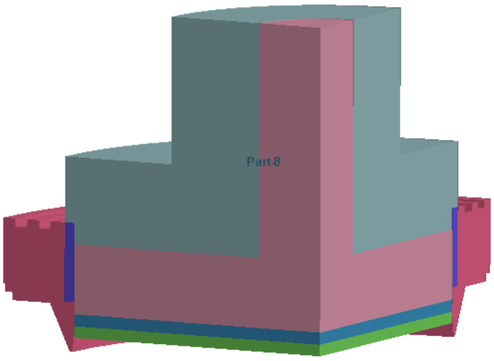
The simulation images of the molds examined are given in Figure 3.13.



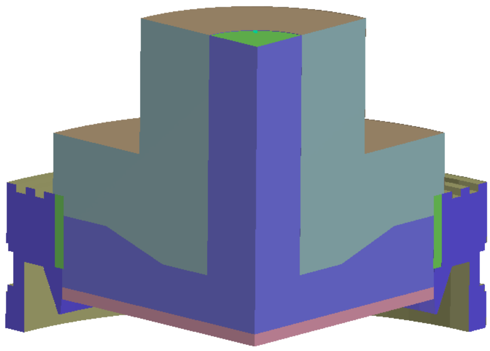
(a) Mold design # 1



(b) Mold design # 2



(c) Mold design # 3



(d) Mold design # 4

Figure 3.13. Cross-sectional images of the molds taken in simulation

3.2.3. Topics in Simulation

3.2.3.1. Solid-Liquid Rate

With the solidification solidifying on the graphite ring;

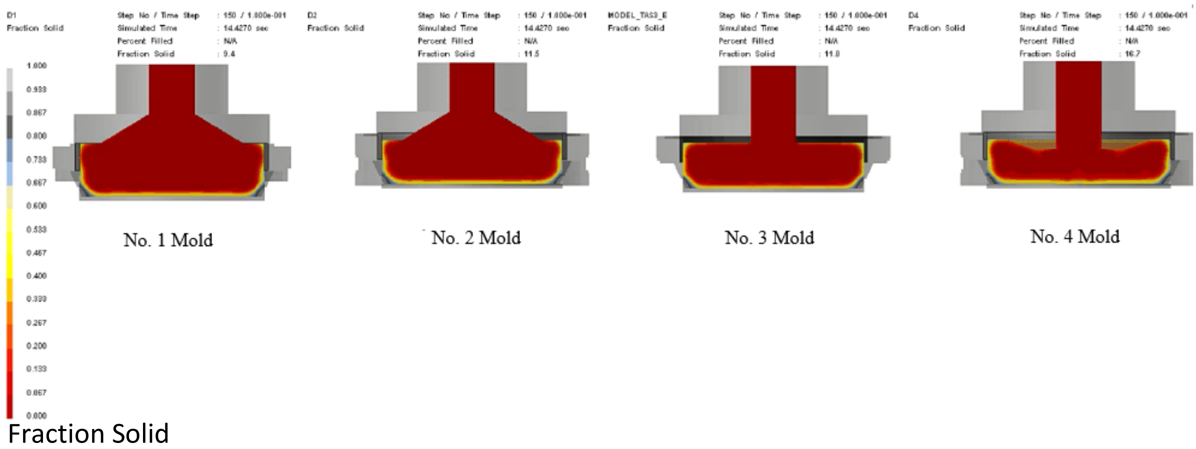


Figure 3.14. Investigation of Solid-Liquid ratio

The image of a moment that was stopped in 14.42 seconds of the video that appeared in the simulation study is given in Figure 3.14. When the simulation was finished, the liquid aluminium has started to solidify in mold. Therefore there is a misleading result towards the end of the video. The reason why liquid aluminium cannot be continuously fed to the mold in the simulation.

However the images of the first moment of the simulation are more meaningful. The highest solid fraction was obtained in the mold 4 in this study is given above. The main difference of mold 4 is that the end of the ceramic thimble piece is extended downward in the mold. It was aimed to increase the liquid pressure in the mold while it was designing this mold. It has been found that it is easier to solidify the mold with increasing pressure. Obtaining different amount of solids at the same casting speeds can also be shown as a sign that the height of meniscus given as h3 is decreasing. It can be an advantage in alloys with a wide range of liquids-solidus. However the study of direct chill(DC) has not been performed for existing alloys, it has not been given spesifically alloy.

3.2.3.2. The Movement of Liquid Aluminium in The Mold

It is necessary to try to avoid turbulence in the fluid movement to be created in the mold. There should be a stable flow in the mold as much as possible. While a stable flow allows solidification to be more controlled, it can form an oxide network, since oxide formation is triggered in liquid aluminium during turbulence, and it can be trapped in the billet with solidification. Oxides can cause significant quality defects on the surface in extrusion and especially in anodizing process. Also it should not be forgotten that after the ceramic filter application on the runner, there is no cleaning application to the liquid aluminium. Therefore all kinds of negative situtaions go directly to billet. Simulation results of fluid movement of the 4 different designs are given in Figure 3.15.

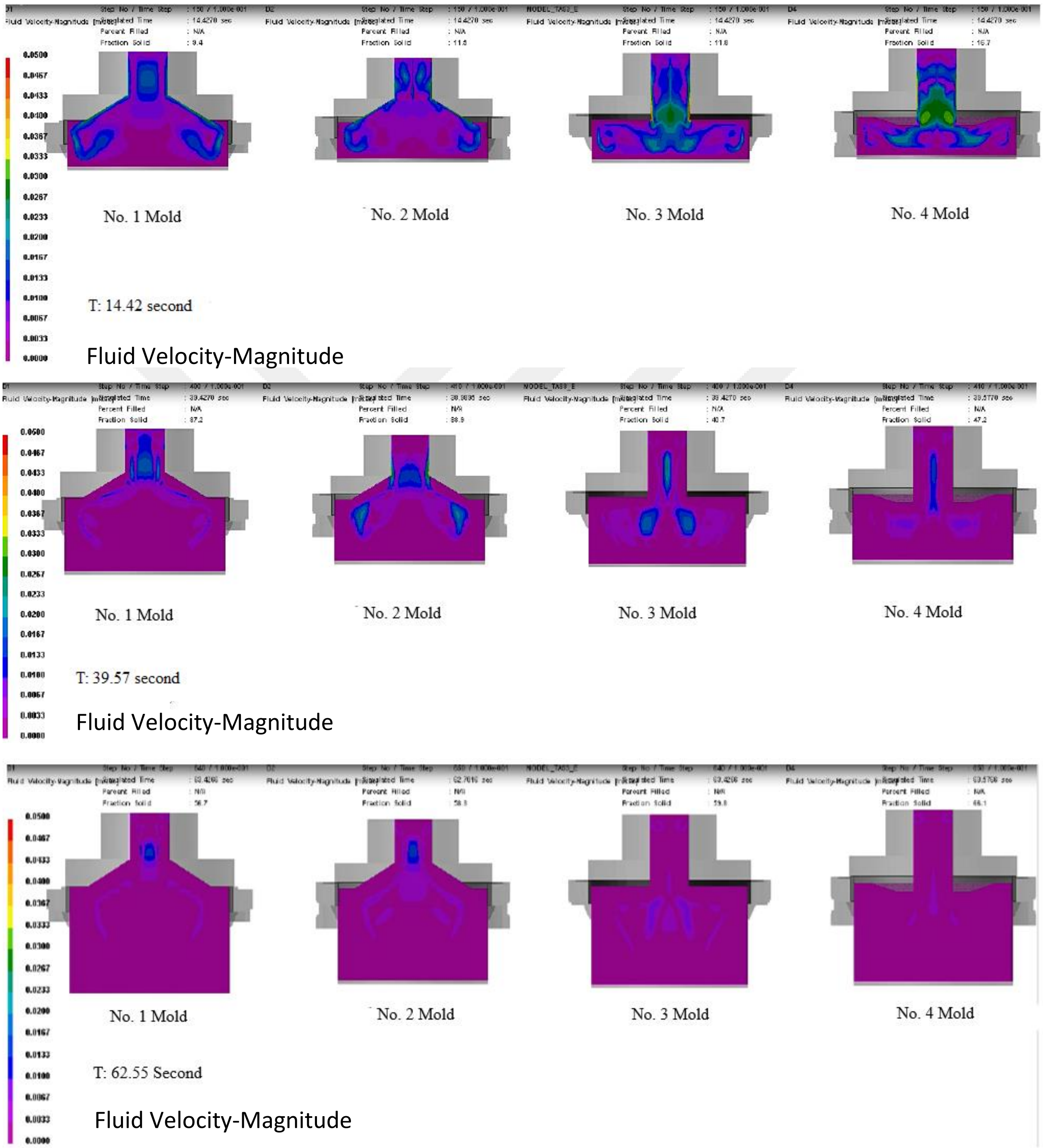


Figure 3.15. Fluid movement in the mold at different time periods

Aggressive turbulences are observed in almost all molds in the early stages of solidification. The turbulence movement is generally severe in the throat part where liquid aluminium enters the mold, while its intensity decreases towards the graphite ring. It is clearly seen that the turbulance intensity decreases especially in the mold 4 with advancing time. Temperature change and temperature formation on graphite are given in Figure 3.15. Also the turbulence in the mold was almost zeroed at 62 second. This is a desirable approach. Turbulent flow was observed in the mold at all levels in other mold approaches.

3.2.3.3. Temperature Change in Solidification

The temperatures were checked during solidification in Figure 3.16. Especially the temperature was tried to be measured in the graphite region.

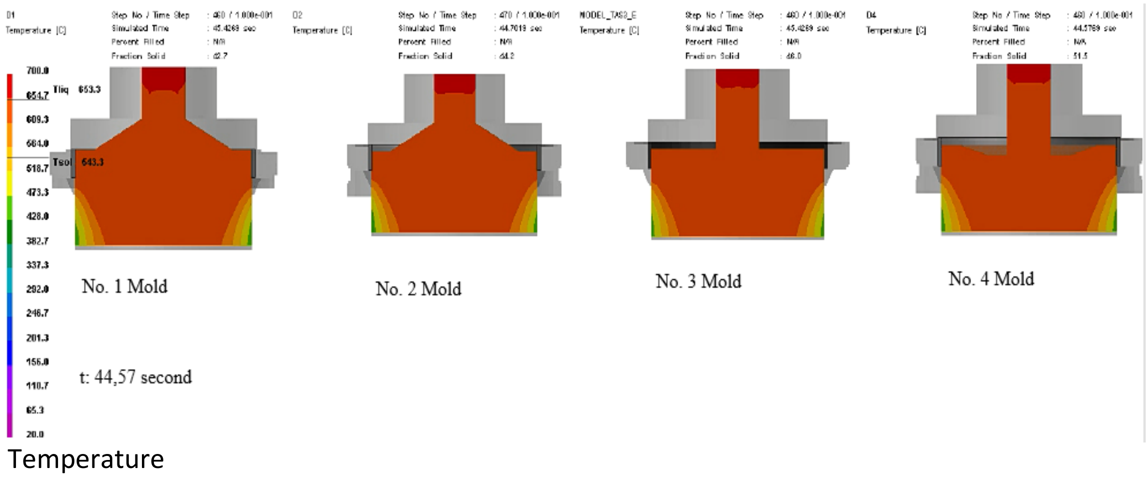


Figure 3.16. Temperature change and temperature formation on graphite

The temperature of 543˚C was determined in the graphite region in the measurements by using software. Especially the temperature change of the billet in the central region was controlled in the temperature simulation. It is thought that the temperature of the center line is high (high meniscus line) may be a sign of the risk of hot tearing. The study has not been performed about on. Although the billet protect the temperature of center line of the much longer distance. Also its observed that the solidification was occured in a shorter period with decreasing temperature in the mold 4.

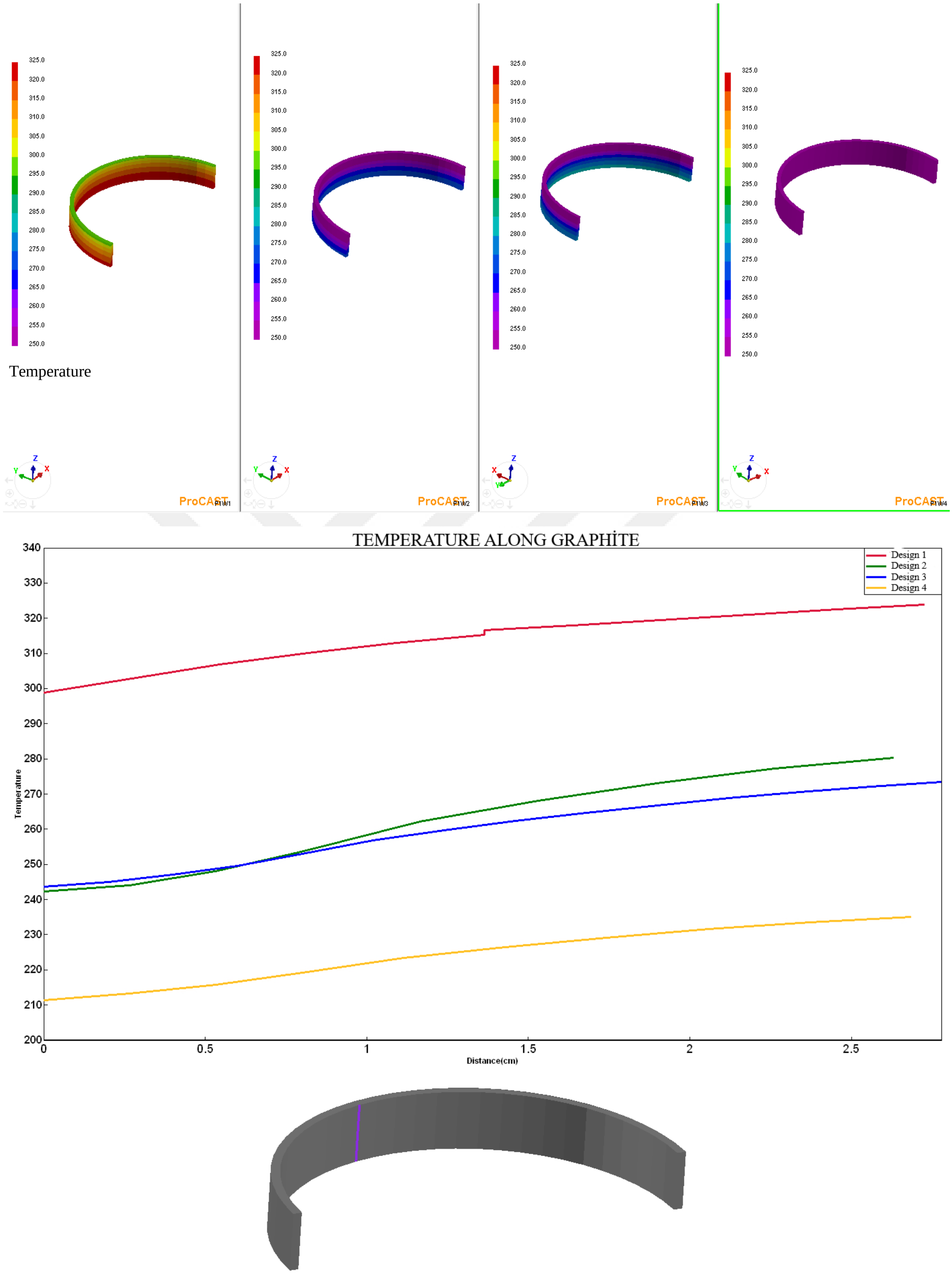


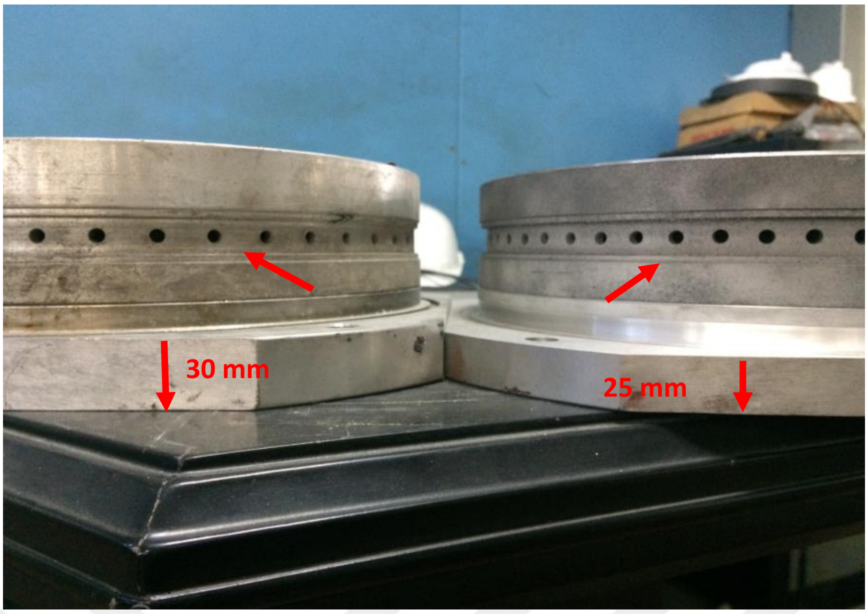
Figure 3.17. Temperature measurements of mold designs

Temperature measurements in the graphites of the mold designed in the simulation program are given in Figure 3.17.. Its observed that the temperature decreased by about 300 degrees in the mold 1 while it decreased to around 210˚C in the mold 4. So it can be seen that cooling has significantly increased.

Billet casting simulations were carried out with the Direct Cooled Casting Process using the ProCast program. The solid-liquid ratio that should be considered in billet casting, the movement of liquid aluminium in the mold and the temperature change parameters in solidification are taken into account in these simulation studies. The highest solid fraction and the least turbulence in the solidification process, decreasing temperature with the solidification in a much shorter time was obtained in the mold 4. Then the prototype of mold 4 was designed and producted in Zahit Aluminium.

Its has been planned to carry out prototype mold casting experiments. The activities to be carried out within this scope are listed below.

1 Mounting the molds to different points on the casting table,
2 The parameters which was obtained by using simulation program are tested in the real environment and then the producing the first billet,
3 The billets that come out; chemical composition, physical, surface and metallurgical tests
   3.1 Chemical Composition: Testing of chemical composition with spectral analyzer
   3.2 Physical Measurements: Diameter fit, ovality, longitudinal curvature, longitudinal buckling,
   3.3 Surface Measurements: Center crack, horizontal and vertical scrapings on the surface and visual inspection of cold folding
   3.4 Metallurgical Investigations: Determination of the shell thickness, condition of the sediment structure, determination of the grain size along the billet section (these measurements will be carried out in the continuation of the homogenization processes applied after casting.)
4 Comparison of the measurement results with the results obtained from the simulation program (this comparison will be done only on surface errors.)



(a) (b)

Figure 3.18. (a) Old mold (b) Regenerated mold (Zahit Aluminium, 2019)

The casting molds was mounted on the casting table. Then the height of the molds has been reduced from 30 mm to 25 cm for increasing solidification speed. Its mean that the molds met faster the liquid metal.

Its estimated that the simulation results by using Procast program, 4 different types of thimble designs were made by controlling the height of the meniscus (the height of the liquid metal).

(a) (b) (c) (d)

Figure 3.19. Thimble designs produced (Zahit Aluminium, 2019)

Four different mold designs were studied as seen Figure 3.19. The the distance between the narrowest and widest distance of the mold called only L of the concave thimble design was changed.

There are many parameters (negative-positive direction) that affect the nature of solidification. Liquid metal temperature and cooling rate are the two most important parameters in solidification. The water that provides solidification does not directly contact the material. Solidification takes place indirectly through the graphite ring in the mold.

The surface quality of the final product billet material directly affects the extrusion section. In the billet, the thickness of the shell region formed during solidification is a region called diffusion zone. During the solidification, depending on the diffusion rates of the elements in the alloy at the solidification temperature, various intermetallics and / or precipitates form in the shell region and the sediment structure is formed. Taking into account all these undesirable situations, the shape of the molds produced as a result of simulation studies is shown below.

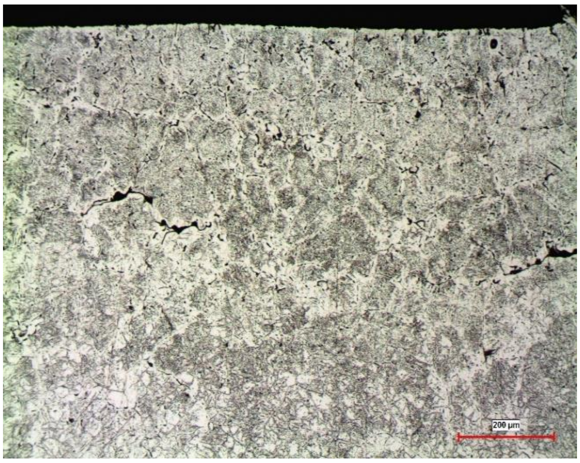
Assembly of 4 thimbles to molds

Figure 3.20. Casting mold and thimble assembly (Zahit Aluminium, 2019)

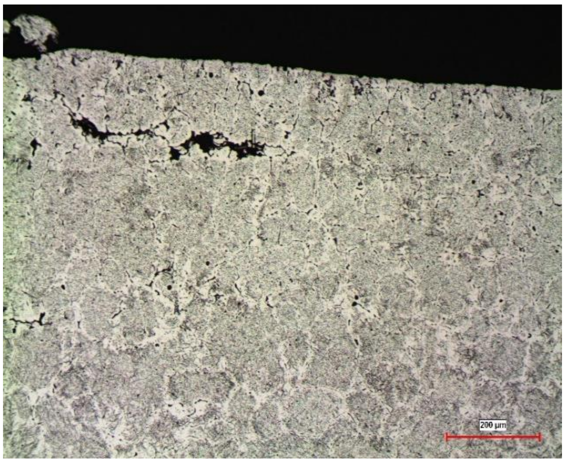
Pre-casting table preparation processes and optimization of casting temperatures were carried out as shown Figure 3.20.

It was observed that the highest quality billet occurred in the convex mold in casting experiments by placing molds with different geometries on the mold table.

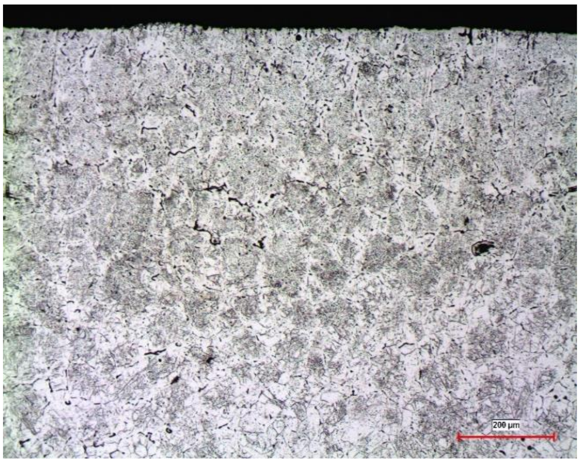
The various intermetallics and/or precipitates are formed depending on the diffusion rates of the elements in the alloy at the solidification temperature in the shell region during solidification which causes the formation of crust on the billet surface. The shell thickness should not exceed 150-200 μm for a billet and should not contain oxide, impurity or very coarse intermetallic structure. The quality problems in extrusion, profile defects in the profile, deterioration in their mechanical properties and a decrease in anodizing quality when thicker crust is obtained. Its observed that billet surface crust thickness is around 400-800 μm was obtained in the previous casting. Especially the early melting areas formed in grain boundary and micro voids was seen in the shell region and under the shell region. The presence of spaces or premature melting in the billet is undesirable condition in terms of extrusion. (This situation is clearly seen on the surface and central microstructure images.) These errors, which occur during casting, can become larger in size and turn from micro space to macro space in the homogenization and subsequent billet preheating process. It may cause problems such as bubble formation on the profile surface, especially during extrusion. For this reason, it is a situation that needs to be resolved. Apart from this, there is a dense intermetallic structure in the surface microstructure. The inhomogeneous early melting areas are clearly seen in Figure 3.21 when the microstructures at the surface and center of the castings were examined before simulation studies.



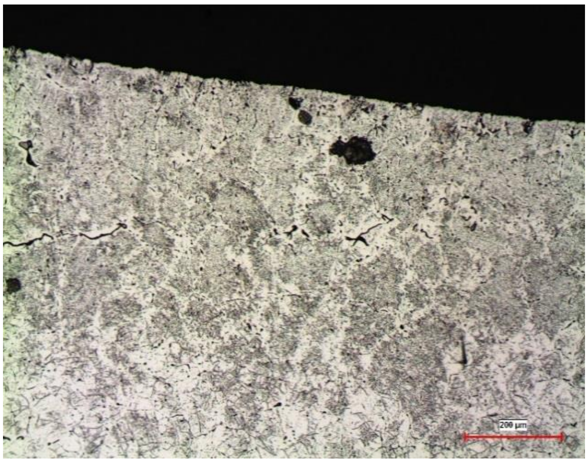
Billet sample no 8852-Surface(Scale 50x)



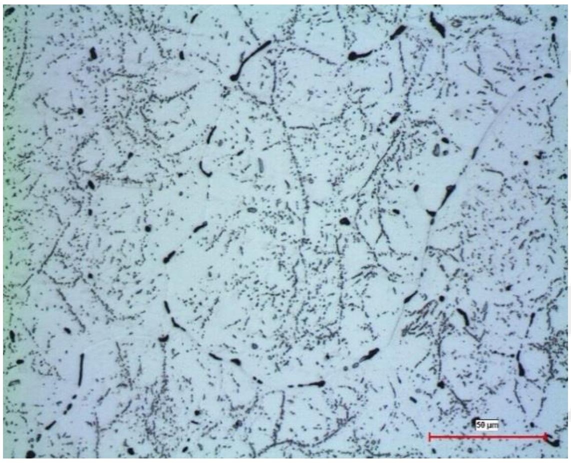
Billet sample no 8890-Surface(Scale 50x)



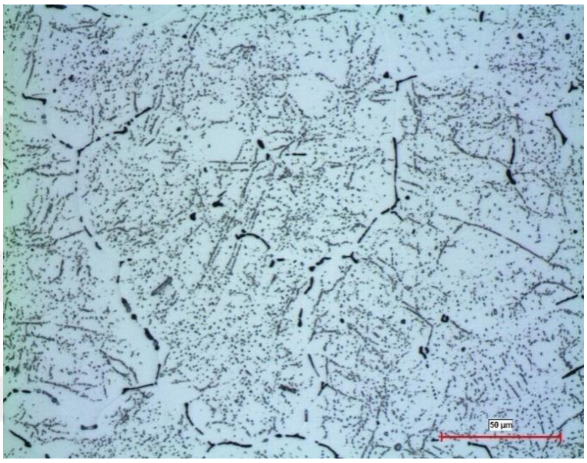
Billet sample no 8902-Surface(Scale 50x)



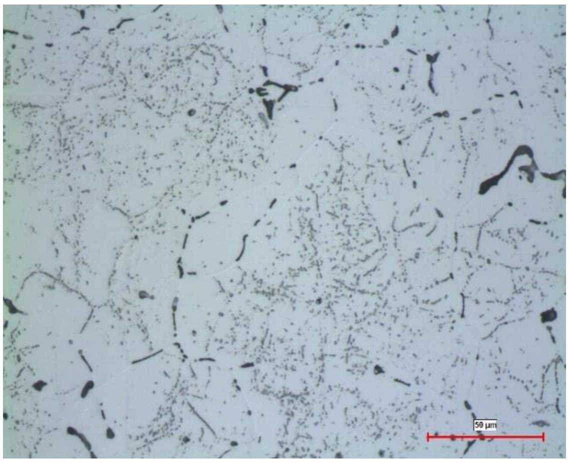
Billet sample no 8922-Surface(Scale 50x)



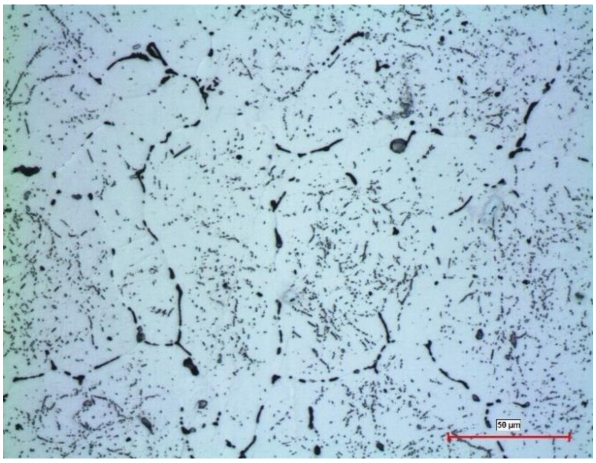
Billet sample no 8852-Center(Scale 100x)



Billet sample no 8890-Center(Scale 100x)



Billet sample no 8902-Center(Scale 100x)



Billet sample no 8922-Center(Scale 100x)

Figure 3.21. Billet microstructures before simulation study

Table 3.1. The parameters of the casting we made before the trial mold simulation. (Zahit Aluminium, 2019)

AT THE BEGINNING OF CASTING

FURNANCE TEMPERATURE (°C)	CASTING TABLE TEMPERATURE (°C)	COOLING TOWER WATER TEMPERATURE (°C)	CASTING TABLE WATER TEMPERATURE (°C)
720	690	29	37

DURING THE CASTING

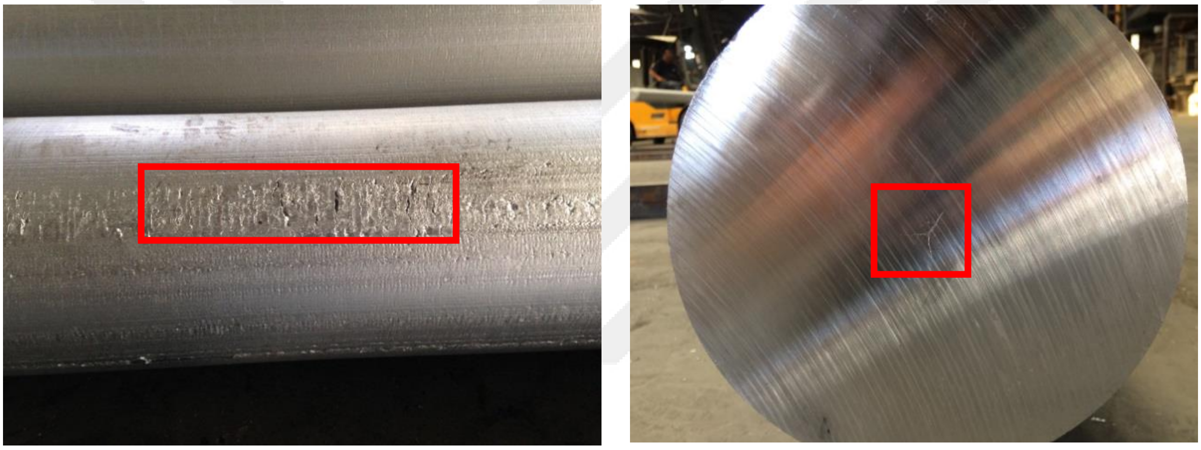
SPEED			
CASTING STARTING SPEED (mm / min)	CASTING SPEED (mm / min)	ALTiB FEED SPEED (mm / min)	DEGAZER ROTATION SPEED (Rpm)
Slow -110	113	50	1.74

CHANGES DURING CASTING			
CASTING LENGTH (mm)	CASTING SPEED (mm/min)	CASTING TABLE TEMPERATURE(°C)	CASTING TABLE WATER TEMPERATURE(°C)
1000	111	680	29
2000	112	686	30.3
3000	113	688	33,6
4000	113	690	36.8
5000	113	690	37
end	113	-	37

AT THE END OF CASTING

RESULT		
CASTING LENGTH (mm)	NUMBER OF BILLET	EXPLANATION
6200 => CAST 6000 => CUT	32	
* Casting was started and the speed of 111mm/min was reached in about 1 minute. * The surface is not very nice and has a central crack * Concave spilled with thimble		
PRE-CAST CHEMICAL ANALYSIS VALUES		

Si	0.39	Mg	0.19
Fe	0.26	Zn	0.07
Cu	0.03	Ti	0.005
Mn	0.012	Al	98.9
CHEMICAL ANALYSIS VALUES AFTER CASTING			
Si	0.39	Mg	0.576
Fe	0.228	Zn	0.027
Cu	0.03	Ti	0.017
Mn	0.024	Al	98.6



(a) (b)

Figure 3.22. Initially, defects on the (a)billet surface and (b)center crack (Zahit Aluminium, 2019)

Chemical analysis processes were performed before and after casting. Therefore the desired chemical composition was reached. The Shell thickness were obtained 800-1000 microns in addition to the many cracks in the surface and center area were obtained. The particle sizes that will be given comparatively in the next section are in the range of 250-300 microns.

The convex mold obtained as a result of the simulation detailed earlier was used for improving micro structure. Casting parameters made with this mold are given in the table below.

Table 3.2. Trial Casting parameters with convex mold. (Zahit Aluminium, 2019)

AT THE BEGINNING OF CASTING

TEMPERATURE			
FURNANCE TEMPERATURE (°C)	CASTING TABLE TEMPERATURE (°C)	COOLING TOWER WATER TEMPERATURE(°C)	CASTING TABLE WATER TEMPERATURE (°C)
708	670	23	29

DURING CASTING

SPEED			
CASTING START SPEED (mm/min)	CASTING SPEED (mm/ min)	ALTiB FEED SPEED (mm/ min)	DEGASSER ROTATION SPEED (Rpm)
Slow -114	123	50	1.75

CHANGES DURING CASTING			
CASTING LENGTH (mm)	CASTING SPEED (mm/min)	CASTING TABLE TEMPERATURE(°C)	CASTING TABLE WATER TEMPERATURE(°C)
1000	118	665	23.6
2000	120	669	28.1
3000	123	670	28.2
4000	123	672	28.7
5000	123	672	29.3
End	123	-	29.3

AT THE END OF CASTING

RESULT		
CASTING LENGTH (mm)	CASTING LENGTH (mm)	CASTING LENGTH (mm)
6200 => Cast 6000 => Cut	32	

* Casting started very slowly, 114 mm/min speed was reached in about 1min.

* Temperatures and casting conditions have been optimized.

* The surface is beautiful and the center crack was not observed.

* Newly made convex casting with thimble.

PRE-CAST CHEMICAL ANALYSIS VALUES			
Si	0.40	Mg	0.13
Fe	0.28	Zn	0.03
Cu	0.04	Ti	0.004
Mn	0.009	Al	98.9

CHEMICAL ANALYSIS VALUES AFTER CASTING

Si	0.39	Mg	0.54
Fe	0.25	Zn	0.03
Cu	0.04	Ti	0.020
Mn	0.009	Al	98.6

Table 3.3. Trial casting parameters made with convex mold (Zahit Aluminium, 2019)

AT THE BEGINNING OF CASTING

TEMPERATURE			
FURNANCE TEMPERATURE (°C)	FURNANCE TEMPERATURE (°C)	FURNANCE TEMPERATURE (°C)	FURNANCE TEMPERATURE (°C)
715	680	18	21

DURING CASTING

SPEED			
CASTING START SPEED (mm/min)	CASTING START SPEED (mm/min)	CASTING START SPEED (mm/min)	CASTING START SPEED (mm/min)
Slow -112	120	50	1.74

CHANGES DURING CASTING			
CASTING LENGTH (mm)	CASTING LENGTH (mm)	CASTING LENGTH (mm)	CASTING LENGTH (mm)
1000	115	680	18.1
2000	117	683	24.2
3000	120	683	27.3
4000	120	684	27.3
5000	120	685	28.1
End	120	-	28.3

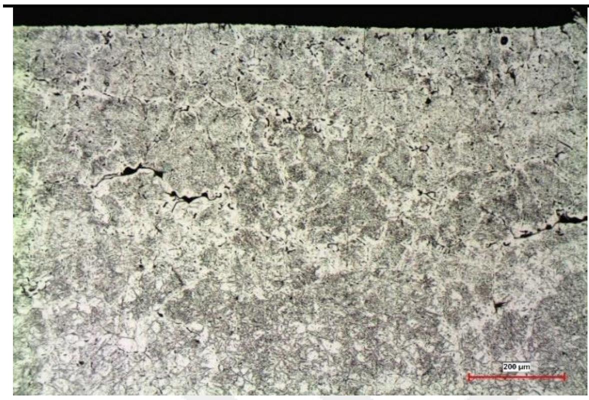
AT THE END OF CASTING

RESULT			
CASTING LENGTH (mm)	CASTING LENGTH (mm)	CASTING LENGTH (mm)	
6300 => Cast 6100 => Cut	32		
* Casting started very slowly, 112 mm/min speed was reached in about 1min. * Temperatures and casting conditions have been optimized. * The surface is beautiful and the center crack was not observed. * Newly made convex casting with thimble			
PRE-CAST CHEMICAL ANALYSIS VALUES			
Si	0.42	Mg	0.21
Fe	0.25	Zn	0.04
Cu	0.03	Ti	0.005
Mn	0.01	Al	98.9

CHEMICAL ANALYSIS VALUES AFTER CASTING

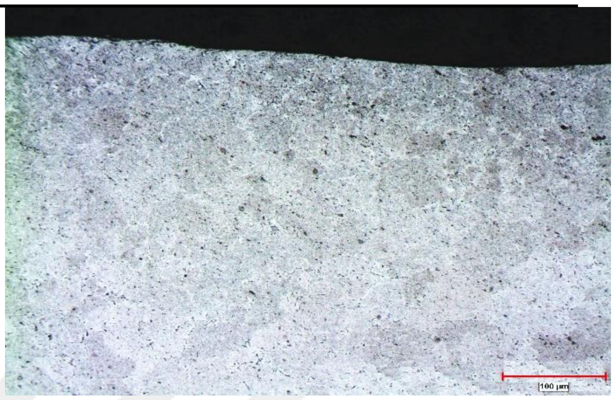
Si	0.42	Mg	0.56
Fe	0.22	Zn	0.04
Cu	0.03	Ti	0.015
Mn	0.01	Al	98.6

4. CONCLUSION AND DISCUSSION



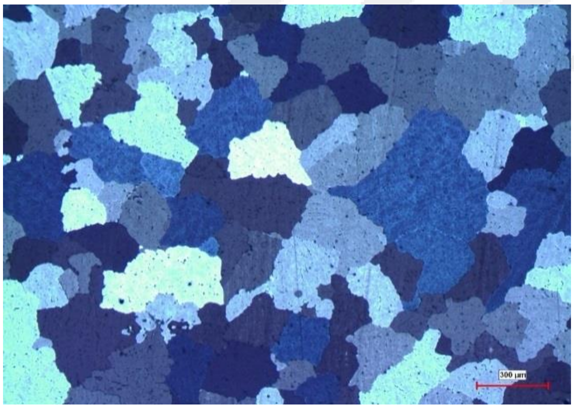
Casting No. 8852: 6951 alloy 203mm

Initial situation: shell thickness 800 microns and sub-surface melting areas are available.(Scale 50x)



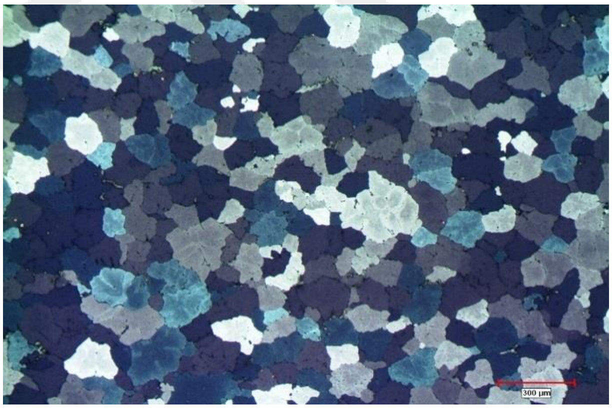
Casting no 9251: 6951 alloy 203mm

Final situation: shell thickness has decreased to 180 microns and sub-surface melting areas have disappeared. (Scale 50x)



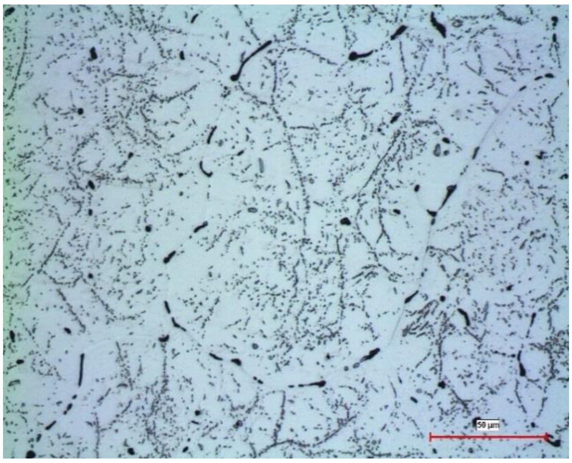
Casting No. 8852: 6951 alloy 203mm

Initial situation: Grain size between 250-300 microns(Scale 100x)

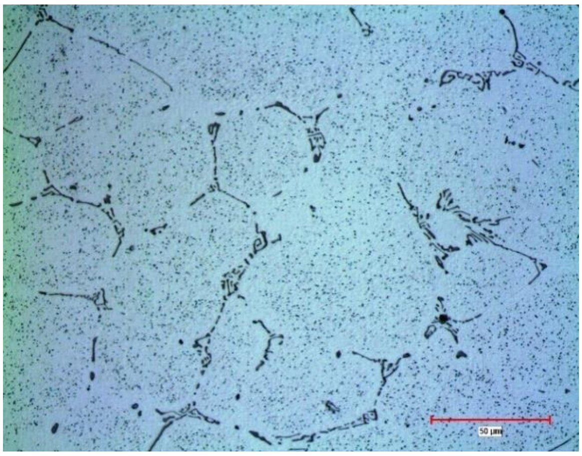


Casting no 9251: 6951 alloy

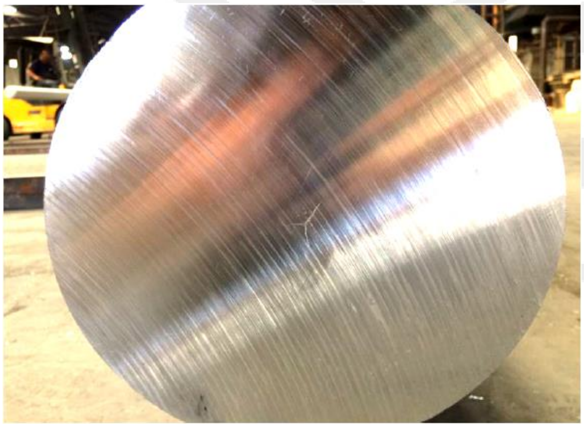
Final situation: Grain size between 150-200 microns(Scale 50x)



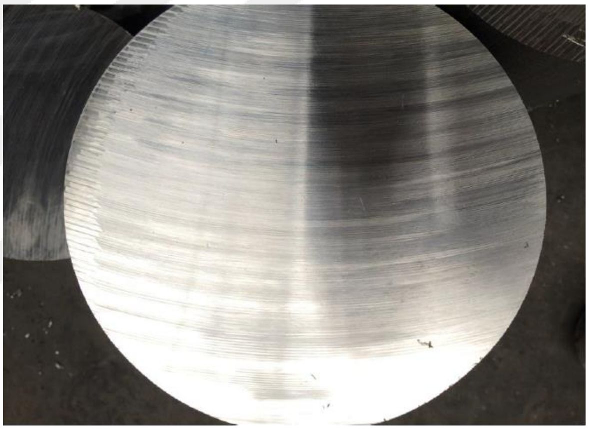
Casting No. 8852: central microstructure view(Scale 100x)



Casting No. 9251: Even in the central region, early melting areas are almost non-existent. Intra-grain and boundary precipitate formation is normal.(Scale 200x)



Original casting 203mm initial situation: center crack



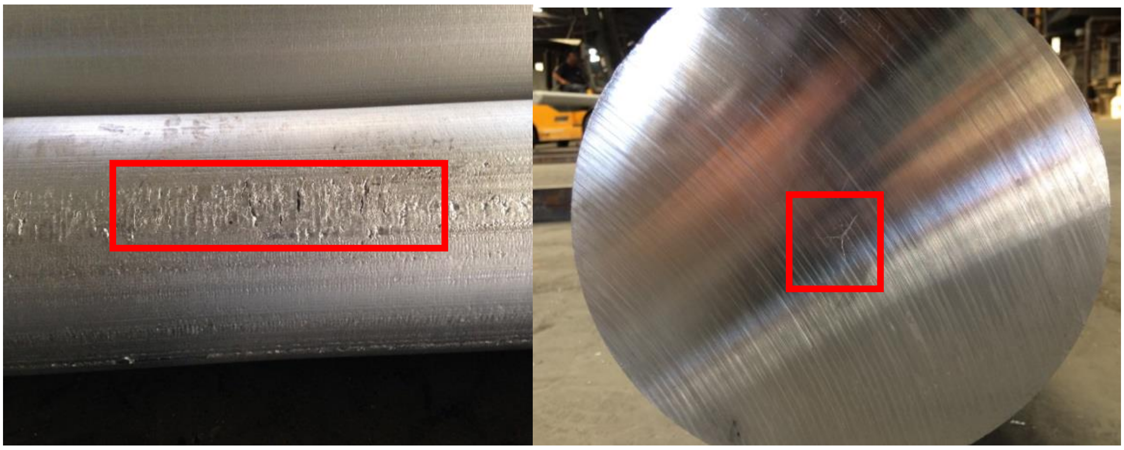
Original cast 203mm final condition: center crack-free billet

Figure 4.1. Latest status comparison

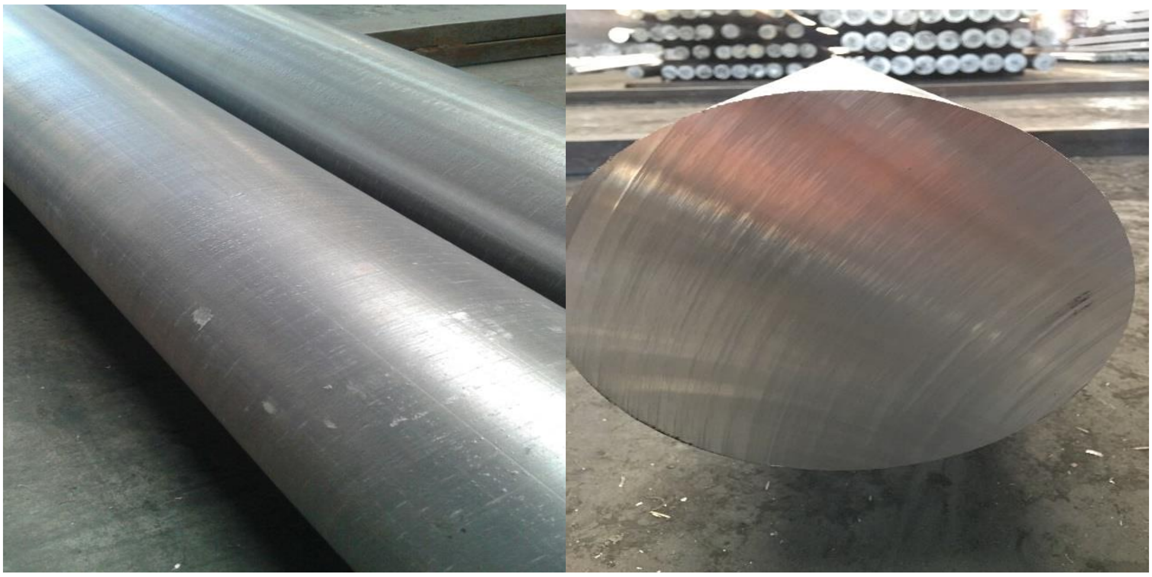
When the microstructure results were examined and the thickness of shell was measured. It was obtained that shell layer thickness was about 400-800 µm. Also its observed that the presence of cavity regions due to early melting with the micro cavities on the surface and centers of the billet during casting experiments with the existing mold before the project. Unfortunately such defects cannot be eliminated with the homogenization process, and even these micro-size structures turn into macro size as a function of temperature. Therefore this situation causes to decrease quality such as bubble/surface roughness on the extrusion aluminium surfaces. In addition, the anodizing (surface treatment) capabilities of these productions decrease. The chemical analyzes of the billets obtained as a result of the studies conducted were compared. The chemical analysis of the billets before the thimble design and the casting experiments was performed with mold selected after the design were compared. Then its obtained that the chemical analysis is same for each case (before and after design).

It was determined that the shell layer thickness decreased from 400-800 μm to 180 microns. when microstructure results and shell thickness results were compared. It was determined that the particle sizes decrease from 250-300 microns to 150-200 microns. Also it was observed that the diffusion to the structure of the elements participating in the solidification occurs more homogeneously and the intermetallic deposits are reduced. In addition surface and center cracks were prevented by reducing the casting temperature, cooling tower temperature and increasing the casting speed. The main reason for this is that the solidification process is controllable with the geometry of the selected mold and the intermetallic precipitation decreases without the early melting areas.

Casting processes are optimized with constant casting speed. Surface and center microstructures of castings obtained in molds made before mold revision are shown in Figure 3.21. The fact that the chemical composition obtained before and after the design is very close to each other shows that the shell thickness and microstructure defects occurring in the billet directly form the basis for the quality billet production in the liquid metal height and the solidification process. The quality of billet in the casting experiments with the thimble geometry was obtained in the simulation studies by using the movement of the liquid metal which needed to control of the solidification, liquid-solid phase ratio and the temperature parameters is shown in Figure 4.2.



Initial situation



Final situation

Figure 4.2. Billet improvement comparison (Zahit Aluminium, 2019)

The casting experiments were carried out by using mold 4 which bark and cracks was minimized in the billet surface and center in the solidification processes of the molten liquid aluminium. The convex geometry mold was selected that has the highest solid fraction with the least turbulence which cause to center cracks in the solidification process. And then the simulation studies were completed this stage.

Real casting trials have been carried out by producing mold 4. The shell thickness of the poured billets has been reduced from 800 microns to 180 microns. The main reason for this is the reduction of the premature melting areas formed in the micro boundaries and grain boundaries inside and under the shell region during the solidification process in the new design. This situation was also observed in microstructure analysis. In addition, faster cooling of the outer surface from the mold geometry to the center prevented hot tears. When the parameters in two different castings are analyzed, in the 2nd casting, the furnace temperature was low, but the cooling tower temperature was reduced by around 30%. The casting speed has increased from 112 mm/min to 120 mm/min. The cracks of surface and center were prevented with improving casting pramaters and thinning in the thickness of the shell. Thererfore the better quality castings were performed.

Improvements of the extrusion processes of the castings are given in Table 4.1.

Table 4.1. Extrusion parameters; before and after optimization (Zahit Aluminium, 2019)

BEFORE OPTIMIZATION						
BILLET PREHEATING (°C)	MOLD NO	MOLD TEMPERATURE (°C)	SLEEVE TEMPERATURE (°C)	PROFILE NO	PROFILE OUTPUT TEMPERATURE (°C)	PROFILE SPEED (mm/s)
470-500	2508-Z16	430-440	410-420	2508	490-515	4-5.4
AFTER OPTIMIZATION						
BILLET PREHEATING (°C)	MOLD NO	MOLD TEMPERATURE (°C)	SLEEVE TEMPERATURE (°C)	PROFILE NO	PROFILE OUTPUT TEMPERATURE (°C)	PROFILE SPEED (mm/s)
470-490	2508-Z16	430-440	410-420	2508	490-515	5-6.5

The extrusion processes of the high quality billets obtained were examined. It has been observed that this quality of the billet decrease press preheat temperature and increase the profile drawing speed. The increasing of quality of the casting has contributed to the reduction of the shell thickness by preventing intermetallic deposits. Therefore it provided to decrease possible bubbles on the profile surfaces and increase the anodizing cababilities.

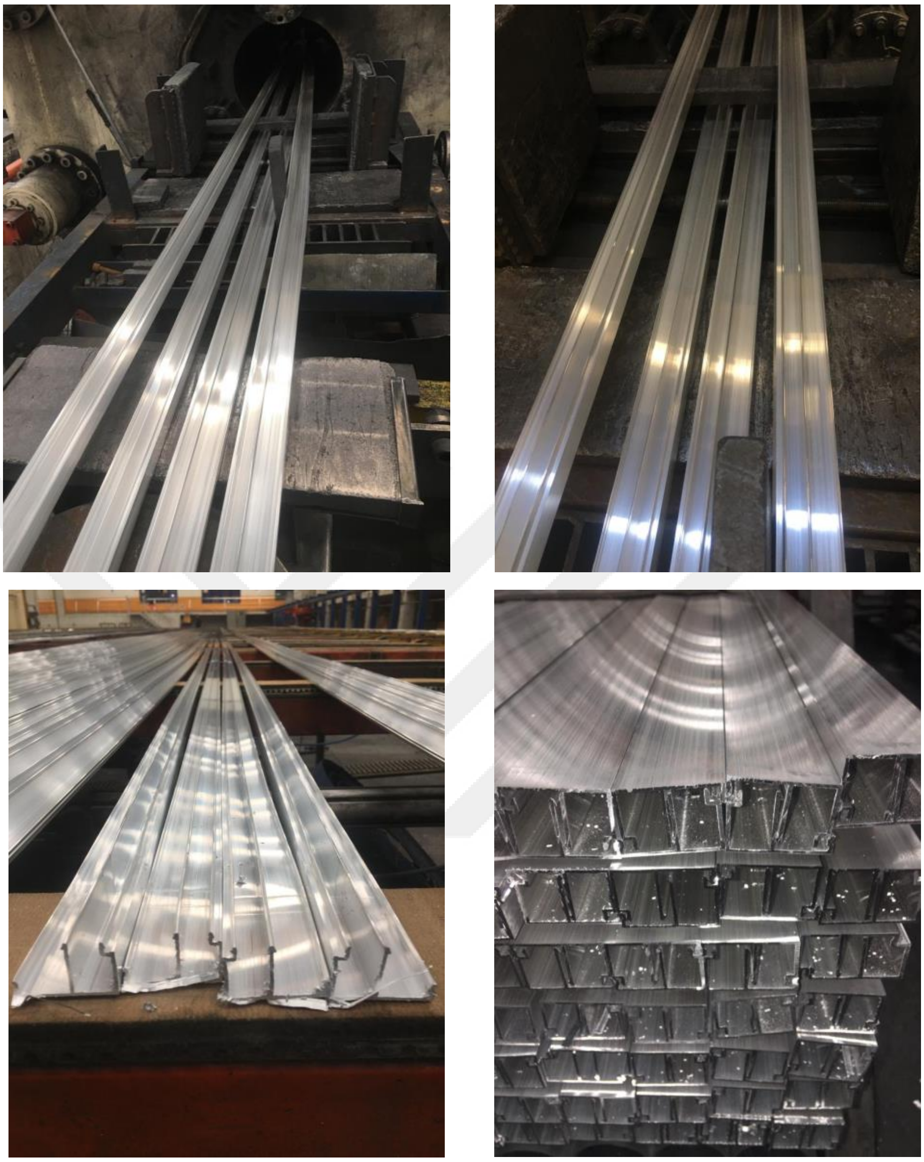


Figure 4.3. Profile Trials Achieved as a Result of Improvement (Zahit Aluminium, 2019)

The bubble faults, surface tears, etc. Faults were not observed and minimized in the extrusion profiles as a result of the improvement of the billets as seen Figure 4.3. Billet preheating temperature has slightly decreased in extrusion presses. Also its observed the profile speed increased. Finally the production speed increased and the billet wastage decrease asfter extrusion process because of decreasing of shell thickness in the billets.

REFERANCES

1. Turbalioğlu, K. and Y. Sun, *The improvement of the mechanical properties of AA 6063 Aluminium alloys produced by changing the continuous casting parameters.* Scientific Research and Essays, 2011. 6(13): p. 2832-2840.
2. William D. Callister, *Materials Science and Engineering.* 1982.
3. Onaran, K., *Malzeme Bilimi*.
4. TANRIÖVER, L., *AA5052/2024 alaşımlarının sürtünme karıştırma kaynağı yöntemiyle birleştirilebilirliğinin araştırılması/Investigation of the joinabilitiy of AA5052/2024 alloys by friction stir welding method.* 2008.
5. ASTM, *Standard Specification for Aluminium and Aluminium Alloys*, in *Designation B-221*.
6. Sun, Y., *Yaşlanabilir Alüminyum Alaşımlarının Aşınma Davranışları.* 1998.
7. HALICI, İ., *Etial-60(AA 6063) alüminyum alaşımında homejenizasyon uygulamasının düşük soğuk deformasyon-yeniden kristalleşme özelliklerine etkisi.* 1996.
8. SU, Ş., *2XXX Grubu Alaşımlarda Katı Eriyiğe Alma Sıcaklık ve Süresinin Yaşlanma Sonrası Özelliklere Etkileri.* 1988.
9. L.F., M., *Aluminium Alloys: Structure and Properties.* Dusaugey E., JIM 37, 452; 39, 484; 41, 438;42, 437., 1976.
10. Eraslan, Y., *Etial-60 Alasımında Döküm ve Homojenizasyon Uygulamalarının Ekstrüzyon Kabiliyetine Etkileri.* 1999.
11. Federation, A., *The Properties of Aluminium and its Alloys.* Broadwayhouse, Calthorpe Road, Birmingham., 1983.
12. Association, T.A., *International Alloy Designations and Chemical Composition Limits for Wrought Aluminium and Wrought Aluminium Alloys* 2009.
13. P., B., *JIMMA 26, 744.* 1976.
14. Barry W. G., H.R.W., *Current and New AA 6000 Series Extrusion Alloys, Proceedings of the Second International Aluminium Extrusion Technology Seminar.* 1977. Vol:1, 271-284.
15. Stefaniay V., G.A., Turmezey T., *Intermetallic Phases in the Aluminium Side-Corner of the AlFeSi Alloy System.* 1978. J. Matter. Sci. 22, 539-546.
16. Association, A. and A.E. Technology, *ET 84: Extrusion Productivity Through Automation : 3rd International Aluminium Extrusion Technology Seminar : Papers*.
17. Zoller V. H., R.A., *Metallkundliche Grundlagen der Leicht Pressbaren AlMgSi-Ligerungen.* Aluminium 51, 1965.

18. D., M., *High Extrudability Alloys in the 6000 Series.* Light Metal Age, 1984.
19. Backerud L., K.E., Tamminen J., *Solidification Characteristics of Aluminium Alloys.* 1986. Volume:1 Wrought Alloys.
20. D., A., *Alüminyum,.* ETIBANK Alüminyum Isletmesi Müessesi Egitim Müdürlügü Tercüme Yayınları, 1986. No: 716-A-214: p. 258.
21. DASCILAR, B., *"Farkli Ekstrüzyon Hizlarinda Ekstrüze Edilmiş Aa6063 Alüminyum Alasimlarinin Yüzey Ve Korozyon Özelliklerinin İncelenmesi"*. 2006.
22. R. Nadella, D.G.E., Q. Du, L. Katgerman,, *Macrosegregation in direct-chill casting of aluminium alloys,.* 2008. Volume 53, Issue 3,: p. Pages 421-480,.
23. B.C.H. Venneker, L.K., *Modelling Issues In Macrosegragation Predictions In Direct Chill Castings.* Journal of Light Metals 2, 2002: p. 149-159.
24. Campbell , J., *Casting.* Butterworth-Heinemann Ltd., 1991. Oxford, England.
25. Çigdem M., E.Y., *The Effect of Mould lubrication on the Surface and Subsurface Quality of Semicontinuously D.C. Cast Al-6063 Alloy Billets.* Practical Metallography, 1997. Vol:36, 11 Germany.
26. J Van de Langkruis, W.H.K., C.M. Sellars, M.R. van der Winden, S. Van der Zwaag, *The Effect of and Precipitates in A Homogenized AA 6063 Alloys On The Hot Deformability and the Peak Hardness.* Materials Science and Engineering A299, 2001. 105-115.
27. N.C.W. Kuijpers, I.T., S. Van Der Zwaag, *Phase Transformation of b-AlFeSi to a-Al(FeMn)Si phase during homogenization of 6xxx Al Alloys.* Delft University of Technology, 2003.
28. Ulucak, T. *Metallurgy of AA 6063 aluminium alloy*. Available from: http://www.angelfire.com/al/Aluminium/6063metalurji.htm.
29. Cyrener E., K.M., *Neue Hütte.* 1985. 30, 4, 130.
30. Beatty, E.C., *How the properties and microstructure of 6063 alloy extrusions depend upon fabrication practice*, in *Kaiser Aluminium&Chemical Corp*. 1981.
31. G. Lang, A.F.C., *Effect of rate of cooling after homogenization on direct-extrusion parameters of 6063 (Al-Mg-Si) billets.* Metals Technology, 1978.
32. Stefaniay V., S.L., Gillemot I. Denkay E., *Investigation of the Proceses Occuring During the Homogenization Treatment of the Alloys AlMgSi0,5 by Electron Probe Microanalysis.* Aluminium 59., 1983.
33. Lendvai N., S.L., Stefaniay V., *Investigation of the Homogenisation Phenomena of AlMgSi Ingots,.* Conference 7th International Light Metal Congress, Leoben, Vienna, 1984.

34. S.R. Claves, D.L.E., W.Z.Misiolek, *Analyses of the Intermetallics Phase Transformation Occuring During Homogenization of 6xxx Aluminium Alloys.* 2002.

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PUBLICATION

1- The Design and Prototype Production of the Casting of EN AW 6063 Aluminium Alloy with Hot-Top Method for Increasing the Quality of Billets by Using Simulation Techniques, 9th ALUS'09 INTERNATIONAL ALUMINIUM SYMPOSIUM, 10-11 October, Istanbul, pg 357(Full text).