Feeder Design Optimization for Aluminum Sand Casting

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***Abstract*— The gating and riser system (feeder) design play very important role for improving casting quality. Many defects such as tensile void, porosity and segregation in products produced by casting methods may be detected. The porosity is the one of the defects most frequently encountered in casting. Porosity formation cause costly scrap loss and limits the use of cast parts in applications requiring high sealing. The amount of porosity is closely related to sand casting process parameters. A considerable reduction in porosity formation can be obtained using riser design optimization technique in the sand casting process. The design of feeder requires knowledge and experience. Therefore, hot spot formation, solidification period, feeder sprue and volume are important criteria. However, these may be not enough to produce high quality castings, and the importance of simulation techniques increases. The aim of this study is to make a feeder design optimisation for a cast part produced from Etial 160 aluminium alloy by sand mould casting method. In this study, gating and riser design, module criteria, feeder volume and size were investigated by SOLIDCast casting simulation program. The real and simulated casting values were compared with each other in the light of macro and micro-porosity results.**

***Keywords*— Feeder design, Casting simulation, Aluminium casting, Porosity, Sand casting.**

I. INTRODUCTION

Casting is a widely used manufacturing method because metal parts can be produced very economically and complex shapes can be obtained with very little processing. A successful casting process can be accomplished by designing the hardware system required to select the casting process and then to enter all regions of the molten metal piece ([1]).

In the casting process, the molten metal in the mold cavity must be fed with molten metal to compensate for the draw, since it is reduced in volume during solidification. If it can not be fed, drawback voids and porosity flaws can occur as a result of the volume of the molten metal shrinking. Nutrients are used to compensate for defects that occur as a result of volume shrinkage during solidification ([1], [5]). The position, number, shape, and dimensions of the feeder in the model design for a casting process are important variables to be determined ([1], [2]). Implementation of the trial and error method in the development of the feed system requires a lot of time, cost and labor. Feeder design is very important in order to obtain a solid casting. For this reason, even nowadays, many foundry engineers carry out their nutritional designs and dimensions in the light of their own experiences ([2], [3]).

Feeder shape and size design, hot spot, solidification time (Module), feed path, feeder volume and Naval Research Lab. (NRL) are used. These criteria may be inadequate for producing cast parts at high quality and simulation techniques are also used for optimum feeder design ([1], [3]- [7]).
[18]

One feature of molten aluminum that concerns the nutrient design in casting is the ability to easily extract hydrogen from refractors containing atmospheres or moisture, resulting in very low solubility of hydrogen in solid aluminum, thereby causing micro- or macro-porosity when hydrogen gas is thrown away when the alloy is solidified [6]. In addition, the feeder design for aluminum alloys has different challenges compared to heavy metals ([1], [6]).

Due to the differences between the feeder size specification criteria and the values suggested by the simulation software, in this study, molding design studies were carried out to avoid macro and micro porosity on a sample piece. For the purpose of helping to choose between the techniques, a casting part made of Etial 160 Aluminum alloy produced by sand mold casting method has been investigated with feeder design criteria and simulation techniques. In feeder design studies, module criterion, feeder volume criterion and SOLIDCast casting simulation software were used. The nutrient sizes obtained from the criteria and proposed by the simulation program were compared with the optimum nutrient size values obtained from the simulation studies. The most appropriate result is obtained from simulation studies.

II. EXPERIMENTAL STUDIES

Experimental studies have been carried out on the basis of the desired fuel tank cover which has high sealing properties produced by Etial-160 Aluminum alloy sand casting method. The sand mold was prepared with 90-110 AFS grain size sand, 4 wt. % bentonite, 6 wt. % water and wet mold sand obtained by mixing it in a mixer. The chemical composition of the Etial-160 Aluminum alloy used as the test material were given in Table I.

TABLE I. ETİAL 160 ALUMINUM ALLOY CHEMİCAL COMPOSİTİON (% WT.)

Si	Fe	Cu	Mn	Mg	Zn	Al
8,62	0,824	3,091	0.2248	0.2804	0,9	Rest

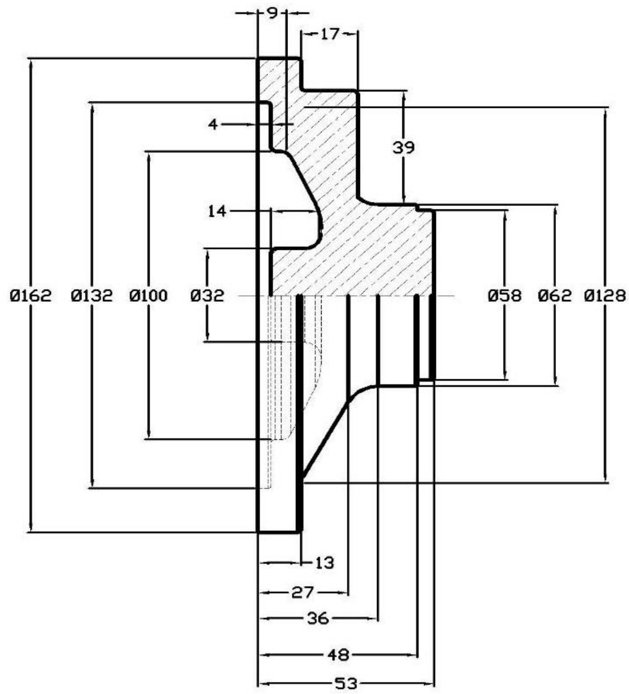
In Figure 1, a cross-sectional image and a photograph showing the result of the production are presented. As a result of the insufficient feeder usage, the fuel tank cover part photo, which is produced, contains porosity as seen in Figure 1.b. This result is a defect for the part and causes the part to be separated. For this reason, the proper nutritional design for the part to be investigated is important for the production of robust and quality parts.

Some criteria are used in nutritional design. Among these, the most commonly used solidification time (module) criterion. The module criterion provides small feeder size values due to the track geometry being examined. For this reason, it is recommended that nutritional volume criterion be evaluated together with its results. Therefore, in the scope of the study, nominal criterion and feeder volume criterion and feeder size calculations have been used.
[20]

Solidification Time (Module) Criteria**:** In casting mold design, the progress of the solidification towards the feeders and the ending in the feeders is called oriented solidification, and the feeders must solidify slightly later than the hot spots of the cast to provide this criterion. In coarse castings, the solidification time of a given section can be calculated by the Chvorinov approach, which is proportional to the volume surface area of that section ([8]). According to this;

$$t = k\,(V / A)^2$$

Where t is the time constant of solidification in minutes, V is the volume of the casting, A is the surface area of the die casting contacted with the die, and k is the constant of the equation which varies according to the casting alloy and the die material.



a)

b)

Figure 1. Fuel tank cover a) technical drawing, b) fault seen in red circle

(V / A) factor is called "module" (M) and it must be larger than the cast module of the feeder in a suitable design. Accordingly, the feeder must solidify later than the nearest hot spot to it. This criterion is usually expressed by the following equation ([5], [8]- [11]).

$$(V / A)_{feeder} > (V / A)_{casting}$$

When calculating the feeder size, the casters require the solidifier to have a longer solidification time than the solidification of the casting piece. With this in mind;

$$\text{Feeder Modular } (M_{feeder}) = 1.2 \times (M_{casting})$$

1.2 is the safety factor.

Nutritional Requirement (Volume) Criteria: Except for some cases, all cast alloys shrink by about 2-7 % in volume during cooling and solidification. This shrinkage, which is called volumetric shrinkage, naturally leads to a certain gap in the last hardened areas of the cast parts (hot spots). Feeders have a specific feed capacity and this capacity has to be limited to a certain volume limit. This limit, which can be expressed by the following relation, should not be smaller than this volume since a limiter will determine the minimum amount of metal that a feeder should have for a casting.

$$V_b = \alpha V_d / \varepsilon - \alpha$$

Where V_d is the volume of the casting part when a single feeder is used, the volume of the part to be connected to the feeder if more than one feeder is to be used, the volumetric draw ratio of the casting alloy α is ε, and ε is the volumetric draw ratio of the casting alloy, Is the feed metal that can be consumed as a percentage of the total volume, and expresses "feeder efficiency" ([5], [9]-[11]).
[21]

As a nutritious volume criterion in the literature:

$$W_{cast} = (C / 100) \times (W_{feeder} \times 100 / S)$$

Equation is also proposed. In this equation, W represents the feed weight, W feed weight,% draw ratio of C alloy, and the total feed metal volume ratio of the liquid metal to feed the cast part in the S feeder. C value is recommended as 16% in sand mold casting applications. An S-scale table is chosen and given as 8% for aluminum alloys ([3]).

The feeder position is considered suitable as a top feeder when considering the shape of the part. Feeder height / feeder diameter dimensioning ratio 1/1 was accepted for initial evaluations. The dimensional adjustment is deemed appropriate because the diameter of the region to which the feeder is to be positioned is 58 mm. The results obtained were again 50 mm in diameter, and the dimensional calculations were applied again.

Computer Aided Casting Design Studies: Molding design for an ideal casting can only be achieved by satisfying all the criteria given above. Casting parts with complicated geometry and different cross-sectional thicknesses require very difficult and intensive engineering knowledge and skill. But by the influence of rapid developments in computer technology, modeling of casting processes; Micro and macro structures can be predicted by casting simulation programs ([12], [13]).

Casting is a multi-stage process and includes all the processes from 2D drawing to determining the design of the optimum casting part. If we examine these processes in turn;

• Making Technical Drawing as a three-dimensional (3D) solid model
• Determination of properties of materials and casting components
• Test casting to determine the module and hot spots of the solid model
• Feeder calculations
• Mold designing
• Analysis of the molding design in the simulation program
• Examination of the results
• Overhaul and redesign in mold design if necessary
• It is possible to specify the optimum design and report the results ([14]).

Since the simulation is a process that can be repeated, the desired changes are tried and studies continue until the optimum result is reached. Since all processes are done on computer, modeling, molding and melting costs are eliminated.
[22]

III. EXPERIMENTAL RESULTS AND DISCUSSION

The weight, volume and surface area values of the fuel tank lid used in the experimental works are given in Table II.

TABLE II.
TEST PIECE WEIGHT, VOLUME AND SURFACE AREA VALUES

Weiht, gr	**Volume, mm^3**	**Surface area, mm^2**
926,72	335757,71	58288,82

The module criterion with feeder height / feeder diameter sizing ratio of 1/1 acceptance and both feeder volume criterion results are given in Table 3. Volume 1 was obtained from the equation $V_b = \alpha V_d / \varepsilon - \alpha$, Volume 2 $W_{cast} = (C / 100) \times (W_{feeder} \times 100 / S)$.

TABLE III.
RESULTS OF FEEDER SİZES CALCULATED BY CRITERIA

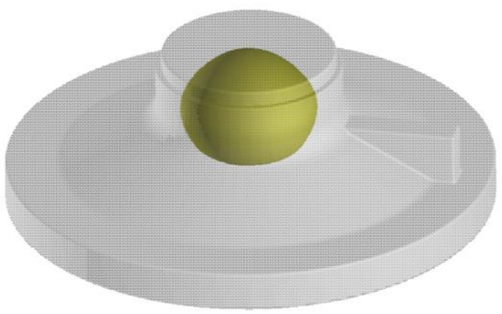
Criteria	**H (mm)**	**D (mm)**	**Hregulated (mm)**	**Dregulated (mm)**
Modul	41,472	41,472	-	-
Volume 1	75,33	75,33	171	50
Volume 2	59,80	59,80	85,50	50

When the results in Table 3 are examined, it is clear that there is a huge difference between the results obtained using the criteria. However, both the module criterion and the volume criterion are evaluated together, and depending on the geometry of the part, the criterion is preferred in terms of the use of the feeder if the criterion required by the criterion is greater. When considering the track examined, the nutrient usage determined as the volume criterion will be appropriate when the module criterion results are small. Volume 1 results are quite large, and the maximum 3/1 ratio for the H / D ratio is also exceeded.

In this study, the models were made with SolidCast casting simulation program. The program is a software that solves the three-dimensional casting-mold geometry with the help of cubic meshes and the finite difference method according to the given boundary conditions. The software performs the cooling model with the help of heat transfer formulas. As the first step in mold design with casting simulation programs, modeling of the relevant part without connecting the feeder and runner is the process of determining the hot spots. Depending on the size of the hot spot determined afterwards, the feeder sizes required in the casting simulation software can be determined depending on the desired boundary conditions. This will lead to the design of molds according to the number of feeders required and the required feeder sizes. In the SolidCast casting simulation program, the equivalent alloy of Etial 160 alloy was selected as the casting alloy material and the casting temperature was set at 720 ºC and the solidification temperature was set at 537 °C. Figure 2 shows the modeling endpoint hot spot and location of the part.

As seen in Fig. 2, when the model is solidified in this way, it is seen that there is only one hot zone in the 0,7069 cm modulus in the middle bosom. For this reason, it is deemed appropriate to carry out the molding design and casting studies by putting 1 feeder on the relevant region. Within the program, the feeder design wizard module specifies the feeder dimensions required to feed the corresponding region. It is possible to design according to different boundary conditions for the feeder account required in the feeder design wizard. When choosing the most economical and effective feeder design choice according to the parameter h = 2d, the feeder with 42.27 mm diameter and 84.54 mm height has been selected by the program. Simulation studies have been carried out and it has been found that the feeder sizes are sufficient for macro porosity and only for microporosity (Fig. 3).

a)



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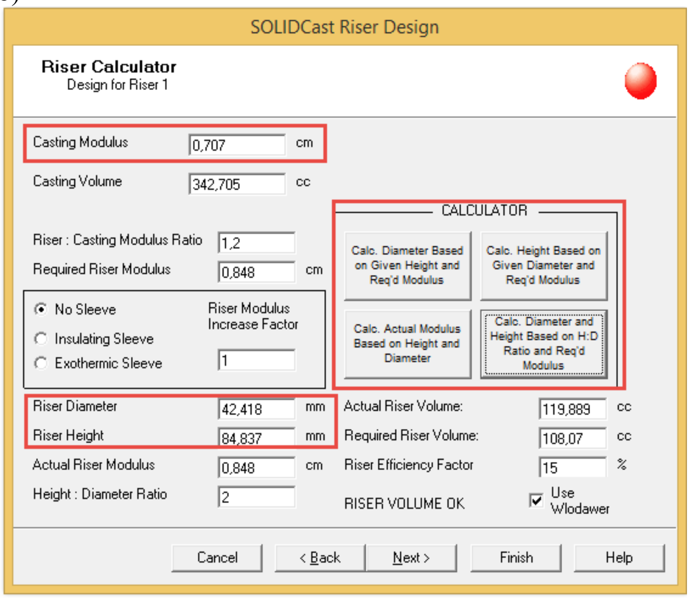
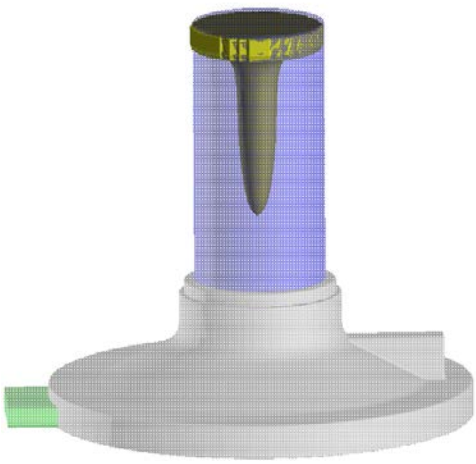


Figure 2. a) Hot spot formed in SolidCast modeling result in casting, b) Feeder design wizard calculation screen image



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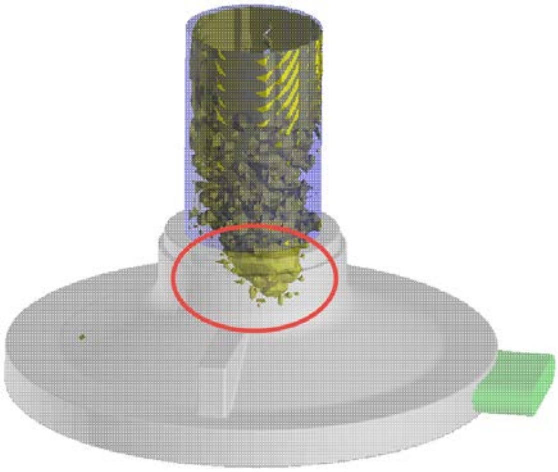


b)

Figure 3. Simulation results of the molding design with Design-1 (42 mm diameter and 84 mm height feeder) a) macro porosity, b) microporosity condition

In the context of this study, it is necessary to take into account the microporosity results in this part design, since the parts to be designed are very desirable to have high sealing properties. For this reason, the simulation has been progressively continued with the enlargement of the feeder sizes, so that the micro pore on the part is lifted out of the way. In such cases the ultimate design and optimum results have been achieved, as the height / diameter ratio is 2, as the feeder neck elevation solution may be the solution to remove the micro-tile from the part. Accordingly, it was determined that the feeder with a diameter of 50 mm and a height of 100 mm would be sufficient. In Figure 4, modeling studies are presented with a solid model image of the molding design which is deemed appropriate.

Figure 4 shows the molding design and components used in the model. Since there is no region of very thin sections associated with the filling of the part and the casting has to be solidified after completion of the filling of the parts of the runway, only the runway entry is specified in the models and the work is done in this way. If there is a risk associated with the filling, or if fluid flow modeling is desired, it is possible to draw the modeling of the roadway into the molding design and make it in the FlowCast filling simulation program of the model. However, this work focuses on solidification modeling depending on part geometry and requirements.

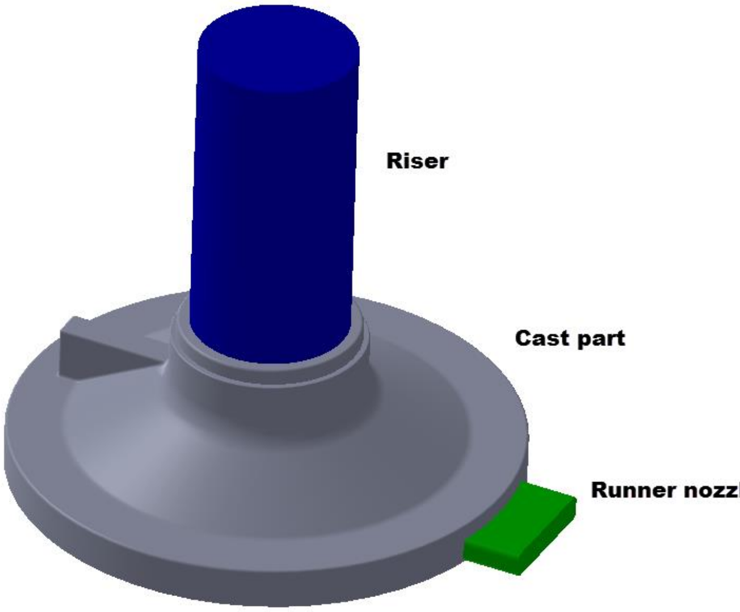


Figure 4. Molding design suitable for modeling program

In the casting model, granular separation is known as a basic process from the modeling process steps, and the selected dimension is important in terms of process accuracy. For this reason, the granules are separated by at least 3 from the thinnest section of the casting piece. Figure 5 shows the screen images taken from the SolidCast program during the meshing process for model and die.

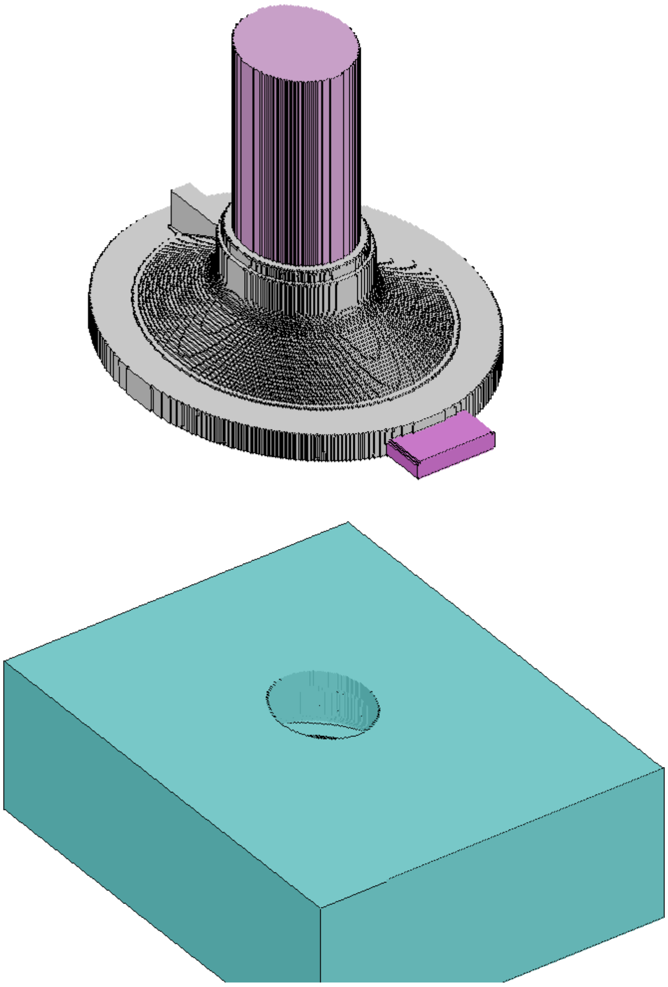
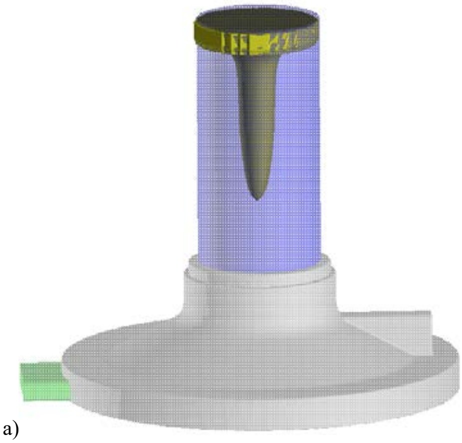


Figure 5. Modeling program image in mold and model granularity

Simulation has been started after separating the particles. After completion of the modeling process, the results are examined for the suitability of the parts and the robustness of the design. In general, to ensure that the casting is considered to be solid, there should be no risk of macro and micro porosity on the casting, and the solidification must be solidified in the last feeders oriented towards the feeders. Once the suitability of the design is determined in this way, many different results can be evaluated in the program depending on the desire. Figure 6.a shows macro-pore analysis, Figure 6.b shows micropore traction, Figure 7 shows solid-dispersion image.

The macro porosity given in Figure 6.a has been investigated with 99.8 % sensitivity considering the sealing properties of the resulting image part. As can be seen from the images obtained, it is understood that the molding design is appropriate and does not involve any drawbacks in terms of macro and micro. It is seen that all the risky nutrients that may occur in molding design are found. The macro porosity image (Fig. 6. b) shows that the microporosity results are only the size that the feeder can tolerate, as long as the feeder size is large, and the risk of microporosity is high when the smaller feeder is used.

TABLE IV.
CRITERIA FOR FEEDER OPTIMIZATION AND FEEDER



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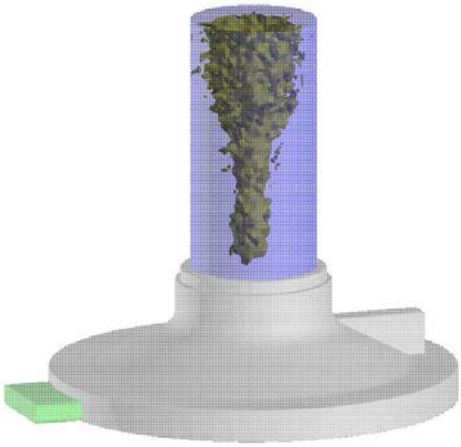


b)

Figure 6. a) Macroporozity, b) Microporozity retraction analysis results image

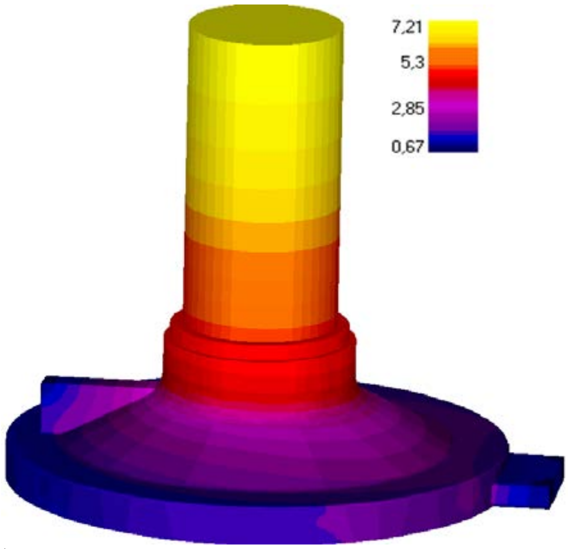
The solidification analysis of the molding design in Figure 7 shows that the solidification first started at 0.66 minutes on the edges of the mold and the solidification of

Criteria	H (mm)	ØD (mm)	Volume (mm^3)	Explanation
Module	41,47	41,47	28006,71	Macro and micro pore available
Volume 1	171,00	50,00	335757,71	Design suitable
Volume 2	85,50	50,00	167878,85	micro pore available
Simulation Design 1	84,54	42,27	118636,03	micro pore available
End Simulation Design	100,00	50,00	196349,54	Design suitable

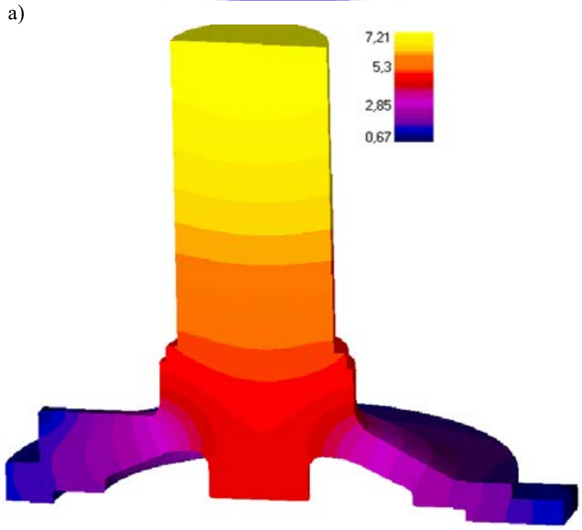
the entire mold ended in 7.21 minutes. From the color scale given on the figure, the blue stain marks the first solidified regions, while the yellow stain shows the last solidified regions. Accordingly, it has been determined that the orientation of the solidification is desired and that the final feeders are terminated starting from the edges of the pieces. It is understood that there is no risk situation in the casting part since the last solidification takes place in the feeders. According to these results, no error is detected on the part, so it is understood that the design can pass through the production as it is.

In the study, the module criterion, the volume criterion and the results of the nutrient sizes obtained by the simulation software for the nutrient-optimized part are given in Table IV.

IV. DİMENSIONS CALCULATED FROM SOFTWARE



a)



b)

Figure 7. a) Solidification distribution analysis, b) Solidification distribution analysis section view

As can be seen from the results given in Table 4, it is possible to produce nutrients of the specified sizes and no macro- and micro-pore risk at the end of the volume 1 criterion and the gradual final simulation designs. When we compare the values for feeder optimization, it is determined that the feeder calculated by modeling is 41.52% smaller than the calculation method using the Volume-1 criterion. According to volume 2 and the most economical design made by the model, the micro pore pulls the risk while the part does not contain macro pore risk in the case of nutrient use. However, in the sample used in the work, it is not desirable in the micro-pores due to the high leak-tightness expectations. For this reason, it is not possible to produce solid parts with desired characteristics with the nutrients calculated with these criteria and module criterion. It can be considered that conventional calculation methods can be used in parts where micro-pore formation can be neglected. In this case, however, as shown in Table 4, it is observed that the nutrient sizes determined by the Simulation Design-1 method are 29.24 % smaller than the nutrients determined according to the Volume 2 criterion. Since module criterion and volume criterion are evaluated jointly based on part geometry, they have not been considered in evaluations because volume criterion must be used in situations where smaller feeders are required than module criteria. As a result, the use of modeling programs in terms of accuracy and economy is very important in terms of nutritional optimization.

V. GENERAL RESULTS

The results obtained from the experimental and modeling studies in the study of the design and production of the Etial 160 aluminum alloy and the tank lid piece with a sand casting method are summarized as follows:

• Hot spot formation occurs at the center of the part depending on the part geometry.
• Classical engineering methods and computer aided casting simulation have been used for necessary feeder calculations for the solid part design to produce solid parts.
• When modeling results are examined, it is observed that they are compatible with actual casting results. According to this result, it can be said that the molding design for the castings to be made with the alloy Etial 160 can be optimally and safely optimized by the calculation and modeling techniques used in this study.
• Casting simulation program for the macro and micro pore-free feeder design for the sample has been observed to be able to design a molding with 41.52 % more economical feeder than the conventional calculation methods.
• It has been observed that for casting simulation program for feeder design that does not contain only macro pore for the sample, molding design with 29.24 % more economical feeder can be realized compared to the conventional calculation methods.
• It can be said that the molding design for the castings to be made with Etial 160 alloy can be optimized with the calculation and modeling techniques used in this study correctly and safely.
• Depending on the part geometry, it is not possible to produce solid parts which are always desired with the feeders determined by classical engineering calculations (volume and module criterion). It can be considered that conventional calculation methods can be used in parts where micro-pore formation can be neglected. However, it is understood that simulation software is more advantageous when economy is taken into consideration.

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