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Investigation of The Effect of Molding Material Difference on Design in GGG70 Ductile Cast Iron Production

Mete ŞEKERDEN[1], Muhammet Emin KESKİN[2*], Melek DURMUŞ[3] Murat ÇOLAK[4]

[1]Bayburt Üniversitesi, Fen Bilimleri Enstitüsü, Makine Mühendisliği Bölümü, Bayburt, Türkiye
[2]Bayburt Üniversitesi, Fen Bilimleri Enstitüsü, Makine Mühendisliği Bölümü, Bayburt, Türkiye
[3]Necmettin Erbakan Üniversitesi, Fen Bilimleri Enstitüsü, Makine Mühendisliği Bölümü, Konya, Türkiye
[4] Bayburt Üniversitesi, Teknik Bilimler Meslek Yüksekokulu, Elektronik ve Otomasyon Bölümü, Bayburt, Türkiye
Mete ŞEKERDEN ORCID No: 0009-0002-3862-9480
Muhammet Emin KESKİN ORCID No: 0000-0003-4342-6303
Melek DURMUŞ ORCID No: 0009-00061439-3759
Murat ÇOLAK ORCID No: 0000-0002-8255-5987

Corresponding author: emnkskn47@hotmail.com

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Abstract: The casting process involves filling a prepared mould cavity with molten metal, which takes the shape of the container. While the liquid metal takes the shape of the container it is in, the method is attractive, while the volumetric changes during the liquid-solid transformation reveal the importance of moulding design for the manufacture of solid parts. Especially in cast irons, moulds with the same design may produce different results depending on the changing casting and foundry conditions because the volumetric change that occurs during the solidification of ductile cast irons is affected by many parameters and develops differently than in steel and aluminium castings. This study used model wet and resin molding materials to create single and double-riser moulding and castings with different section thicknesses. The importance of the type of mold material used in castings and the number of feeders for the robust production of the cast part was evaluated using experimental and modeling techniques. When the results were examined, it was seen that the shrinkage risk was lower with resin mould than with green sand moulding. In addition, depending on the riser connection point, the importance of the riser neck has emerged.

Kalıp Malzemesi Farkının GGG70 Küresel Grafitli Dökme Demir Üretiminde Kalıplama Tasarımı Üzerine Etkisinin İncelenmesi

Anahtar Kelimeler
GGG70, Kalıplama tasarımı, Kalıp rijitliği, Sıcak nokta, SolidCast.

Öz: Döküm yöntemi ergitilmiş sıvı metalin hazırlanmış kalıp boşluğuna doldurulması ile parça imalatını kapsamaktadır. Sıvı metalin bulunduğu kabın şeklini alması, yöntemi cazip hale getirirken, sıvı katı dönüşümü esnasındaki hacimsel değişiklikler sağlam parça imalatı için kalıplama tasarımının önemini ortaya çıkarmaktadır. Özellikle dökme demirlerde aynı tasarıma sahip kalıplarda değişen döküm ve dökümhane şartlarına bağlı olarak farklı sonuçlar ortaya çıkarabilmektedir. Çünkü küresel grafitli dökme demirlerin katılaşması sırasında oluşan hacimsel değişim birçok parametreden etkilenerek, çelik ve alüminyum dökümlerindekinden farklı şekilde gelişmektedir. Bu çalışmada, farklı kesit kalınlıkları içerecek şekilde tasarlanan model yaş ve reçineli kalıp malzemeleri ile tek ve çift besleyicili olarak kalıplama ve dökümler yapılmıştır. Dökümlerde kalıp malzemesinin değişimine bağlı olarak besleyici sayısının döküm parçaların sağlam imalatındaki önemi deneysel ve modelleme teknikleri ile değerlendirilmiştir. Sonuçlar incelendiğinde aynı kalıplama tasarımında reçineli kalıp ile yapılan ölçümlerde yaş kalıp kumuna nazaran çekinti riskinin daha az ortaya çıktığı görülmüştür. Ayrıca besleyici bağlantı noktasına bağlı olarak besleyici boğazının önemi ortaya çıkmıştır.

1. INTRODUCTION

Cast irons have a wide variety of properties such as strength, hardness, toughness, high corrosion resistance, easy machinability and vibration damping. In cast irons, the shape, and shape of the carbon in the internal structure after solidification determines the type of cast iron. Classification in cast iron determines variables such as the chemical composition of the material, cooling rate, production method, and heat treatment methods after production [1]. Ductile iron is one of the types of cast iron where carbon is formed as graphite spheres due to the addition of small amounts of spheroidizers like magnesium and cerium to the molten iron before casting [1,2]. Ductile iron is a type of material with perfect castability, easy machinability, wear resistance, high strength to low weight ratio, fatigue strength, high corrosion resistance and toughness. Due to these properties, it is a widely used material in the machinery and automobile industries for structural components such as machine tool bearings, bearings, rolling mills, pistons, cylinders and pump housings [3].

In shaping methods using the casting method, the solidification stage is important for the mechanical properties of the material, depending on the product's internal structures. Inoculation is crucial to achieve desired mechanical properties in the spheronization of ductile cast iron materials [4]. The microstructures of cast irons show different properties depending on their chemical composition, added inoculation element, casting parameters, and cooling conditions [5]. The mechanical properties of ductile cast iron castings largely depend on the volume, size, distribution, sphericity, and quantity of graphite in cast iron [6]. Changes in the matrix structure and sphericity of graphite can affect mechanical properties, influenced by alloying elements and ambient conditions during solidification. [7]. Ductile cast irons, which are widely used in the automotive and energy industries, can be further strengthened by changing the process parameters or applying an additional heat treatment [8]. When the literature is examined, it is seen that the material properties are improved by changing the casting conditions, heat treatment, and added alloying elements. In a study, the effect of the austempering process on the microstructure and wear properties of cast irons was investigated. And as a result, it was determined that as the amount of Al increased, the ferrite ratio and the amount of graphite in the matrix increased, while the sphericity of the graphites was impaired [9]. In a different study, the effect of normalized heat treatment on the microstructural change and mechanical properties of unalloyed ductile cast iron after annealing at intermediate critical austenitizing temperatures was investigated. At the end of the examination, they concluded that the processes performed differed considerably in the microstructure and the mechanical properties were improved. [10].

To obtain the material with the desired properties, the solidification process of the material, the mold material and the molding design are very important, apart from the addition of the alloy element. [11]. We can define it as a molding design, which is finally integrated with the runners and risers of the part. The ability to make a part sound depends on molding design considerations such as modulus, volume, feed path, and hot spot criteria [12]. In the design, it is necessary to determine the location, number, and size of the riser depending on the geometry of the part. The hot spot, defined as the isolated region during solidification, is the most important criterion in the design of the riser, both in determining the number of risers and in determining the riser locations. The hot spot can be multiple and of different sizes depending on the part geometry and casting conditions. [11-17]. In addition, in the molding design of cast irons, there are also difficulties because the volumetric change occurs in the form of shrinkage and expansion due to the increase in density during solidification. The resulting shrinkage and expansion are affected by many parameters such as mold material, chemical composition, alloy overtemperature, inoculation quality, solidification time of casting (modulus), and casting speed. High carbon equivalent, high mold rigidity, high solidification time (high modulus), high inoculation quality (high nodularity), low casting temperature (low excess heat) and low casting to reach high dilation press and consequently lowly shrinkage [18-20].

The difficulties encountered in molding design and the need for intensive experience have been developed with the developments in computer technologies and modelling studies. Macro and micro-size errors in the cast part can be predicted to a large extent thanks to modelling programs. In this way, the runner-riser design can be designed on these simulation applications by determining which number and size of the risers are needed and in which position they will be placed on the 3D solid model. Modelling of the designed product can be done on the computer and many necessary results after casting can be obtained without any cost or loss of labour. [21-24].

With casting simulation programs, the riser design stages of cast irons are outlined;

- Determining the hot spots of the cast part and the modules of these regions,
- Calculation of percentage values of shrinkage time, net expansion or contraction depending on factors such as the chemical composition of the alloy to be cast, casting temperature, mould rigidity and casting modulus
- Determining the location, volume and quantity of the required riser (if necessary) according to the calculated values,
- We can sort it out as the design is completed and the results are evaluated [16,17].

In this study, a model with different section thicknesses was designed experimentally. Moulding and castings were made by applying changing casting parameters. As parameters, castings were made in green sand mould and resin moulding sand in accordance with two different designs, with a single top riser and a double top riser. The designs were supported by the computer-aided 3D drawing program SolidWorks, and the modelling studies were supported by SolidCast casting simulation programs. After casting, the samples were cut from the locations determined in the modelling program and penetrant tests were applied, and microstructure samples were taken from the parts of the castings with different cross-sectional thicknesses and the sphericity was determined with image analysis software. Modelling and actual casting results were compared. Thus, in this study, the importance of moulding sand and the number of risers connected to the hot spot in the robust manufacture of cast parts were evaluated by experimental and modelling techniques.

2. MATERIAL AND METHOD

In this study, the design of the model with different cross-sections was done to examine the effect of the feeder path under changing casting conditions. The model given in Figure 1 is aimed to require a single or double riser depending on whether the feeding path remains open or close.

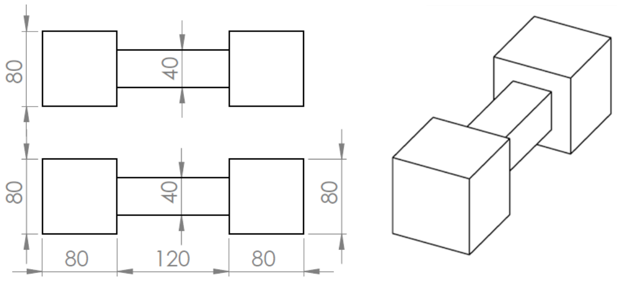


Figure 1. Dimensional drawing of casting model.

Model design studies were carried out from the SolidWorks program and solidification models were made with SolidCast software. As the first step of the molding design, the model was solidified in the SolidCast program without runner and riser. Thus, the hot spots and modulus of the part were determined. When the module of the relevant part is determined as 1.42 cm, 2 hot spots appear. However, in the evaluations made with the modelling program, it has been determined that the feeding path will remain open at module values above 1.2 cm. The volumetric change curve and required riser dimensions were determined by SolidCast casting simulation software, depending on the relevant part weight, casting material mould rigidity, and chemical composition values. Example images of calculations taken from SolidCast software are given in Figure 2.

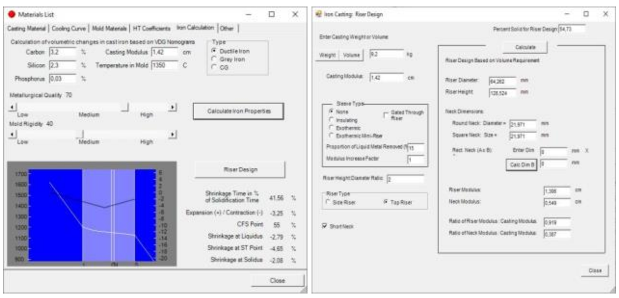
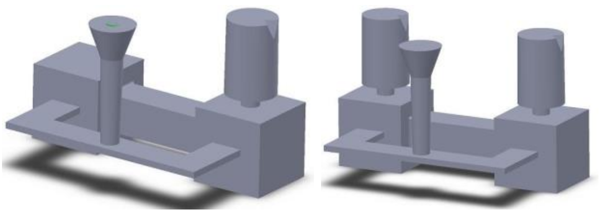


Figure 2. a) Volumetric change curve calculation from SolidCast software, **b)** Specifying riser sizes in the Riser Design Wizard.

As seen in Figure 2. a, the carbon, silicon and phosphorus values of the alloy, and the temperature of the casting part in the mould were entered and volumetric change curve calculations were made depending on the module value calculated by the program. In the volumetric change curve calculation, there are also the metallurgical quality and mould rigidity values that vary depending on the foundry and are the focus of the study. Relevant values are values ranging from 0 to 100, differing according to mould material and foundry spheroidization and inoculation procedure. After the volumetric change curve calculation, the riser design was started. In the riser design tab specific to cast irons in Figure 2. b, optional required features (sleeve type, riser height: diameter ratio, riser type etc.) are entered and riser calculations are started. In this study, riser type was preferred as the top riser and riser height, diameter and throat linkup measure were determined hence. Within the scope of the study, single and double-riser moulding designs were made according to the use of green sand moulding and resinous moulding sand in the calculations of the volumetric change curve, and considering the differences in spheroidization and inoculation efficiency, and keeping the feeding path open. Moulding design drawings in accordance with the dimensions determined by the SolidCast program were made with the SolidWorks program as seen in Figure 3.



a) Single riser design **b)** Double riser design
Figure 3. Moulding design images.

In order to compare all the results obtained from the experiments in accordance with the design, the cast sample model, risers and runners were produced as free models. Moulding and casting processes were carried out in 2 commercially operating foundries. Moulds were prepared with green sand moulding in one of the foundries where the experiments were carried out, and moulding was made with alpha-set resin sand in the other foundry. Melting operations were carried out in induction furnaces located in the companies. After melting, castings after spheronization and inoculation processes were carried out by both companies depending on their own application procedures. After the casting parts were removed from the moulds, the runners and risers were cut and examined.

The samples taken from the thermal centre of the thin and thick sections of the part for microstructure investigations were evaluated with the image analysis system after grinding and polishing. Microstructure examinations were performed using Clemex Vision Lite image analysis software on images taken from the Nikon Eclipse L150 optical microscope. With the modeling simulation program, the globalization of the samples, the average diameter of the spheres and the dispersion rate of the globalization were determined as a percentage.

After the casting samples were cut vertically from the centre of the thick section and medium thin section regions on the right and left, their surfaces were processed by milling and subjected to penetrant tests. Liquid penetrant testing is a non-destructive testing method and is used to detect invisible superficial defects such as cracks. Commercially used BETA BT68 penetrant paint was applied to the surfaces to be examined with cleaning liquid after machininig. Here, it is aimed to see the pores formed on the surface, which cannot be detected with the naked eye. After a certain period of time, the paint fills into the pores on the applied surface. After waiting for enough, the paint special spray surface is applied and the surface is cleaned with a cloth. After removing the penetrant paint from the surface, BETA BT70 developer was applied to the section surface by spraying, so that the penetrant paint filled into the pores became visible as macro, and the pore status of the relevant surface was determined.

Modeling studies were carried out with the help of solidcast casting program.. After the designs in STL format were transferred to the program, the alloy and thermo physical properties were defined. The thermophysical values of the casting alloy are shown in Figure 4 for the CU DI Ferr alloy corresponding to the ferritic ductile iron alloy in the database of the simulation program.

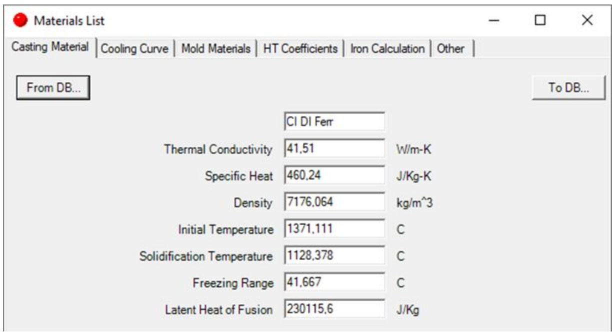


Figure 4. CI DI Ferr alloy values.

3. RESULTS

The values related to the analysis results of the samples taken for the control of the chemical composition of the alloys used in the casting experiments are given in Table 1.

Table 1. Chemical composition of the casting alloy used in the experiments

Element (%)	C	Si	Mn	Cr	Ni	Cu	Mg	P	S	Fe
	3.22	2.34	0.3	0.04	0.04	0.14	0.021	0.06	0.04	Bal.

When the result is examined, it is understood that the chemical analyzes were determined as expected depending on the alloy additions added to the furnace and it is in accordance with the GGG70 alloy standard.

3.1. Microstructure and Image Analysis Results

The microstructure pictures taken at 50X magnification obtained from the thin and thick sections of the cast samples are given in Figure 5. The average image analysis results for the processing of the images are given. In Table 2, the % sphericity, mean sphere diameter and per cent area measurements of the samples were taken from the pictures taken at 100X magnification in order to cover a wider area.

Table 2. Image analysis measurement results

Riser Status	Section Location	% Sphericity	Sphere Diameter (µm)	% Spherical Graphite Amount	Number Spheres (Piece)
Green Sand Top Single	Thin	83.8	20.8	9.6	224
	Thick	83.3	24.5	9.2	198
Green Sand Top Double	Thin	84.1	22.4	9.7	215
	Thick	83.9	26.3	9.9	193
Resin Top Single	Thin	87.5	20.2	10.1	235
	Thick	87.2	23.9	9.6	198
Resin Top Double	Thin	86.8	25.6	9.7	206
	Thick	88.6	28.9	9.8	191

First of all, the suitability of the spheroidization and inoculation process of the materials produced in both foundries was evaluated from the microstructure drawings and image analysis results. Depending on the evaluations, as seen in Figure 5, most of the graphite appeared in spherical form. When the results given in Table 2 are examined, while the globocity is measurand at more or less 83% in wet moulding sand, the globocity value in moulds prepared with resinous sand. It has been found to be around 87%. This shows that the inoculation and spheronization processes of the foundries are sufficient and appropriate. A striking point in all castings is the change in sphere diameter depending on the change in section thickness. As the section thicknes increased, an increment was observed in the mean diameters of the graphites, which were formed due to the prolongation of the solidification time. Depending on the solidification time in the microstructures occurring in the section thicknesses, larger graphite formation in the thick section area draws attention. Similarly, in cases made with double risers, when the whole of the cast is considered, it has been determined that the graphites that appear due to the prolongation of the solidification time tend to grow. In studies on the subject, it has been reported that the diameter of the sphere increases with the increase of the modulus and the number of spheres per unit area decreases [25-30]. When the effect of the moulding sand difference on the microstructure is examined, it is noteworthy that the graphite form, though not in size, appears in a more regular formation in the resinous mould. It is thought that this situation is caused by the prevention of the expansion of the mould during the expansion of the alloy, depending on the die rigidity, so that the sphericity ratio of the graphite increases.

3.2. Penetrant Test Results and Comparison with Modeling Results

Porosity investigations due to insufficient feeding on the cross-sectional surface of the cast samples were carried out by penetrant tests. The test results of the vertically cut surfaces from the centre of the thin and thick section regions of the model are given in Figure 7. In Figure 7, the modelling results are also given and thus the results obtained are compared. Modelling results are result images of shrinkage risk with 99.8% precision.

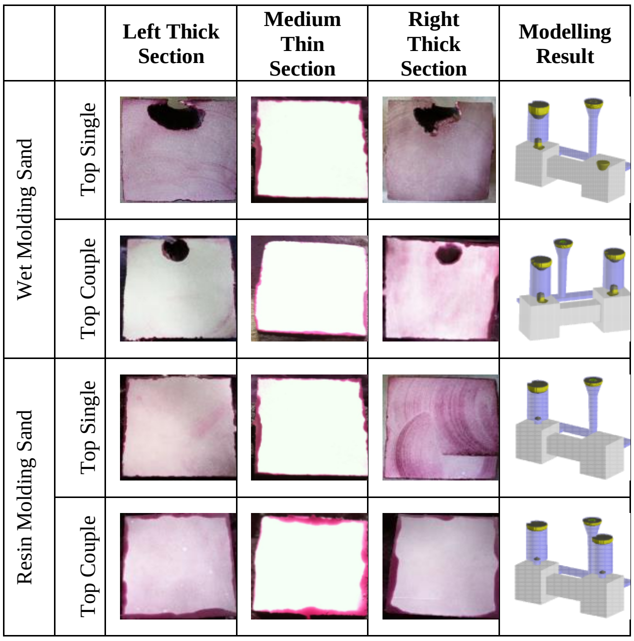


Figure 7. Casting experiments penetrant test and modeling result images.

The simulation and actual castings results seen compatible with acceptable error margin. When the results are examined in general, it is observed that the design is suitable and there is no error in the resin mould, while errors occur in castings made with green sand. This may be related to the hardness of the resin mould being much stronger than the green sand mould. It is thought that there is no error in the expansion that occurs during the induracation of the cast iron, as the casting part can’t sprawl in the gum mould due to the high rigidity of the mould. While the difference between green sand moulding sand and resinous moulding sand properties is entered in the modelling program, different values and casting iron properties and sand differences are specified in the "Mold Ridiđity" section of the mould rigidity section. As a result of modelling matches, models were made by entering 40 for wet moulding sand and 90 for resinous moulding sand. When the results of the casting samples made with wet moulding sand with a single riser from the top are examined, it is seen that there is a clear shrinkage in both of the thick sections. As a result of the evaluations made regarding this situation, it is thought that the narrow riser throat connection and the expansion of the mold dimensions during the expansion of the green mould sand caused the current situation. As can be seen from the penetrant test results and modelling results, there is no shrinkage risk on the cast part when the relevant design is poured into moulds prepared with resinous sand. It is thought that the errors that occur when the same design is produced with wet moulding sand are caused by the opening of the riser's throat due to expansion and not feeding the mould sufficiently. When the shrinkage rates in the feeder are examined depending on the moulding sand change; Although there was more shrinkage in the feeder in green moulding sand, it was observed that the casting sample sizes increased due to the expansion of the mould dimensions. However, although there is less shrinkage in the riser in the resin mould, it has been observed that there is no shrinkage in the cast part due to the expansion effect due to the solidification of the feeder's throat after feeding the mould. When castings made with resin moulding sand with a double riser from the top are examined, it is understood that there is no shrinkage risk on the part like single feeder castings made into resin moulds. In the literature, there are many studies in which consistent results are obtained as a result of modelling of castings and the importance of expansion pressure and casting errors due to hot spots are emphasized. And it is understood that they are compatible with the results within the scope of the study [31-38].

4. DISCUSSION AND CONCLUSION

The results obtained from the study, in which the casting of GGG70 material in single and double riser green and resinous sand moulds was examined comparatively with modelling techniques, are given below;

- In cast iron castings, foundry conditions have a significant impact on riser design.
- When parts with the same design are cast under different casting conditions, significant differences are observed in the results.
- When the sample microstructures are examined, the solidification period is efficient on the sphere diameter and dimension. Sphere diameters formed in thin-section regions with smaller modulus are relatively smaller in diameter by showing a more homogeneous distribution compared to regions with large cross-sections.
- It has been observed that the mould rigidity is not very good, and when moulding with green sand moulding, the casting part expands during solidification and expands the mould, and the dimensions of the output casting part are larger. In this case, the part is also scrapped due to an error in the part due to insufficient feeding.
- The required feeder design varies according to GGG70 chemical composition, casting temperature, casting modulus, mould rigidity (moulding sand material used), and inoculation quality (metallurgical conditions). When these conditions change for the same model, the riser requirement can be single or double.
- While designing the riser in cast irons, the volumetric expansion features show the shrinkage expansion together. For this reason, especially the throat connection should be chosen carefully while designing, and the situations called vomiting should be prevented by calculating to complete the solidification of the throat at the point where the expansion starts in the part after shrinkage.
- Cast simulation programs are efficient device for riser blueprint and give results consistent with real casting

results when pouring conditions are transferred to the program exactly.

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