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Casting Design Modification to Improve Casting Yield in Producing Thin Wall Ductile Iron Plate

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Abstract. Cooling rate plays an important role in the formation of thin wall ductile iron microstructure due to their thickness, which is 3 mm below based on Stefanescu. Cooling rate is closely related to casting design and determines the microstructure. This paper discusses the effect of casting design modification to casting yield and microstructures. Modification was made on a patented design used previously to produce thin wall ductile iron plates. The design was minimized and casting simulation was used to analyze castability of the design. After that, the design were casted in several pouring temperatures. Improvement was made to casting design based on the failure during the experiment. Casting process took place after simulation analysis. The casting product was fully casted as shown by the simulation. The casting yield has improved to 28%. When all plates were examined for microstructure, the result showed that all the microstructure of the plates was not graphite in ferrite matrix as occurred in the patented design but it was graphite in pearlite matrix.

Introduction

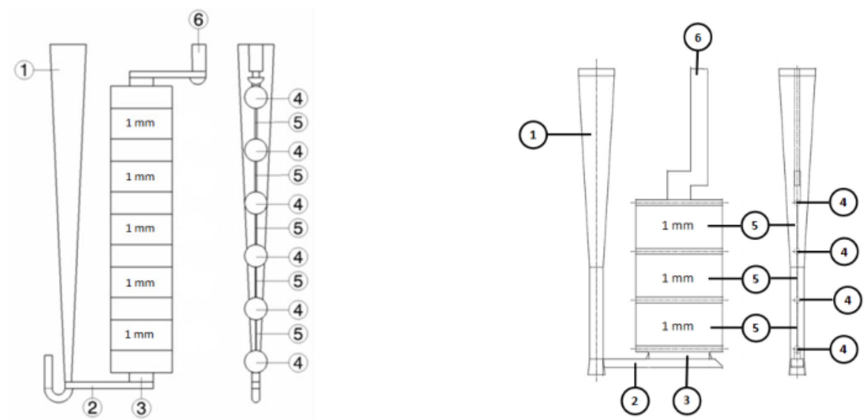
Ductile iron and austempered ductile iron have more advantages compared to aluminium but aluminium is chosen to be used in automotive industry due to its light weight. To compete with it, ductile iron introduces thin wall ductile iron and thin wall austempered ductile iron [1]. Thin wall casting is a casting technique that able to produce a casting product with maximum thickness below 5 mm in all or part of it. This technique makes ductile iron able to reduce its weight and compete with aluminium. Cooling rate is an important parameter in thin wall casting technique since it will determine the formed microstructures especially when it comes to the design with high complexity. Soedarsono et al. [2,3] and Suharno et al. [4] have able to produce 1 mm TWDI part. By these works a patented design to produce 1 mm plate of thin wall ductile iron with graphite in ferrite matrix was made [2-12]. Modification is made to this design in an attempt to improve casting yield. However, a modification in design could disturbed cooling rate which will affect the product.

Casting simulation plays an important role during modification process to reduce trial and error in experiments. Juretzko and Stefanescu [13] used NovaFlow&Solid, MagmaSoft, and ProCas during their research of TWDI. The work by Wooley et al [14] utilized MagmaSoft software to predict and solve the problems of micro shrinkage in TWDI. Sudarsono et al.[2,3,5-7], Suharno et al [4] and Sulamet-Ariobimo et al. [8-10] used Z-Cast simulation developed by KITECH – South Korea. Thus, experiment is needed to verify the result of the design.

This paper discusses the effect of casting design resizing to casting yield and microstructures.

Experimental Method

The casting design was showed by Figure. 1. Figure 1.a. presented the patented design and Figure 1.b. presented the modified one. The modified design was simulated with SOLIDCast version 8 trial version. The casting simulation results were analyzed based on temperature gradient showed in the legend and the result of experiment. Modification were made for several times to gain an optimum design.



a. Patented Design [1-10] b. Modified Design

1. down sprue 2. runner 3. ingate 4. riser 5. plate 6. gas tunnel

Figure 1. Casting Design

The experiment was conducted on foundry scale. The moulds were made using refractory silica sand and water glass produced by CO_2 process. The metal cast was ductile iron grade FCD500. HC-5m was used as the nodularizer consists of Fe-Si-Mg 5% in sandwich method. HS-70 was used as the inoculant and placed inside the ladle. Tapping temperature was 1520^{O}C. The pouring temperature was varied to ensure the castability of the purposed design.

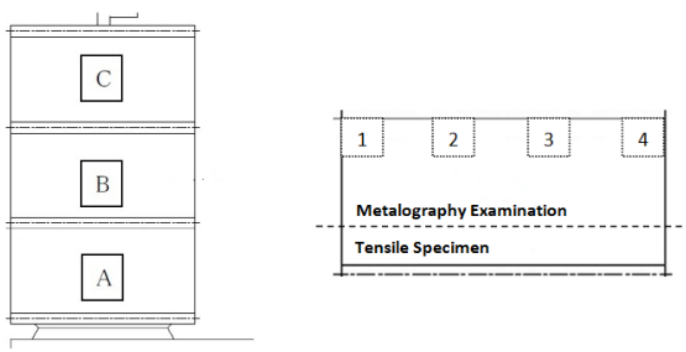


Figure 2. Sample Location

Analysis of the experiment results were conducted on macro and micro examination. Macro examination was applied on casting products to evaluate and improve the purposed design, while micro examination was applied to analyze the effect of the purposed design to cooling rate. The samples were taken from several areas as shown in Figure 2. The sample coding can be seen in Table 1.

Tabel 1. Sample Coding

Code		Pouring Temperature (°C)	Remarks
TR-1		1330	1st Pouring
	T1-A		1st Pouring – bottom plate
	T1-B		1st Pouring – middle plate
	T1-C		1st Pouring – top plate
TR-2		1360	2nd Pouring
	T2-A		2nd Pouring – bottom plate
	T2-B		2nd Pouring – middle plate
	T2-C		2nd Pouring – top plate
TR-3		1410	3rd Pouring
	T3-A		3rd Pouring – bottom plate
	T3-B		3rd Pouring – middle plate
	T3-C		3rd Pouring – top plate
R		1385	1st Pouring after Correction
	R-A		1st Pouring after Correction – bottom plate
	R-B		1st Pouring after Correction – middle plate
	R-C		1st Pouring after Correction – top plate
S1-1		1385	1st Batch – 1st Pouring Sample
	S1-1A		1st Batch – 1st Pouring Sample – bottom plate
	S1-1B		1st Batch – 1st Pouring Sample – middle plate
	S1-1C		1st Batch – 1st Pouring Sample – top plate
S1-2		1365	1st Batch – 2nd Pouring Sample
	S1-2A		1st Batch – 2nd Pouring Sample – bottom plate
	S1-2B		1st Batch – 2nd Pouring Sample – middle plate
	S1-2C		1st Batch – 2nd Pouring Sample – top plate
S1-3		1345	1st Batch – 3rd Pouring Sample
	S1-3A		1st Batch – 3rd Pouring Sample – bottom plate
	S1-3B		1st Batch – 3rd Pouring Sample – middle plate
	S1-3C		1st Batch – 3rd Pouring Sample – top plate
S2-1		1395	2nd Batch – 1st Pouring Sample
	S2-1A		2nd Batch – 1st Pouring Sample – bottom plate
	S2-1B		2nd Batch – 1st Pouring Sample – middle plate
	S2-1C		2nd Batch – 1st Pouring Sample – top plate
S2-2		1375	2nd Batch – 2nd Pouring Sample
	S2-2A		2nd Batch – 2nd Pouring Sample – bottom plate
	S2-2B		2nd Batch – 2nd Pouring Sample – middle plate
	S2-2C		2nd Batch – 2nd Pouring Sample – top plate
S2-3		1355	2nd Batch – 3rd Pouring Sample
	S2-3A		2nd Batch – 3rd Pouring Sample – bottom plate
	S2-3B		2nd Batch – 3rd Pouring Sample – middle plate
	S2-3C		2nd Batch – 3rd Pouring Sample – top plate
S3-1		1395	3rd Batch – 1st Pouring Sample
	S3-1A		3rd Batch – 1st Pouring Sample – bottom plate
	S3-1B		3rd Batch – 1st Pouring Sample – middle plate
	S3-1C		3rd Batch – 1st Pouring Sample – top plate
S3-2		1375	3rd Batch – 2nd Pouring Sample
	S3-2A		3rd Batch – 2nd Pouring Sample – bottom plate
	S3-2B		3rd Batch – 2nd Pouring Sample – middle plate
	S3-2C		3rd Batch – 2nd Pouring Sample – top plate
S3-3		1355	3rd Batch – 3rd Pouring Sample
	S3-3A		3rd Batch – 3rd Pouring Sample – bottom plate
	S3-3B		3rd Batch – 3rd Pouring Sample – middle plate
	S3-3C		3rd Batch – 3rd Pouring Sample – top plate

Results and Discussion

Modifications made on the patented design to increase the casting yield were applied on number of plates produced, number of risers and diameter of the risers. The pantented design produces 5 plates and got 6 risers. In the modified design, the plates produce were only 3 and since that only has 4 risers. Using a modul calculation presented by Wlodawer [15] as shown in Table 2, the riser diameter could be reduced to 6 mm but to facilitate the machining process the riser diameter became 10 mm. The calculation based on the modification shows that the modified design could increase the casting yield of plate to plate and riser volume of 42%. As the patented design only shows 3% as shown in Table 3.

Table 2. Calculation of Riser Diameter based on Wlodawer Equation

Part	**Dimension (mm)**	**Volume (mm^3)**	**Area (mm^2)**	**Modul = V/A**	**Calculation**
Plate	L : 150 W : 75 T : 1	11250	22950	0,5	
Riser	L : 150 ø : d	$117.75d^2$	$1{,}57d^2+471d$	$M_R = 1{,}2.M_P$ $M_R = 0{,}6$	$(117.75d^2) / (1{,}57d^2+471d) = 0{,}6$ $d = 6$

Table 3. Calculation of Riser Diameter based on Wlodawer Equation

Design Code	**Volume (mm^3)**			**Weight (kg)**			**Casting Yield**
	Plate	**Riser**	**Total**	**Plate**	**Riser**	**Total**	**(%)**
Patented	56250.0	2137162.5	2193412.5	0.41	15.60	16.01	$2{,}56 \approx 3{,}00$
Modified	33750.0	47100.0	80850.0	0.25	0.34	0.59	$42.37 \approx 42$

The simulation process was run after the calculation of gating system and the completion of casting dimension. The simulation was run with pouring temperature of 1400^{O}C. The simulation results, as shown in Figure 3, shows that the purposed modified design was filled completely and the last part to be solidified was the riser.

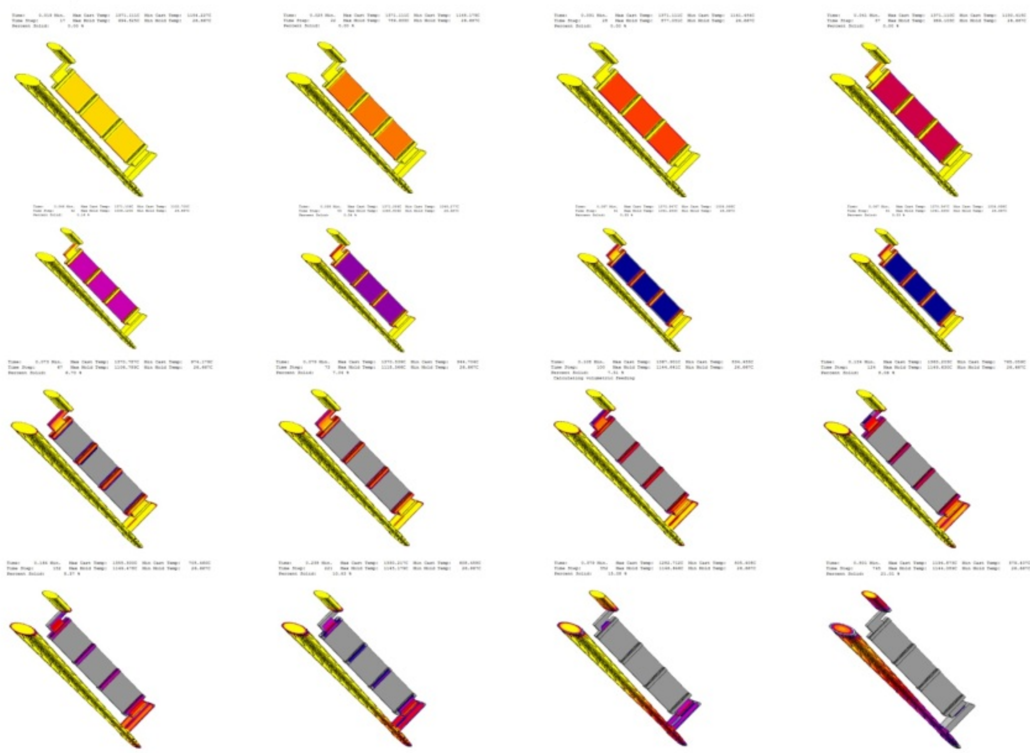


Figure 3. Solidification Process.
The sequences of the pictures are left to right and back left to right in the next row.
Solid phase represented by grey color

The colors shown in Figure 3 represent temperatures. The highest temperature was represented by yellow and the lowest was by grey color. Grey color also represent solid phase. As demonstrated in Figure 3, the fast color changing was noted to happen in plate part. The colors in risers and gating system changed very slowly even looked like unchanged. After all the plates turned grey, colors of the risers were started to change, followed by the ingate, runner and gas tunnels. Down sprue was the last one to solidify. Based on the solidification sequences shown by the simulation result the purposed modified design can produce TWDI plates.

TR-1 TR-2 TR-3

Figure 4. Casting Products for Purposed Modified Design

Casting process took place after the simulation analysis to calibrate it. The casting process was held in three pouring temperatures of 1330, 1360 and 1410^{o}C. The result of the casting process are shown by Figure 4. The results of casting process was not in line with the simulation. This can happened because every casting simulation software should first be calibrated by experiment. The casting product of 1330^{O}C pouring temperature shows only 1 riser and 1 plate were formed but both forrmed completely. As the casting product of 1360^{o}C pouring temperature showed that only 3 risers and 2 plates were formed with only the first and second risers formed completely. The casting product of 1410^{O}C shows that only two plates were formed but they formed completely and 3 risers with only 2 risers formed completely. Based on this observation, it was concluded that failure occurred due to the lack of hidrostatic pressure since the number of parts formed increase as the pouring temperature increase. The viscosity of molten metal tends to decrease as the temperature increase. To overcome this problem the height of down sprue should be increased.

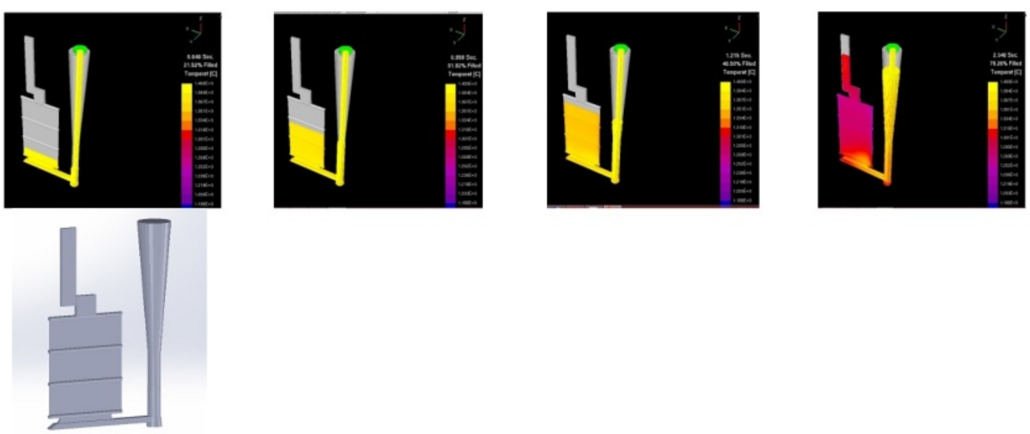


Figure 5. Simulation of Filling and Solidification Process of Repaired Modified Design

The height of the down sprue was increased from 380 mm to 560 mm. The new purposed modified design was simulated again and the result can be seen in Figure 6. The result of filling process presents smoother filling and the solidification run as the first trial. Casting process was carried out and the result was presented in Figure 6. The pouring temperature was 1385^{O}C and the filling rate was 3 second. This time, the result of casting process followed the simulation. All the plates and other parts were formed completely.

Figure 6. Casting Product for Repaired Modified Design

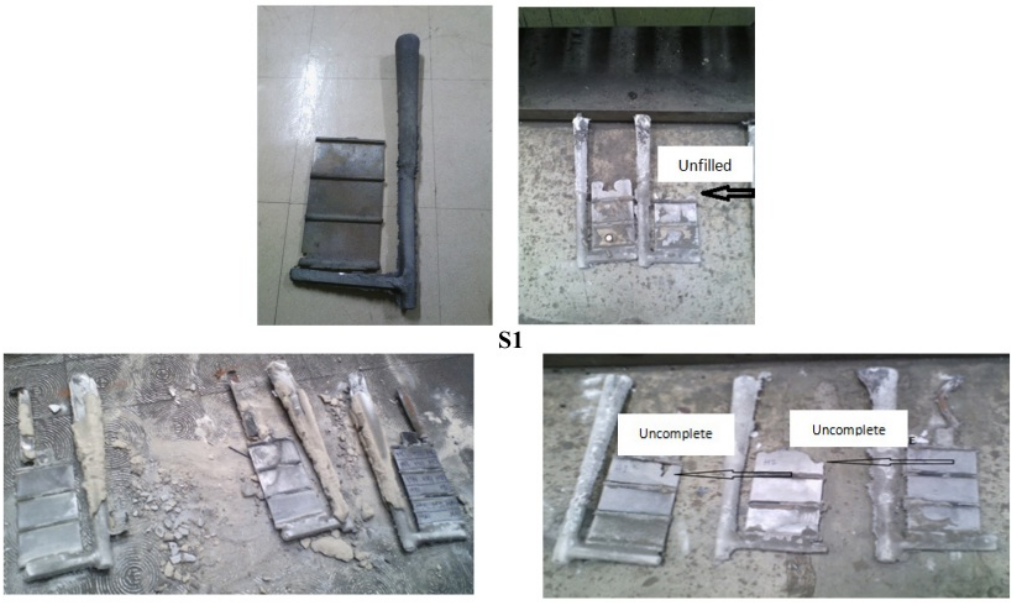


Figure 7. Casting Product from Repaired Modified Design for Testing Samples

Table 4. Casting Yield of Each Design

Design Code	Weight (kg)		Casting Yield
	Total Cast	Plate	(%)
Patented	30,0	0.41	1.37
Modified	0,9	0.25	27.78

Casting process of the repair-modified design continued to produce samples. The process was using three different batch of FCD500 with various pouring temperatures. The results show that not all of the plates were fully casted as were presented in Figure 7. This happened due to the discontinuity during the pouring process. The pouring process was disturbed due to the condition of the ladle.

The calculation of casting yield regarding the modified design was presented in Table 4. The casting yield increased from 1.37% to 27.78%. It was still below the casting yield that was calculated based on total weight of plates and risers due to the presences of gating system.

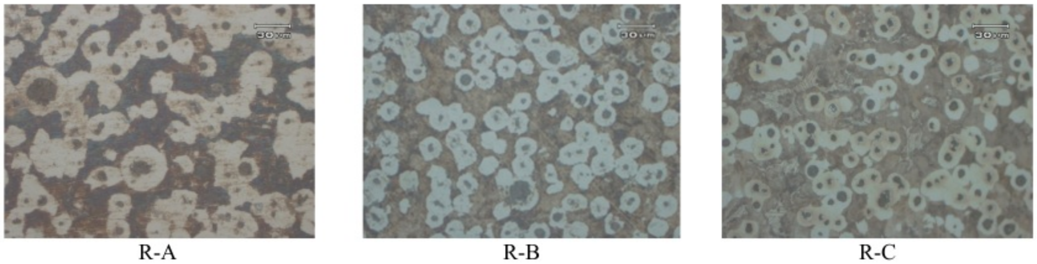


Figure 8. Microstructure examination of repaired modified design – etched

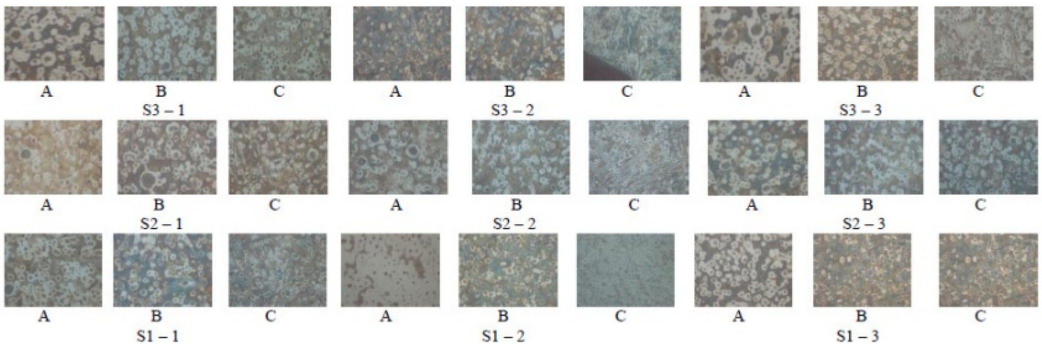


Figure 9. Microstructure examination of sampels – etched

Microstructure examination shows that all the plates have nodule graphite in pearlitic matrix as shown in Figure 8 and 9, while the microstructure of the patented design was nodule graphite in ferrite matrix. This happened because the modified design was smaller and has higher cooling rate.

Conclusions

Modification was made to a patented casting design to increase its casting yield. The modification covered reduction of plate number that automatically reduced the number of the risers and also the resizing of riser diameter. This modification improved the casting yield to 27,78%. The modification also enhanced the cooling rate of the design which is shown by the formation of nodule graphite in the pearlite matrix as the microstructure.

Casting simulation has an important role in design modification since casting simulation could reduce the trial and error proces. However the result of casting simulation is not always in line with the experiment. Therefore, casting simulation should be verified and calibrated by experiment.

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