The Application of Thin Wall Ductile Iron Process in Connecting Rod

by Rianti Dewi

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Abstract. The aim of applying thin wall casting (TWC) technique in ductile iron is to restore the uses of ductile iron in automotive components. TWC will allow ductile iron to compete with lightweight materials, such as aluminium. Nowadays, lighter weight automotive components are needed to reduce fuel consumptions. Applying TWC technique, also known as thin wall ductile iron (TWDI) and thin wall austempered ductile iron (TWADI), in ductile iron also meant guaranteeing that the quality and characterization of the ductile iron are not compromised. This study attempts to investigate the thinnest part of I-beam that can be produced without disturbing the quality and characterization of ductile iron following the outcome of I-beam thickness changing from 4 to 3 mm. The casting design used in this study is the same casting design used in previous study. All the designs were analyzed using Z-Cast simulation software and feasibility for production is examined. All the designs were then casted in a foundry to verify the result of simulation. The cast products were tested in a metallography examination and a tension-compression test which will be discussed comprehensively in other studies. The cast products showed that thin wall ductile iron connecting rod with an I-beam thickness of 2 mm can be produced. Further study for 1mm beam thickness is still needed.
Keywords: TWDI, TWADI, connecting rod, vertical casting, design.

INTRODUCTION

Weight of materials is important parameter since force is a product of weight and velocity. Lighter weight with equal velocity will result in lower force. This leads to an increase in the use of lightweight materials. Aluminium is preferred over steel and cast iron although its fluidity and formability are lower than cast iron and steel as ferrous metals. To overcome this matter and to regain the uses of cast iron, thin wall casting as a new casting technology is presented.

Thin wall casting is a casting technology that is able to produce casting products with wall thickness of less than or equal to 5 mm in parts or all over its parts. This definition was based on Caldera [1]; while Stefanescu took it equal to below 3 mm [2]. Both applied thin wall casting in producing ductile iron plate, known as thin wall ductile iron (TWDI) plate. The thinnest TWDI plate is 1 mm [3].

Martinez et.al [4] applied thin wall casting method in producing hollow connecting rod for two-cylinders prototype engine. In this research Martinez et.al able to reduce its weight for up to 33%. While Sulamet-Ariobimo et.al gain weight reduction to 27% when applying thin wall casting method to the connecting rod of Vespa PX150 as presented in Fig. 1 [5]. The difference between the thin wall connecting rod made by Sulamet-Ariobmo et.al [5] to Martinez et.al [4] is in the design used in the I-rod area.

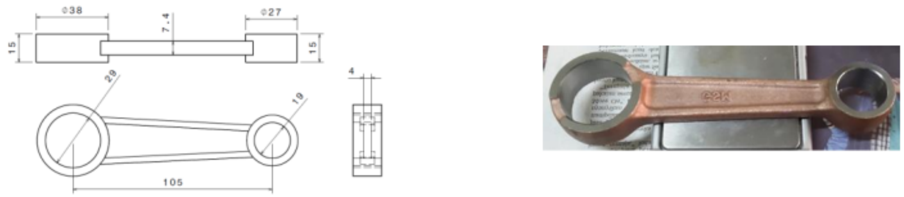


Figure 1. Connecting rod of Vespa PX150

Unlike Martinez et.al [4] who made the hollow connecting rod, Sulamet-Ariobimo et.al applied thin wall casting technique by reducing the thickness of I-beam as presented in Fig. 2. They chose this modification to avoid the difficulty of using the core in mould making process. In the first step, they reduced the I-beam thickness from 4 mm to 3 mm. And based on the result of the previous studies, they reduced the thickness from 3 mm to 1 and 2 mm.

To ensure that TWDI plates and components can be produced by all foundries, even the small scale one, Sulamet-Ariobimo et.al chose not to interfere with the processes running in the foundry and made casting designs to produce thin walls. They began their projects with making casting designs to produce TWDI and TWADI plates [6], [7] [8]. Through these projects they were able to determine the key parameters regarding TWDI design. Based on that finding, they built designs for TWDI and TWADI components [5], [9], [10].

The aim of this studies is to discover the lowest possible wall thickness to be applied to the I-rod in order to reduce weight of the connecting rod without decreasing the quality of ductile iron and still fulfilling design requirements.

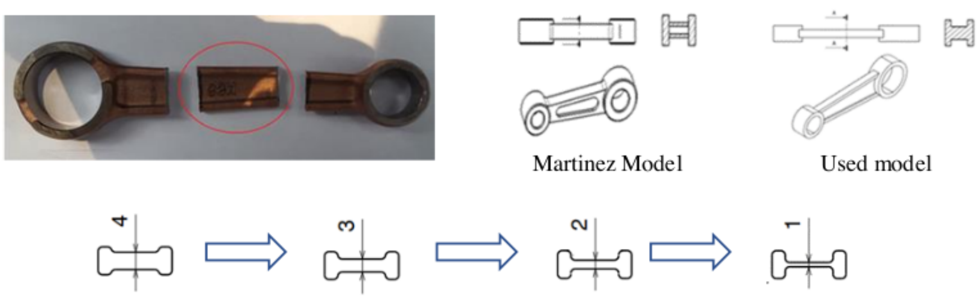


Figure 2. Modified Area and Modification

EXPERIMENTAL METHODS

Casting design was built based on patented casting design number IDP000070457 deigned to produce three plates of TWDI with 1 mm thickness with the matrix of pearlite as presented in Fig. 3.a [8]. This design was the modification of casting design with the patent number IDP000039503[6] as presented by Fig. 3.b. The purposed casting design can be seen in Fig. 4. This design was made to produce connecting rod with I-beam thickness of 3 mm [5]. This design was then developed to produce connecting rods with the I-beam thickness of 2 and 1 mm.

The casting designs were then analyzed using Z-Cast simulation for filling, solidification and defects. Z-Cast is a casting simulation made by KITECH – South Korea. Z-Cast estimates the mould filling process and metal solidification. The boundary conditions of Z-Cast are cast material, mould material, pouring time, pouring temperature and heat transfer coefficient. Color scheme in filling process reveals the condition of temperatures in molten metal. The temperature unit is degree Celsius (^{O}C) and degrade from white to blue in color. In the solidification process, color indicates temperature as well as the filling process. The blue color in this process indicates phases changing from molten to solid metal. Lighter blue color is associated with lower temperature and tendency of solidification process completion. Blue and red color schemes in shrinkage mode indicate shrinkage. Red indicates shrinkage in products, while blue indicates shrinkage in the gating system. These results indicate a need for scrutiny because in certain designs, the simulation cannot clearly recognize the function of each part.

The previous design was directly applied to the design of connecting rod with I-beam thickness of 2- and 1-mm. Modification is only applied in the thickness of the I-beam. The designs were simulated in Z-Cast. Following the result of Z-Cast analysis, the casting designs were then improved. The improvement was made based on the shrinkage simulation results. Coding of the design is presented in Table 1. The coding is divided into three groups. The first one is for the basic design produced by the previous study. The code used is also the code used in previous study. The second group is for the direct application of casting designs, and the third one is for the improved designs.

a. Patented No. IDP000039503　　　b. Patented No. IDP000070457

Figure 3. Casting Design.

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

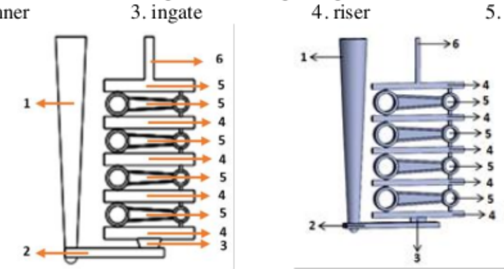


Figure 4. Casting Design

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

Table 1. Coding of the Design

Code	Description
D – S4M [5]	Basic design for 3 mm I-beam thickness
D – 2mm	Modified design for 2 mm I-beam thickness
D – 1mm	Modified design for 1 mm I-beam thickness
DM1 – 1mm	Modified design in ingate for 1 mm I-beam thickness – enlargement of ingate dimension
DM2 – 1mm	Modified design in ingate for 1 mm I-beam thickness – removing ingate

The improved designs were produced in foundry scale to verify the simulation results and casting yield were calculated to find out the weight reduction. Chemical composition uses in casting process can be seen in Table 2. Metallography examination and compression test were conducted to guarantee the quality of TWDI materials.

RESULT AND DISCUSSION

In their previous study, Sulamet-Ariobimo et.al were able to produce thin wall connecting rod with I-beam thickness of 3 mm. This I-beam can improve casting yield to up to 41% and reduce weight to up to 3.5% from normal connecting rod with I-beam thickness of 4 mm using FCD450 and 13.4% from original component using SCM420 [5]. This study then continues by using the casting design to produces lighter connecting walls by reducing I-beam wall thickness to 2 and 1 mm.

The comparison of the filling process is presented by Fig. 5. The filling process in D-S4M [5] appears slower when compared to D-2mm and D-1mm. Upon verification with the simulation data, D-S4M needed 1.5 second to reach 30% volume, while D-2mm and D-1mm were able to reach 45% volume in 0.8 and 0.769 second, respectively. The temperature colors inside the cavities are a mixture between yellow and orange, with yellow dominant. D-1mm has more orange color compared to the others. During the filling process, temperature drop (showed by blue color) happens in D-1mm within the first connecting rod. This may be associated with premature solidification. All fillings managed to reach 100% volume and blue color appears in all designs with varying percentages. The highest occurs in D-S4M and the lowest occurs in D-2mm. This is also an indicator that filling process in D-S4M requires more time than D-2mm and D-1mm. This also confirms that premature solidification will not occur as long as there are still molten metals running through the system. In the solidification process, blue color is seen in the I-beam and dominates D-1mm and D-S4M. Blue color indicates the source of solidification. I-beam is the thinnest part in the component; therefore, the initiation of solidification is appropriate. While at 100% solidification, the final zone to have completed the solidification process is the freeze zone located in the riser connected to the ingate. This also supports the casting designs. Data gained from the simulation reports show that D-S4M has the fastest solidification rate at 340 seconds to reach 100% volume, while D-1mm has the lowest, at 388 seconds. But based on the blue color gradation, although D-2mm has faster solidification time, D-1mm has lighter blue color. While in D-1mm, blue shrinkage is found in the area of ingate. It is also seen that the highest amount of shrinkage can be found in D-S4M, follow by D-2mm. D-1mm has the smallest one. These results should be noted, because ingate shrinkage may possibly cause issues in the finished product.

Table 2. Chemical Composition of Liquid Metals

Chemical Composition % Weight		**Standard ASM Handbook**	**Modified Connecting Rod – I-beam Area**		
			3 mm [5]	**2 and 1 -mm**	
				Batch – 1	**Batch – 2**
Carbon	C	3.600 – 3.830	3.620	3.670	3.810
Silicon	Si	1.800 – 2.800	2.540	2.680	2.650
Manganese	Mn	0.150 – 1.000	0.420	0.440	0.400
Copper	Cu	0.015 – 1.000	0.230	0.270	0.190
Chromium	Cr	0.030 – 0.070	0.090	0.003	0.050
Nickel	Ni	0.050 – 2.000	0.007	0.001	0.010
Manganese	Mg	0.030 – 0.060	0.040	0.005	0.040
Phosphor	P	< 0.3000	0.020	0.001	0.010
Sulphur	S	< 0.020	0.020	0.002	0.010
Molybdenum	Mo	0.01 – 0.100	0,00	0.010	0.010
Carbon Equivalent	CE	4.59	4.47	4.37	4.70

Based on this finding, modifications are made to D-1mm since the shrinkage profile, although its color is blue, suspected occurs on products. The modifications are made as presented by Fig. 6 and Fig, 7. Modification in Fig. 6 shows enlargement in both ingate from 5 mm to 7.5 mm. While modification in Fig. 7 removes the ingate, allowing the product to act as the ingate.

The filling results for improved design as presented by Fig. 5 show that filling process in DM2-1mm is faster than DM1-1mm. In 0.514 second, DM2-1mm is able to fill 30.025% of the volume; while DM1-1mm is only able to fill 30.0018%. This is in line with the modification applied to DM2-1mm, which removes the ingate and allows the product to serve as the ingate. The same conditions will also occur when comparing the filling speed of DM2-1mm to previous designs. DM2-1mm reaches its 100% filling in 1.703 second. Both DM1-1mm and D-1mm need 1.704 seconds to reach the 100%. A drop in temperature happens in both improved designs, with DM1-1mm having highest percentage. Both designs are able to reach its 100% filling volume and during the final filling. DM2-1mm has no trace of blue color. When compared to all designs D-S4M still has the highest percentages of blue color and DM2-1mm has no trace of it. Blue color is seen in the I-beam in the beginning of solidification process and dominating in all designs except D-2mm. In D-2mm there is also blue color but the blue color is not dominating as much as in the other design. It just located in the middle of I-beam. As is the case with previous designs, the direction of solidification and last to freeze zone are in compliance. D-S4M still has the fastest solidification rate at 340 seconds to reach 100% volume, while DM1-1mm has the lowest at 390 seconds. Shrinkage result of DM1-1mm shows that the improved design is able to move the shrinkage to riser and ingate. Meanwhile DM2-1mm obtains opposing results: shrinkage take place within the big rod. This finding shows that eliminating ingate is not a right choice.

Based on the analysis of simulation result, D-2mm and DM1-1mm are cast. The result of the casting process is presented in Fig. 8. There are two results for 2- and 1-mm I-beam thickness since there are challenges during the pouring process which caused product failure. The failure is attributed to the discontinuity during the pouring process and mold leakage, therefore not design-related. In the second pouring, connecting rod with 2 mm thickness of I-beam was successfully produced, but vice versa for the 1 mm thickness of I-beam. Further analysis is needed to resolve this issue.

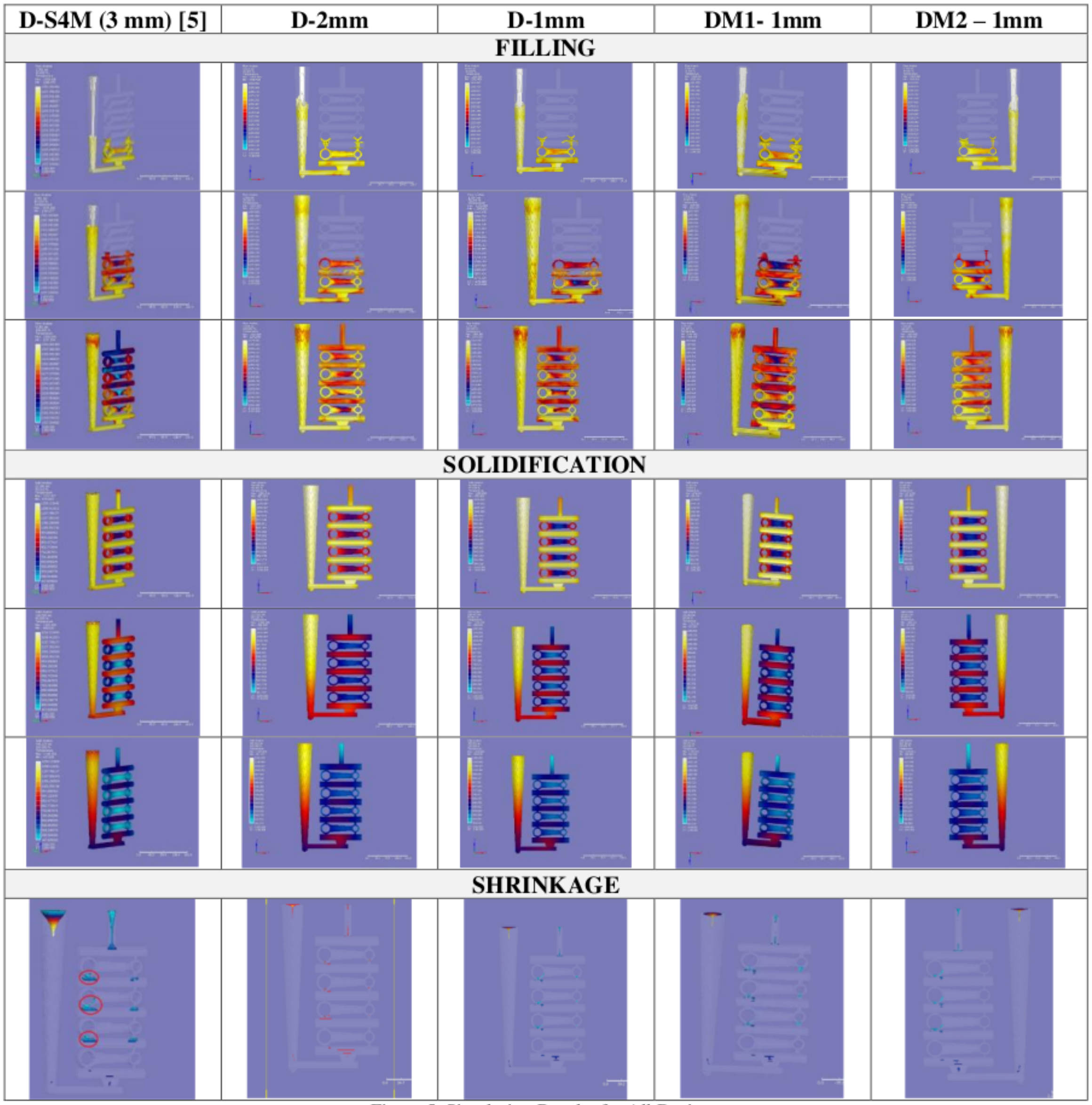


Figure 5. Simulation Results for All Designs

a. Design of D-S4M b. Improved Design for DM1-1mm

Figure 6. Modification of Ingate for D-1mm

a. Design of D-S4M b. Improved Design for DM2-1mm

Figure 7. Modification of Ingate for D-1mm

a. I-beam Thickness 3 mm b. I-beam Thickness 2 mm c. I-beam Thickness 1 mm

Figure 8. Casting Products

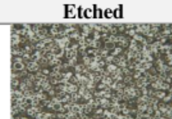
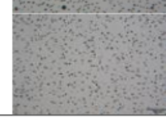
I-beam thickness	Rod-end		I-beam	
	Un – etched	Etched	Un – etched	Etched
3 mm				
2 mm				

Figure 9. Metallography Examination

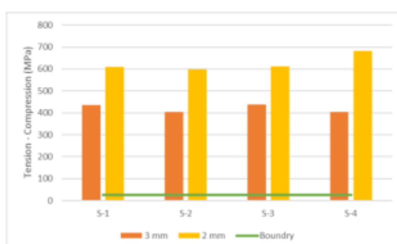


Figure 10. Compression Strength

The result of Metallography examination for both 3- and 2-mm thickness is presented in Fig. 9. The microstructure of both types is nodule graphite in pearlitic matrix. The un-etched microstructure of 3 mm I-beam thickness shows the existence of primary graphite. The graphite tends to be smaller in I-beam. Compression–tension test was chosen as the method for mechanical testing due to the load that will be borne by the connecting rod. The result is presented in Fig. 10. The green line is the load that the connecting rod must accommodate. The instrinsic compressive strength of TWDI surpasses its strenght requirements.

CONCLUSIONS

The conclusions of this study are:

1. The thinnest part applied in connecting rod without degrading its quality is 2 mm I-beam thickness.
2. Casting design of the 3 mm I-beam thickness can be applied directly to make 2 mm.
3. Metallography examination reveals that the microstructure of TWDI connecting rod is nodule graphite in the pearlitic matrix and the compression strength of TWDI connecting rod was able to fulfil the requirement needed by connecting rod.
4. In making a cast product, casting design is just one of many parameters that will support the casting soundness products.
5. Premature solidification will not occur as long as there are still molten metals running through the gating system.
6. In modifying casting design, care should be taken to ensure that the right design decisions are made. The use of casting simulations are recommended.
7. In casting process, smaller or thinner dimension is not directly associated with rapid cooling rate.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Faculty of Industrial Technology Universitas Trisakti for the research funding. Department of Metallurgy and Material Engineering Faculty Universitas Indonesia and KITECH – Korea for Z-Cast Simulation Software. Last but not least, PT. Geteka Founindo for producing the connecting rod prototype.

REFERENCES

[1] M. Caldera, ; M Chapetti, J. M. Massone, and J. A. Sikora, “and Technology,” 2007.

[2] D. M. Stefanescu, L. P. Dix, R. E. Ruxanda, C. Corbitt-Coburn, and T. S. Piwonka, “Tensile Properties of Thin Wall Ductile Iron.”

[3] J. W. Soedarsono and R. Dewi Sulamet-Ariobimo, “Effect of casting design to microstructure and mechanical properties of 1 mm TWDI plate,” in *Applied Mechanics and Materials*, 2012, vol. 110–116, pp. 3301–3307. doi: 10.4028/www.scientific.net/AMM.110-116.3301.

[4] R. Martinez, R. A. Martínez, R. E. Boeri, and J. A. Sikora, “Applications of ADI in high strength thin wall automotive parts,” 2002. [Online]. Available: https://www.researchgate.net/publication/266186440

[5] “Thin Wall Austempered Ductile Iron Connecting Rod for Lighter Automotive Component-Production of Thin Wall Ductile Iron Connec…,” 2017. [Online]. Available: https://www.sae.org/publications/technical-papers/content/2017-32-0125/

[6] B. Suharno, J. W. Soedarsono, T. P. Soemardi, and R. D. Sulamet-Ariobimo, “The effects of plates position in vertical casting producing thin wall ductile iron,” *Advanced Materials Research*, vol. 277, pp. 66–75, 2011, doi: 10.4028/www.scientific.net/AMR.277.66.

[7] J. Wahyuadi Soedarsono, T. Priyana Soemardi, B. Suharno, R. Dewi Sulamet-Ariobimo, E. Zulfikar Damanik, and W. Dwi Haryono, “Effect of the Austempering Process on Thin Wall Ductile Iron,” 2011.

[8] R. D. Sulamet-Ariobimo, Y. Gemilang, D. Dhaneswara, J. W. Soedarsono, and B. Suharno, “Casting design modification to improve casting yield in producing thin wall ductile iron plate,” in *Materials Science Forum*, 2018, vol. 929 MSF, pp. 10–17. doi: 10.4028/www.scientific.net/MSF.929.10.

[9] R. D. Sulamet-Ariobimo, M. Fadlan, S. Kamili, T. Sukarnoto, Y. Mujalis, and Y. Oktaviano, “Effects of Austempering Process to Mechanical Properties of Thin Wall Ductile Iron Connecting Rod,” in *IOP Conference Series: Materials Science and Engineering*, Sep. 2019, vol. 547, no. 1. doi: 10.1088/1757-899X/547/1/012051.

[10] R. D. Sulamet-Ariobimo *et al*., “The effects of austenitizing process to mechanical properties of thin wall ductile iron connecting rod,” in *AIP Conference Proceedings*, Sep. 2020, vol. 2262. doi: 10.1063/5.0016141.

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