Effects of Austempering Process to Mechanical Properties of Thin Wall Ductile Iron Connecting Rod.

by Rianti Sulamet-ariobimo

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R.D. Sulamet-Ariobimo[1]* **M. Fadlan**[1], **S. Kamili**[1], **T. Sukarnoto**[1], **Y. Mujalis**[1] **and Y. Oktaviano**[1]
[1]Mechanical Engineering Department, Faculty of Industrial Technology, Universitas Trisakti, Jakarta, Indonesia

*Corresponding author (E-mail): riantiariobimo@trisakti.ac.id

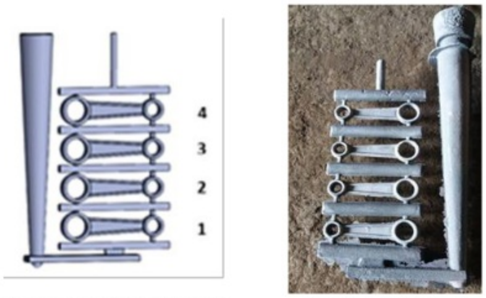
Abstract. Austempering process was carried out on thin wall ductile iron (TWDI) connecting rod produced by the design built in previous research. Austempering process was applied to improve the mechanical properties of the component, so it will be equal to forged steel. The aim of this work is to study the effects of austempering holding time to microstructure and mechanical properties of TWDI connecting rod. The process was applied to all connecting rods resulting from the vertical casting. The austenitising temperature was 960^0C with 35 minutes holding time and the austempering temperature was 350^0C with varied austempering holding time, that were 15, 30, 45 and 60 minutes. The process was held in fluidized bed furnace. Metallographic examination, tensile and compression stress-strain test were conducted directly to the connecting rod. The results showed that austempering process improved the mechanical properties of TWDI connecting rod and the result of the compression stress-strain test showed that the austempered TWDI connecting rod met its requirements.

Keywords: TWDI, TWADI, connecting rod, vertical casting, holding time.

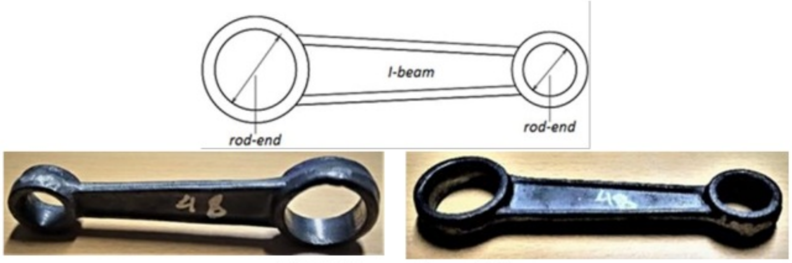
1. Introduction

The needs of lighter automotive components for fuel saving have enhanced the application of thin wall casting technology on ductile iron which is known as thin wall ductile iron (TWDI). Casting design to produce TWDI connecting rod was established [1,2] and the connecting rod was produced [3]. Preliminary examination on the connecting rod showed that the casting design was able to produce connecting rod without any major defects such as porosity or shrinkages [1] as presented in Figure 1. The connecting rod was built based on the casting design which was patented with patent number IDP000039503 and IDP000040306 [1-10]. It uses vertical casting system with counter gravity flow to adjust the filling speed. This casting design is different from the design made by Martinez et al [11].

Properties of produced connecting rod should be improved to fulfill the requirement. The improvement will be made through austempering process. Austempering process on ductile iron was able to improve its properties to be similar or even higher than forged steel [11,12] and known as Austempered Ductile Iron (ADI).



(a) Established design [1,2,3] (b) Casting products.



(c) TWDI connecting rod [3]

Figure 1. Casting design and products.

Austempering process will cover heating to austenitization temperature, holding in austenization temperature and following by austempering process which is isothermal quenching to a media with temperature of 250 to 400^0C [13] for several times before cooling in air to reach room temperature. Adjustments should be made if austempering process is applied to TWDI since the thickness of TWDI is only 5 mm or below. Soedarsono et al applied austenitization temperature of 960^oC for 30 minutes and austempering temperature of 350^0C for 10 minutes in their research to make thin wall austempered ductile iron (TWADI) plate which increased the UTS between 44 to 309% and elongation between 50 to 100% [12]. The objective of this study is to analyze the effect of isothermal quenching duration of thin wall ductile iron connecting rod components.

2. Materials and Methods

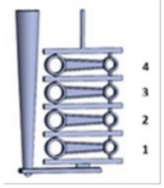
TWDI Connecting rods were produced in industrial foundry using vertical casting design. The chemical composition was presented in Table 1. Each mold of the casting design produced 4 connecting rods and 4 molds were produced in one pouring. This study used 2 pouring. The first pouring was directly characterized and the second one was austempered.

Austenitization temperature for the austempering process was 960^0C with 35 minutes holding time. Then, the connecting rods were directly moved to fluidized bed furnace for isothermal cooling. Fluidized bed furnace which is more environmental friendly was used as isothermal media replacing salt-bath. The durations of the isothermal cooling were varied to 15, 30, 45 and 60 minutes. The durations were applied to every mold. The codes for all connecting rods were presented in Table 2.

Table 1. Chemical Composition of TWDI

Element		**ASTM Standard** (% weight)	**Testing Result** (% weight)	
			Pouring – 1	**Pouring – 2**
Carbon	(C)	3,60 – 3,80	3.67	3.60
Silicon	(Si)	1,80 – 2,80	2.78	2.80
Manganese	(Mn)	0,15 – 1,00	0.35	0.40
Magnesium	(Mg)	0,03 – 0,06	0.04	0.04
Phosphor	(P)	< 0,30	0.01	0.01
Sulfur	(S)	< 0,02	0.01	0.01
Copper	(Cu)	0,015 – 1,00	0.22	0.20
Chromium	(Cr)	0,03 – 0,07	0.06	0.06
Nickel	(Ni)	0,05 – 2,00	0.04	0.05
Molybdenum	(Mo)	0,01 – 0,10	0.01	0.01
CE – 1	%[illegible] + 0,31%Si		4,53	4,47
CE – 2	%C + 0,31%Si +0,55%P-0,027%Mn+0,4%S		4,53	4,47

Table 2. Samples Coding

	Pouring 1 – TWDI		**Pouring 2 – TWADI**	
	Code	**Condition**	**Code**	**Condition**
	A	Extended Pouring Cup Normal Coating	A	Normal Pouring Condition Isothermal Quenching for 15 min.
	B	Normal Pouring Cup Normal Coating	B	Normal Pouring Condition Isothermal Quenching for 30 min.
	C	Normal Pouring Cup No Coating	C	Normal Pouring Condition Isothermal Quenching for 45 min.
	D	Extended Pouring Cup Special Coating	D	Normal Pouring Condition Isothermal Quenching for 60 min.

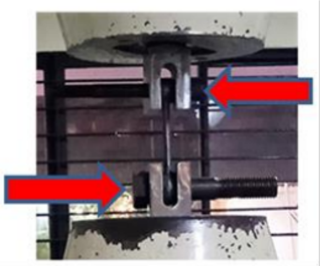


Figure 2. Special holder for tensile and compression test

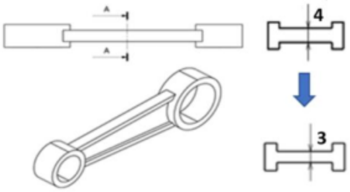


Figure 3. Thickness reduction in I-beam area [1-3].

After austempering process, all the connecting rods were subjected to mechanical testing which cover tensile and compression test. The test was run directly to the connecting rod. Special holder, as presented in Figure 2, was used during the test to hold the connecting rod. Universal Testing Machine (UTM) Shimadzu EHP-EB20186838 was used for tension testing. The maximum load was 20 ton and testing speed was 0.05 mm/mm/minute with level of confidence 95%. Gotech AI – 7000 LA10 Servo Control Computer System Universal Tensile Machine with the maximum capacity of 1000 kg was used for compression test. Calculation for compression strength was based on the area of the I-beam since modification was applied only to that area as shown by Figure 3. On the other hand, tensile strengths were not calculated because the break point happened in rod area as presented by Figure 4. The I-beam area calculation were presented in Table 3.

Samples for metallography examination were taken from the cross section of the connecting rods which have been tested in tensile and compression. The metallography samples were taken from I-beam and end rod area as presented in Figure 5.

Table 3. Area of I-beam

Rod Position	**I-beam Area – in mm^2**							
	Pouring 1 – TWDI				**Pouring 2 - TWADI**			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
1	42.07	37.02	39.05	49.15	49.51	46.44	50.40	51.81
2	44.24	40.76	41.08	43.01	49.59	51.04	49.78	52.61
3	41.10	39.24	42.11	40.00	49.04	50.48	50.08	50.41
4	-	-	-	-	50.00	48.82	51.30	53.07

Figure 4. Break point during tensile test.

Figure 5. Metallography samples

3. Results and Discussion

Chemical composition test results showed that all elements are beyond the limit of ASTM standard for both pouring except for nickel in Pouring 1. Nickel content in the first pouring is 20% below the minimum level. Usually, nickel is added to ductile iron to improve its tensile strength and hardenability. Since connecting rods from Pouring 1 were not austempered then the lack of nickel will not give any significant effect.

Carbon equivalent (CE) calculation results presented by Table 1 show similar number for 2 equations in all pouring. There are 1.3% differences between CE values from Pouring 1 to Pouring 2 but this difference is not significant. CE calculation for both pouring are in the limit for TWDI [11,14]. Based on the CE values which are all below 4.67 the matrix of the microstructure will not be 100% ferrite [4,9].

Figure 6 shows the un-etched microstructure of TWDI and TWADI. The size of graphite formed in rod-end area of TWDI tends to be bigger compared to the one formed in I-beam [SENAMM]. Primary graphite is also formed more in rod-end than I-beam. Graphite distribution in rod-end is more even than in I-beam area. The un-etched microstructure of TWADI showed more even graphite distribution and graphite count in both I-beam and rod-end area than TWDI, but as well as TWDI, the size of graphite in I-beam is finer than rod-end. Primary graphite only formed in the end-rod although it is not as much as in TWDI. This condition will result in higher mechanical properties.

The etched microstructure of TWDI as presented in Figure 7 shows that the matrix is not 100% ferrite. This is supported by CE values which is below 4.67. It has the matrix of ferrite-perlite. Matrix formation in I-beam is not similar with rod-end. Austempering process tends to overcome this problem. As seen in Figure 7, after austempering process the matrix in I-beam is similar to rod-end.

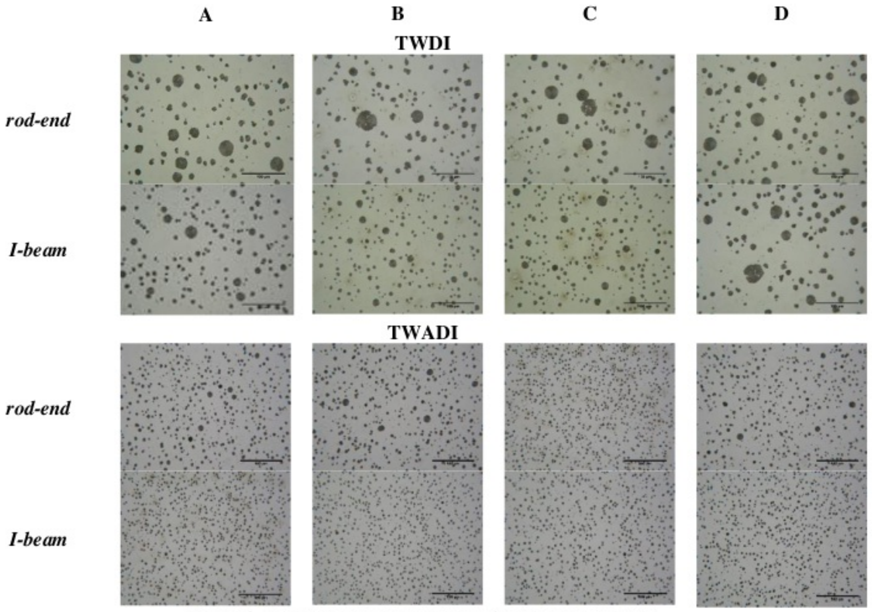


Figure 6. Un etched microstructures of TWDI and TWADI

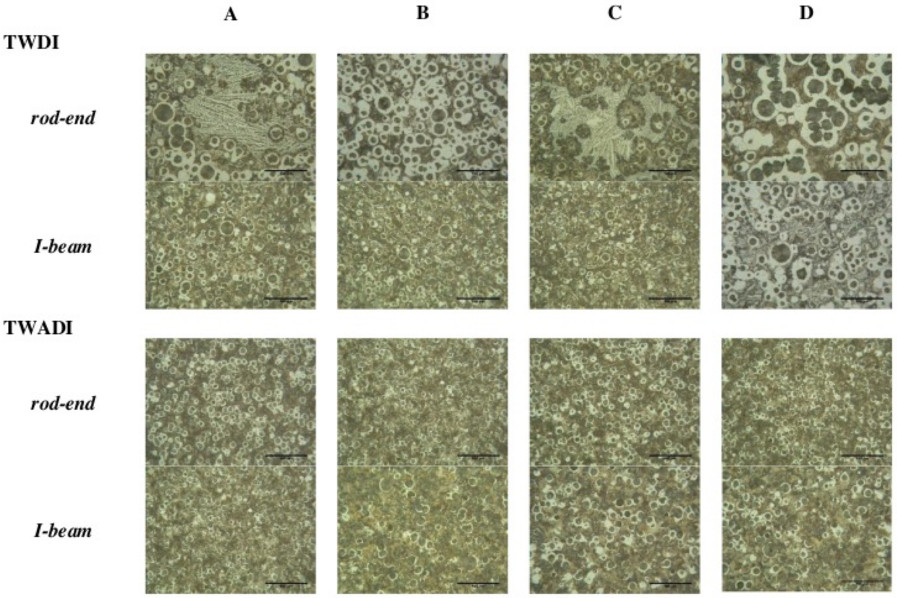


Figure 7. Etched microstructures of TWDI [3] and TWADI

As mention previously, the tension and compression testing were applied directly to the connecting rod. Tensile strength is not calculated since the broken point was not happening in the I-beam. But this condition shows that reducing the thickness of I-beam is not detrimental to the connecting-rod. Evaluation of tensile testing is based on the load used to break the connecting rod. Figure 8 shows that all variations made to the pouring process of TWDI do not give any significant improvement. Even the normal pouring condition gives the highest values for all casting position. Austempering process improves the tensile load as presented in Figure 9. The tensile load of TWADI increases between 115 to 147%. The highest tensile load is found in casting position 3 for all process conditions. As shown by TWDI, TWADI tensile load look similar for all casting position. There are no significant differences between the tensile load. Tensile load tends to decrease as duration of austempering process increases.

Compression load of TWDI, as shown in Figure 8, shows the same tendency as the tensile load, which shows no significant differences between each pouring condition. But not like the tensile load the highest compression load is found in the use of extended pouring cup together with use of special coating treatment. Compression load is 46% higher than tensile load. Compression strengths of TWDI also do not show any significant differences. TWADI compression load increase between 107 to 130% and compression strength increase between 63 to 93%. Compression load and strength tends to increase as the duration of austempering process increases. Closer examination on connecting rod 1 TWADI D reveals that lower compression load and strength shows in Figure 9 is caused by casting defect form in the connecting rod.

In contrast with tensile strength, compression strength should be calculated to determine the ability of TWADI connecting rod replacing the previous one. Compression strength of the previous connecting rod is 15 kg/mm2, while the compression strengths of TWADI connecting rod calculated based on I-beam area are between 67 to 79 kg/mm2. Based on the compression strength the TWADI connecting rod can be used to substitute the previous connecting rod.

4. Conclusions

The result of tensile and compression from TWDI show that variation applied in the pouring process do not give significant effect. The highest tensile load gain is 1280 kg and the lowest is 890 kg. While the highest compression load is 1980 kg and the lowest is 1500 kg. The highest compression strength is 44 kg/mm^2 and the lowest is 40 kg/mm^2.

Austempering TWDI will produce similarity of microstructure formation in I-beam and end-rod which will enhance the mechanical properties. In this study, austempering process improves the tensile load by 115 to 147%. The highest tensile load of TWADI is 2800 kg and the lowest is 2075 kg. While in compression test, austempering process improves the compression load by 107 to 130% and compression strength by 63 to 93%. The highest compression load is 4097 kg and the lowest is 3449 kg. The highest compression strength is 79 kg/mm^2 and the lowest is 67 kg/mm^2. Tensile load tends to decrease as the duration of austempering process increase. Compression load tends to increase as the duration of austempering process increase.

Based on the calculation of compression strength using I-beam area, the TWADI connecting rod can be used as substitute to the Vespa New PX 150.

5. Acknowledgements

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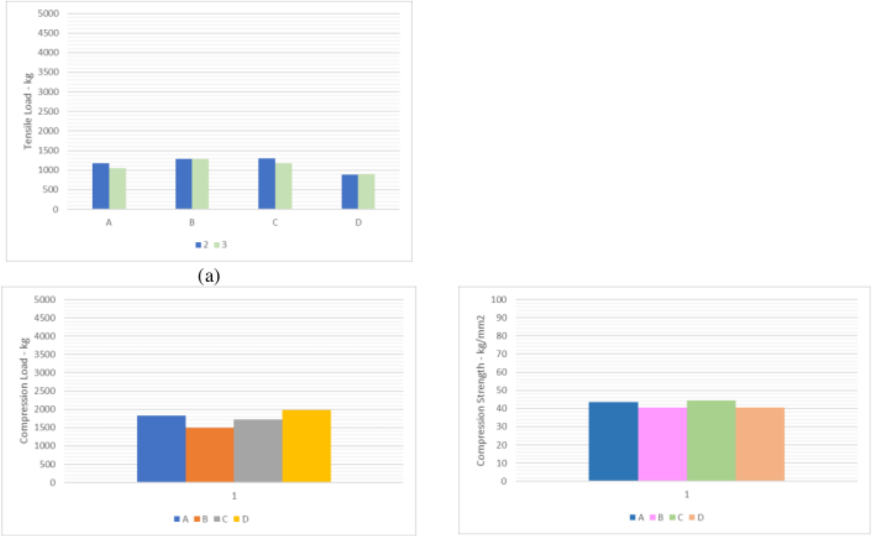
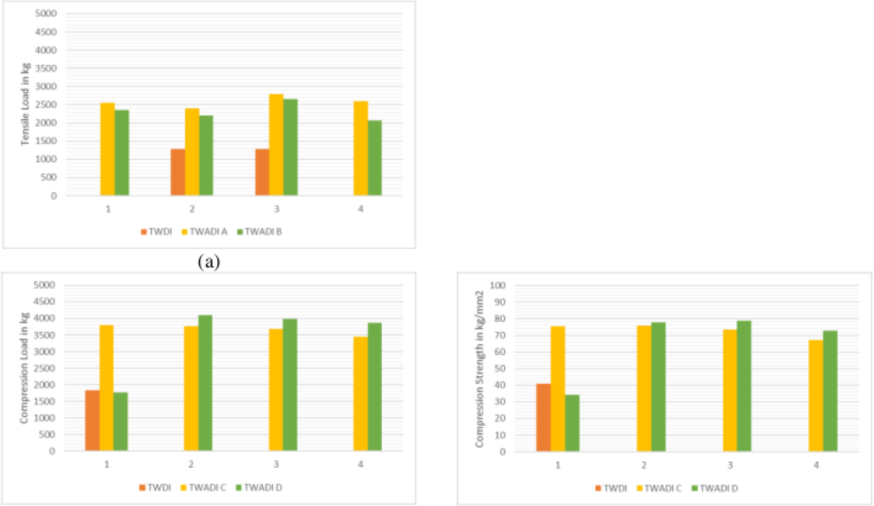


(a)

(b) (c)

Figure 8. Result of mechanical testing of TWDI
(a) Tensile Testing : Tensile Load in kg
(b) & (c) Compression Testing : (b) Compression Load in kg & (c) Compression Strength in kg/mm^2



(a)

(b) (c)

Figure 9. Result of mechanical testing of TWDI & TWADI
(a) Tensile Testing : Tensile Load in kg
(b) & (c) Compression Testing : (b) Compression Load in kg & (c) Compression Strength in kg/mm^2

6. References

[1] Sulamet-Ariobimo RD, Yudha G, Sukarnoto T, Mujalis Y, Oktaviano Y. Thin wall austempered ductile iron connecting rod for lighter automotive component – Production of thin wall ductile iron connecting rod. JSAE 20179125/SAE 2017-32-0125. 2017.

[2] Sulamet-Ariobimo RD, Yudha G, Oktaviano Y, Mujalis Y, Sukarnoto T. *Penerapan teknologi pengecoran dinding tipis pada batang piston*. Proc. of SENAMM IX. 2016:

[3] Sulamet-Ariobimo RD, Fadlan M, Sukarnoto T, Oktaviano Y, Mujalis Y. *Efek modifikasi cetakan terhadap pembuatan batang piston dinding tipis*. Proc. of SENAMM X. 2017:667-75.

[4] Soedarsono JW, Suharsono B, Sulamet-Ariobimo RD. Effect of casting design to microstructure and mechanical properties of 3 mm TWDI plate. Adv Mat Res. 2012; 415-417:831-37.

[5] Soedarsono JW, Sulamet-Ariobimo RD. Effect of casting design to microstructure and mechanical properties of 1 mm TWDI plate. AMM. 2012; 110-116:3301-7.

[6] Suharno B, Soedarsono JW, Soemardi TP, Sulamet-Ariobimo RD. The effect of plates position in vertical casting producing thin wall ductile iron. Adv Mat Res. 2011; 277:66-75.

[7] Soedarsono JW, Suharno B, Sulamet-Ariobimo RD. Effect of casting design to microstructure and mechanical properties of 5 mm TWDI plate. AMM. 2012; 152-154:1607-11.

[8] Sulamet-Ariobimo RD, Soedarsono JW, Suharno B. Effect of casting design to microstructure and mechanical properties of 2 mm TWDI plate. Adv Mat Res. 2013; 652-654:2404-8.

[9] Sulamet-Ariobimo RD, Soedarsono JW, Suharno B. Effect of casting design to microstructure and mechanical properties of 4 mm TWDI plate. Adv Mat Res. 2013; 702:269-74.

[10] Sulamet-Ariobimo RD, Soedarsono JW, Suharno B. Cooling rate analysis of thin wall ductile iron using microstructure examination and simulation. AMM. 2015; 752-753:845-50.

[11] Martinez RA, Boeri RE, Sikora JA. Application of ADI in high strength thin wall automotive parts. Proc. of 2002 World Conference on ADI. 2002:143-9

[12] Soedarsono JW, Soemardi TP, Suharno B, Sulamet-Ariobimo RD, Damanik EZ, Haryono D. Effect of the austempering process on thin wall ductile iron. JMSE. 2011; 1(2);236-42

[13] Kaczorowski M, Krzyňska A. Mechanical properties and structure of austempered ductile iron – ADI. Arch Foundry Eng. 2007; 7(1):161-6.

[14] Stefanescu DM, Dix LP, Ruxanda RE, Corbitt-Coburn C, Piwonka TS. Production of thin wall low nodularity ductile iron through the delayed in mold process. 5AFS Trans. 2002; 110:1149-58.

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