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The Effects of Austenitizing Process to Mechanical Properties of Thin Wall Ductile Iron Connecting Rod

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Abstract. Aluminium casting is lighter than cast iron, but cast iron has much more benefit. Especially when thin wall casting technology and austempering process applied in cast iron. Based on this, the shifting from cast iron to aluminium need further consideration. Thin wall casting technology will help cast iron in weight problem, while austempering process will improve the properties. Austempering process was carried out on thin wall ductile iron (TWDI) connecting rod component. The aim of this work is to analyse the effect of austenitizing time to mechanical properties of thin wall austempered ductile iron connecting rod. The process was applied to all connecting rods resulting from the vertical casting which is made in foundry scale. The austenitizing temperature was 9600C with various holding time of 15, 30, 45 and 60 minutes and the austempering temperature was 3500C with 35 minutes isothermal time. 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 austenitizing time hold an important role in producing TWADI since austenitizing time responsible in producing the ausferrite.

Keywords: TWADI, connecting rod, vertical casting, austenitizing time.

INTRODUCTION

Further considerations should be taken before replacing cast iron with aluminium casting. Aluminium casting indeed lighter than cast iron and has lower melting temperature with high thermal conductivity. But when it comes to mechanical property, energy consumption and production cost, cast iron is still superior to aluminium [1]. Especially when thin wall casting technology is applied during the manufacturing process. Thin wall casting technology will reduce the weight of the cast iron. When thin wall casting technique was applied to connecting rod, the design presented by Martinez et al. could reduce its weight to 33% [2], while the design used by Sulamet-Ariobimo et al. could reach the number of 27% [3]. The superiority of cast iron is more increasing when austempering process applied to Thin Wall Ductile Iron (TWDI). Austempering process on ductile iron was able to improve its properties to be similar or even higher than forged steel [2,4] and known as Thin Wall Austempered Ductile Iron (TWADI).

Studies regarding the application of austempering process in TWDI to produce TWADI were conducted. But most of these studies used plate as the casting product. Its application to automotive components was started by Martinez

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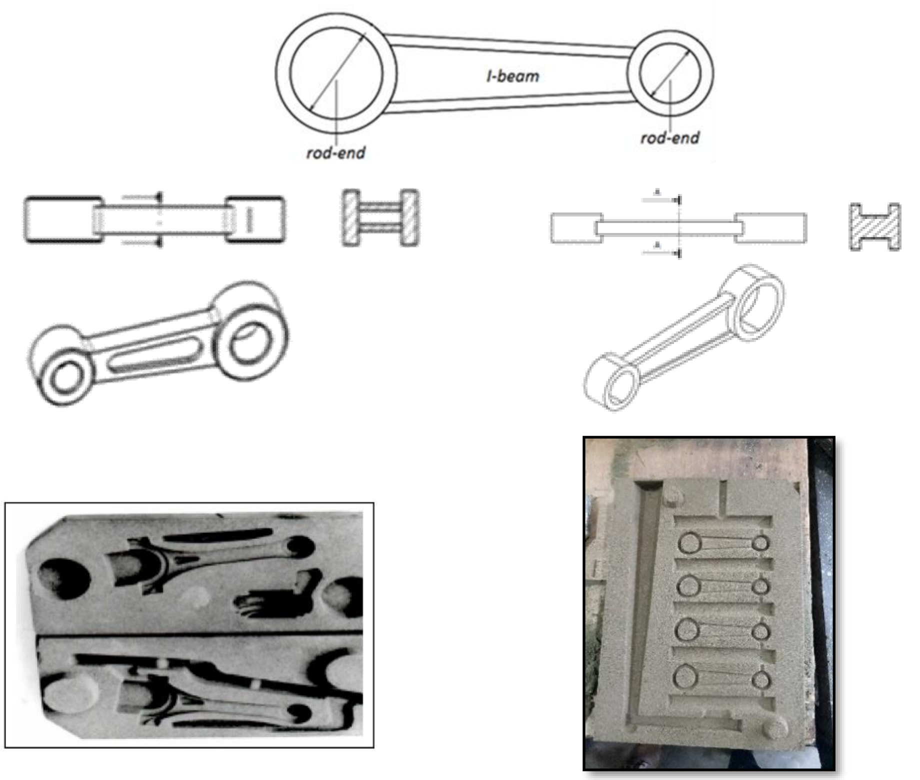
et al. by producing TWADI hollow connecting rod for Vespa PX150 [2]. This worked was then followed by Franś et al. which produced TWDI and TWADI of cantilevers and control arm [1]. Sulamet-Ariobimo et al. followed the work of Martinez et al. and Franś et al. in producing TWADI components. Based on the work of Martinez et al., Sulamet-Ariobimo et al. produced thin wall austempered connecting rod for Vespa PX150. The TWDI connecting rod developed by Sulamet-Ariobimo et al. is not a hollow connecting rod [3]. Both designs are presented in Fig. 1.



a. Design of Martinez et al. [2]　　　b. Design of Sulamet-Ariobimo et al. [3]

Figure 1. TWDI Connecting Rod

In general, austempering parameter consist of austenitizing temperature, austenitizing time, austempering temperature and austempering time. Mourad et al. studied the effect of austempering temperatures. They used plate sample 200 mm x100 mm with the various thickness of 2, 4, 6, and 8 mm. The austenitizing temperature was 900^0C for 30 minutes and austempering temperature of 350^0C and 400^0C with isothermal time of 10 minutes for 2- and 4-mm thicknesses and 30 minutes for 6- and 8-mm thicknesses. The result showed that optimal result was obtained by austempering temperature of 350^0C [5]. While Franś et al. studied TWADI plate of 20 mm x 28 mm with the thickness of 2 mm. The austenitizing temperature was 880^0C for 20 minutes time and austempering temperature of 400^0C with various holding time of 5, 15, 30 and 90 minutes. The result showed that it is possible to produce austempered ductile iron castings of with a wall thickness of 2.0 mm and high mechanical properties using only 50 minutes as a total heat treatment time. Other finding from this studied was based on the dimension of plate and other research parameters, isothermal time for austempering process can be limited to 5 to 10 minutes [6]. Soedarsono et al applied austenitizing temperature of 960^0C for 30 minutes and austempering temperature of 350^0C for 10 minutes in their studied to make thin wall austempered ductile iron (TWADI) plate of 150 mm x 75 mm x 1 mm which increased the UTS between 44 to 309% and elongation between 50 to 100% [4]. Savićević et al. studied the effect of austempering temperature from 250 to 420^0C. They started at 260^0 with an increase every 20 degree. The austenitizing temperature was 850^0C for 45 minutes and the austempering time of 60 minutes. They found out that tensile strength decreases as the increasing of austempering temperature [7].

Austempering process for TWDI component is more complicated compare to TWDI plate, since components has more shape and dimension to consider than plates. Franś et al. applied the result of their previous studied to make cantilevers and control arms from TWADI [1]. While Sulamet-Ariobimo et al. applied the result of their studied to make connecting rod [8].

All the studied in ADI and TWADI focused on austempering process and austenitizing temperature. While, it is hard to find study about the effect of austenitizing time. Whereas, austenitizing time affects the homogeneity of the forming microstructure. The objective of this study is to analyze the effect of austenitizing time to mechanical properties of thin wall austempered ductile iron connecting rod.

MATERIALS AND METHODS

Modification was applied to connecting rod of Vespa PX150 by reducing the thickness of I-beam from 4 mm in the original part, Fig. 1, to 3 mm as shown in Fig. 2. This reduction will reduce the weight of the component to 25% [3].

The modified connecting rods, which produced in industrial foundry, were all austenitized at 9600C for varied duration, which is 15, 30, 45 and 60 minutes, and then quenched in fluidized bed furnace which was held at 3500C for 35 minutes. After that they were cooled in the air. Fluidized bed furnace was chosen as isothermal quench media replacing salt bath since it is more environmentally friendly.

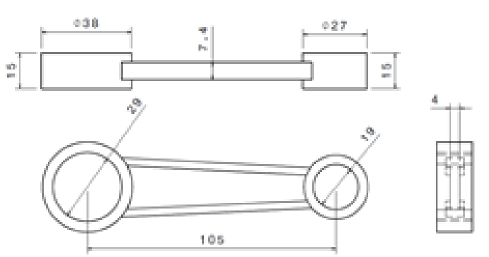


Figure 2. Original Dimension of Connecting Rod [3]

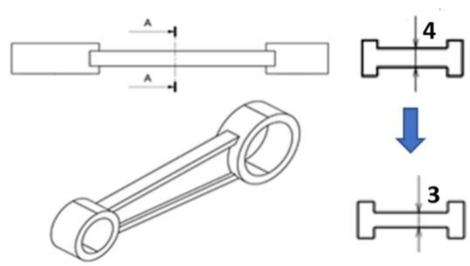


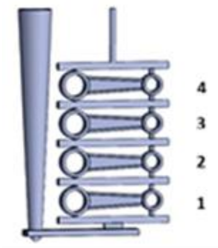
Figure 3. Thickness reduction in I-beam area [3,8].

Table 1. Chemical Composition of TWDI

Element		**ASTM Standard** (% weight)	**Foundry Standard** (% weight)	**Testing Result** (% weight)	
				Pouring – 1	**Pouring – 2**
Carbon	(C)	3.60 – 3.80	3.50 – 3.90	3.67	3.63
Silicon	(Si)	1.80 – 2.80	2.40 – 2.80	2.78	2.49
Manganese	(Mn)	0.15 – 1.00	0.30 – 0.50	0.35	0.43
Magnesium	(Mg)	0.03 – 0.06	0.03 min.	0.04	0.04
Phosphor	(P)	< 0,30		0.01	0.01
Sulfur	(S)	< 0,02	0.015 max.	0.01	0.02
Copper	(Cu)	0.015 – 1.00	0.15 max.	0.22	0.22
Chromium	(Cr)	0.03 – 0.07		0.06	0.04
Nickel	(Ni)	0.05 – 2.00	0.02 min.	0.04	0.01
Molybdenum	(Mo)	0.01 – 0.10		0.01	0.01
CE – 1		%C + 0,31%Si		4,53	4,40
CE – 2		%C + 0,31%Si +0,55%P-0,027%Mn+0,4%S		4,53	4,40
CE – Test				4,59	4,47

All the modified rods were produced from vertical casting design [9]. Each mold of the casting design produced 4 connecting rods and 4 molds were produced in one pouring. This study used 2 pouring. Two molds of the first pouring were directly characterized and the other two molds together with the second pouring were austempered. Since all process happened in industrial foundry, all the liquid metal used in this research is industrial liquid metals produced by the foundry for their commercial products. The chemical compositions were presented in Table 1. The codes for all connecting rods and their process were presented in Table 2.

Table 2. Samples Coding

	Pouring 1 – TWADI (CE = 4,59)		**Pouring 2 – TWADI (CE = 4,47)**	
	Code	**Condition**	**Code**	**Condition**
	0’	TWDI	15’	TWADI – Austenitizing Holding Time 15 minutes (Tensile Specimen)
	45’	TWADI – Austenitizing Holding Time 45 minutes	30’	TWADI – Austenitizing Holding Time 30 minutes (Tensile Specimen)
	60’	TWADI – Austenitizing Holding Time 60 minutes	45’	TWADI – Austenitizing Holding Time 45 minutes (Compression Specimen)
			60'	TWADI – Austenitizing Holding Time 60 minutes (Compression Specimen)

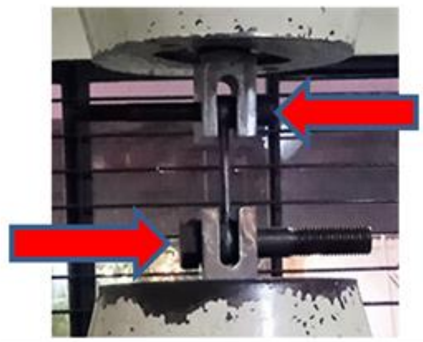


Figure 4. Special holder for tensile and compression test [3]

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 4, 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. Tensile strengths were not calculated because the break point happened in rod area as presented by Figure 5. The I-beam area calculation for compression 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 7.

Table 3. Area of I-beam

Rod Position	**I-beam Area – in mm^2**							
	Pouring 1				**Pouring 2**			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
1							84.92	93.05
2							74.40	71.27
3			76.00	98.27			79.00	79.13
4			76.01	85.52			98.30	90.68

Figure 5. Break point during tensile test.

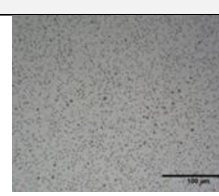
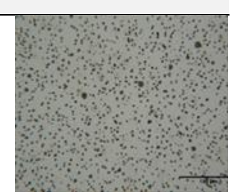
Figure 6. Result of Compression Test

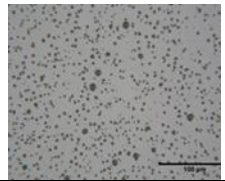
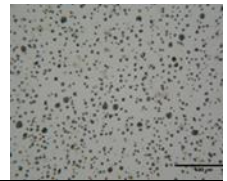
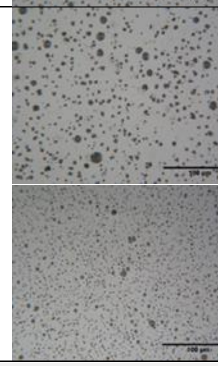
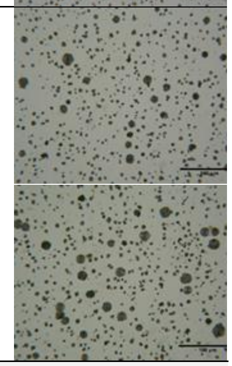
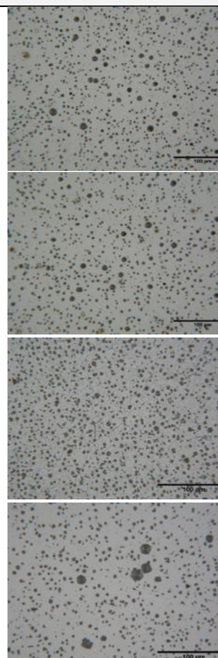
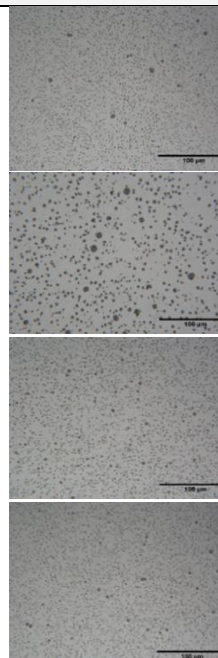
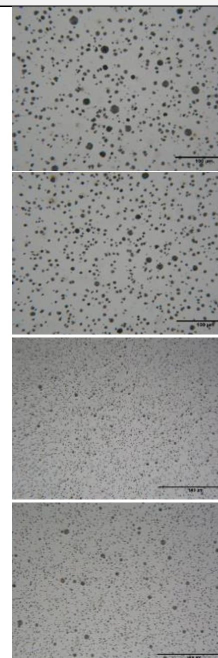
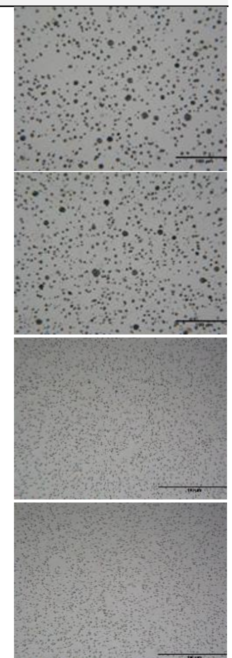
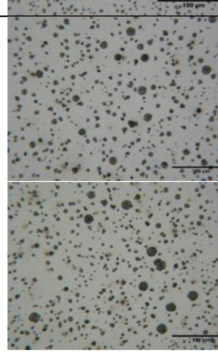
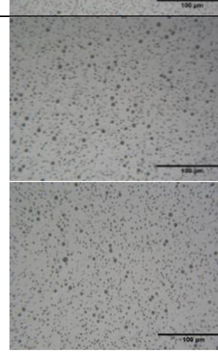
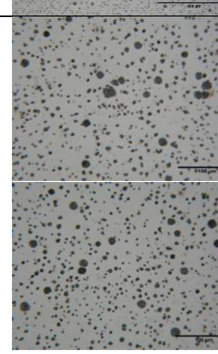
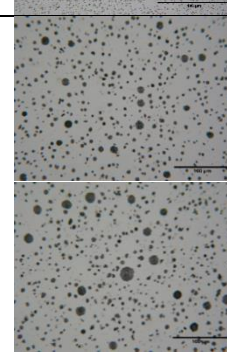
Figure 7. Metallography samples

RESULTS AND DISCUSSION

The result of used liquid metal chemical composition showed that all elements are beyond the limit of ASTM standard for both pouring except for nickel. Nickel content in the first pouring is 20% below the minimum level and 80% for second one. The aim of nickel addition in ductile iron is to increase hardenability of austempered ductile iron. In austempering temperature below 350^0C, nickel will slightly reduce tensile strength but increases ductility and fracture toughness. The austempering temperature used in this work was 350^0C. So, the effect of nickel deficiency for tensile strength, ductility and fracture toughness will not be seen. As for hardenability, the effect will be seen clearly in the second pouring.

Carbon equivalent (CE) of both pouring are calculated using two type of equation as shown in Table 1. The result for both calculations showed that no noticeable differences between the result of both equations. When these results compared to experiment, it was found 0.06 and 0.07 % differences for each pouring. The CE values are considered similar since the differences is not significant. CE comparison between the first and second pouring revealed the difference of 0,13% for calculation and 0,12% for experiment. Although the gap is quite broad but both CE are still inside the standard recommended CE of 4.4 to 4.6 [2]. Based on the CE values which are all below 4.67 the matrix of the microstructure will not be 100% ferrite [10,11].

TWADI				
	15’	**30’**	**45’**	**60’**
P- 1				
I-beam				

				
rod-end				
P – 2				
I-beam				
rod-end				

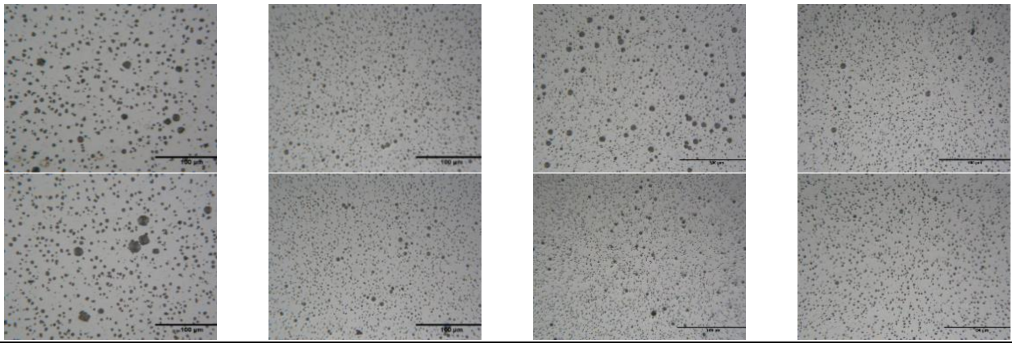


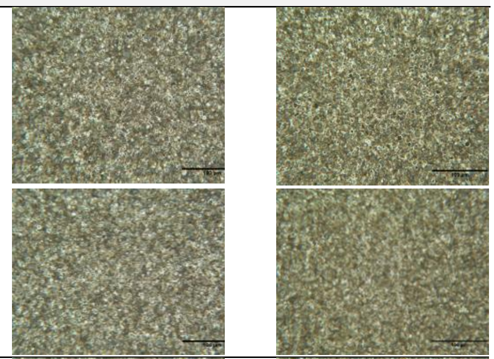
Figure 8. Un-etched microstructures of TWADI

TWADI

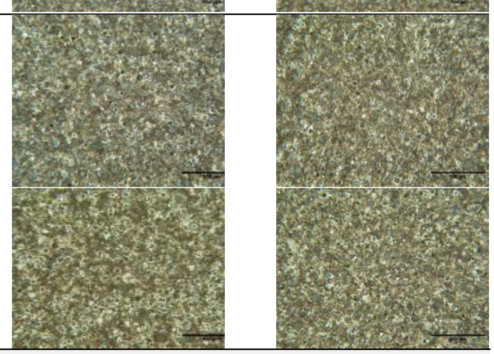
15’ **30’** **45’** **60’**

P- 1

I-beam

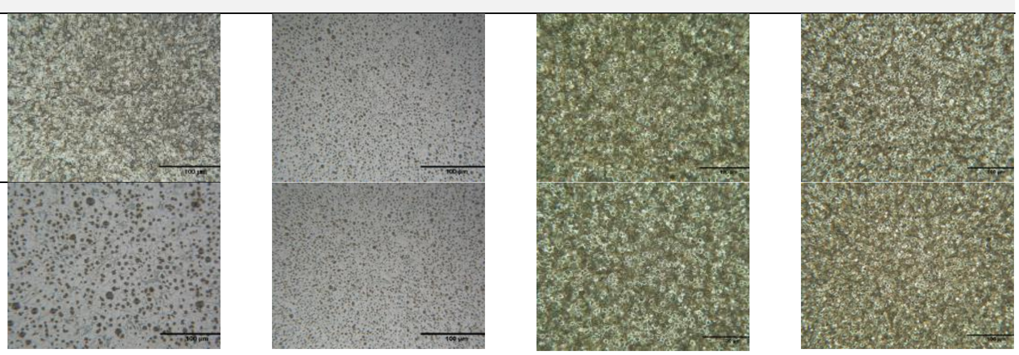


rod-end



P – 2

I-beam



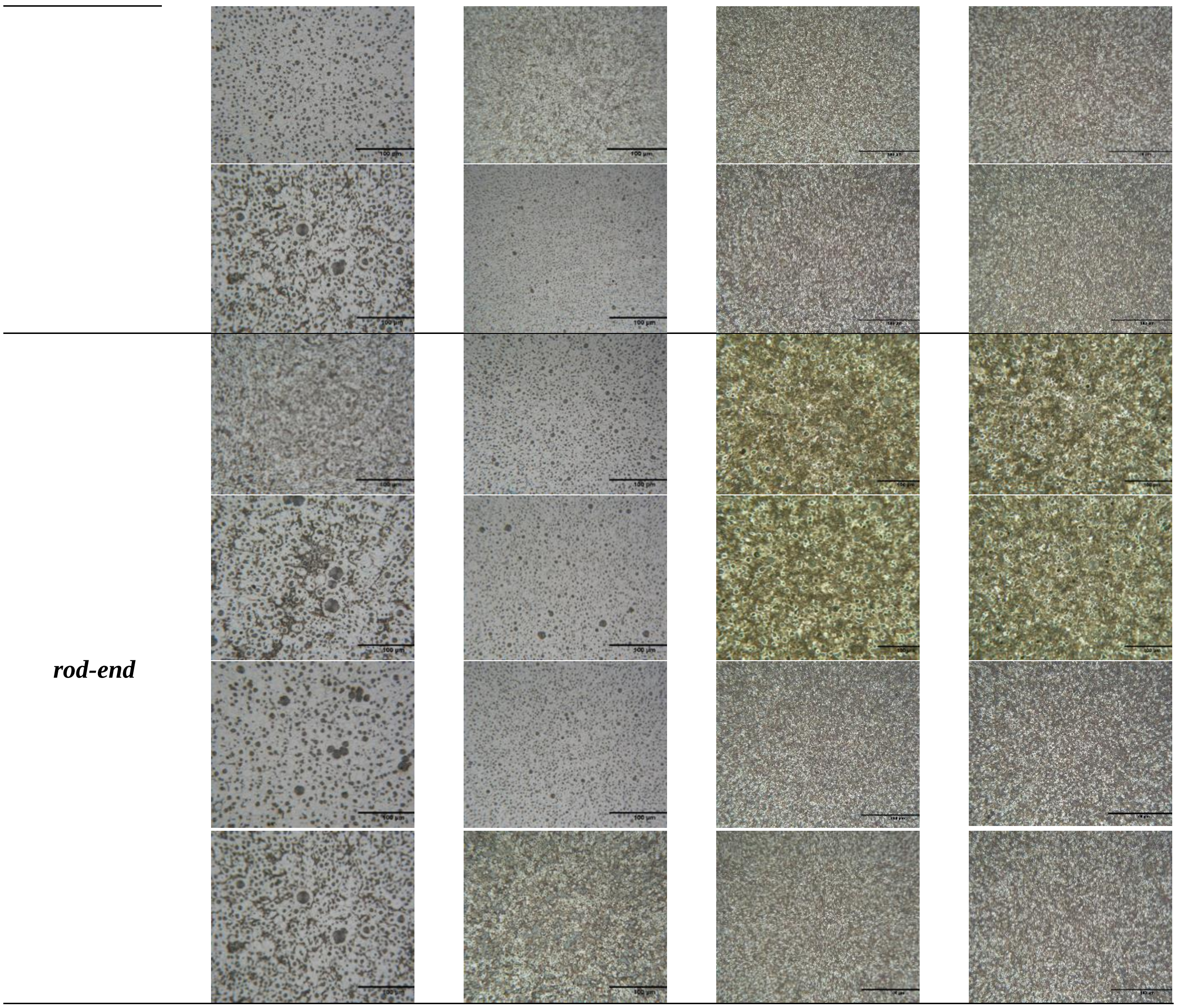


Figure 9. Etched microstructures of TWADI

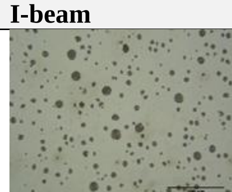
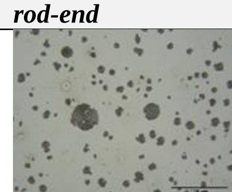
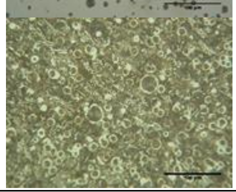
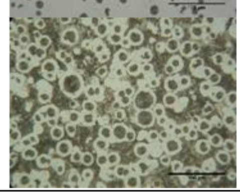
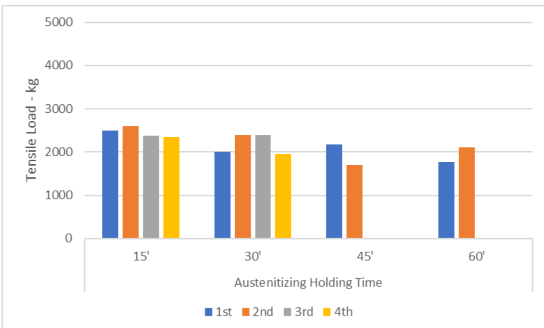
	I-beam	***rod-end***
Un – etched		
Etched		

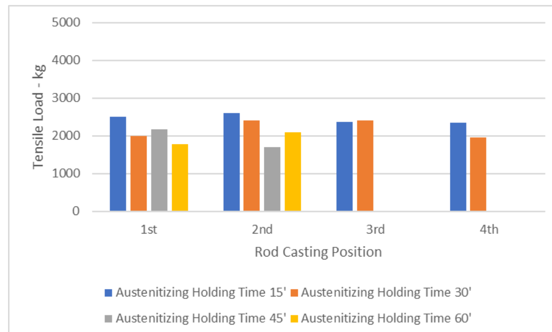
Figure 10. Microstructures of TWDI [8]

Fig. 8 shows the un-etched microstructure of TWADI. Nodules graphite distribute evenly in all condition and primary graphite is formed in both I-beam and rod-end area. The etched microstructure in Fig. 9 shows the matrix of TWADI is changing following the austenitizing time. Austenitizing time of 15 and 30 minutes are associated to full ferrite and combination of ferrite – pearlite matrix. Whilst, austenitizing time of 45 and 60 minutes are associated to full pearlite. All the matrix revealed in this study shows that the austempering process is either not complete or exceeded. The austenitizing time tends to homogenize the microstructure in I-beam area and rod-end.

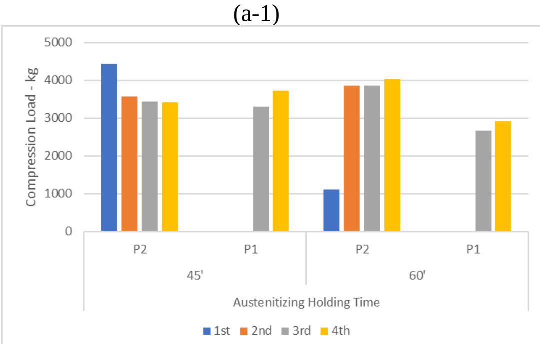
Compared to TWDI (Fig. 10), the matrix that are formed in TWADI is look alike with the microstructure of I-beam (etched). This finding supports the previous analysis concerning austempering process. Mourad et al. in their research using 10 minutes austenitizing time for plates thickness of 2 mm and 4 mm. Frans̋ et al. suggested 5 to 10 minutes for 2 mm thickness. While Sulamet-Ariobimo et al. applied 30 minutes for 1 mm thickness. They all can produce ausferitte. In austempering components, Frans̋ et al used 20 minutes for their austenitizing time, while Sulamet-Ariobimo et al. used 35 minutes. Frans̋ et al succeeded in forming ausferrite while Sulamet-Ariobimo et al. managed to homogenized the microstructure in its I-beam and rod-end. They gained 100% pearlite.



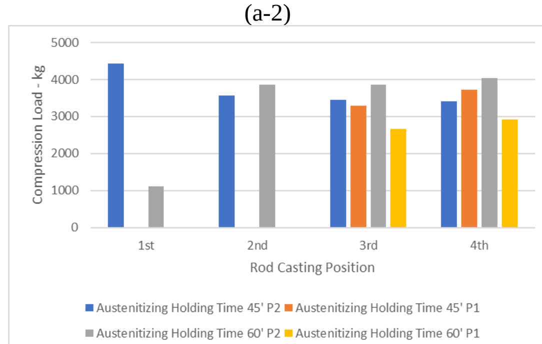
(a-1)



(a-2)



(b-1)



(b-2)

Figure 11. Result of mechanical testing of TWADI
(a-1) Tensile Load in kg to Austenitizing Time & (a-2) Tensile Load in kg to Casting Position
(b-1) Compression Load in kg to Austenitizing Time & (b-2) Compression Load in kg to Casting Position

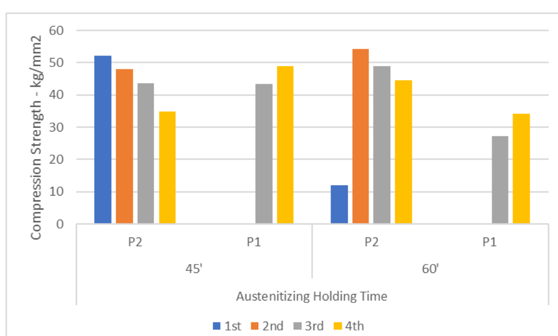
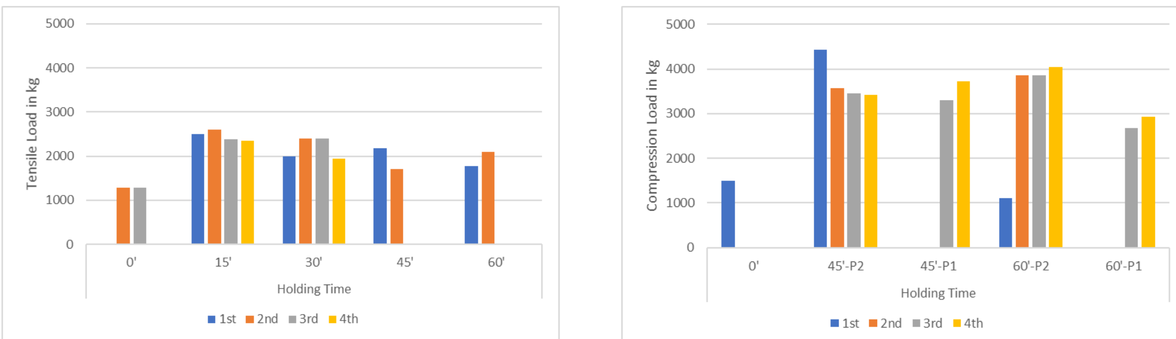


Figure 12. Compression Strength

The result of tensile and compression tests was shown in Fig. 11. Generally, the tensile load range between 1700 to 2600 kg. The difference is 42% to average tensile load. The curve trend tends to decrease as the austenitizing holding time increase. The highest is found in 15 minutes. As for the rod casting position, tensile load tends to fluctuated following the austenitizing holding time, but the highest is still obtained from 15 minutes holding time.

As mention previously, the austenitizing holding time applied for compression test was only 45 and 60 minutes. Special notice should be taken for connecting rod with the first casting position with 60 minutes austenitizing holding time since the data seems to be out layered. It is suspect that there is defect inside the rod and further investigation should be done. By ignoring the out-layer data, the range of the compression loads were 3416 to 4437 kg (29%) for P2, while for P1 were 2675 to 3725 kg (30%)

In contrast with tensile strength, compression strength (Fig. 12) was calculated to determine the ability of TWADI connecting rod to meet the design needs. Compression strength needed by the design for connecting rod is 15 kg/mm2. The compression strengths of TWADI connecting rod calculated based on I-beam area are between 27 to 52 kg/mm2. Based on the compression strength, the TWADI connecting rod can fulfill the needs of the design.



(a-1) (a-2)

Figure 13. Result of mechanical testing of TWDI & TWADI

(a-1) Tensile Load in kg to Austenitizing Time & (a-2) Compression Load in kg to Austenitizing Time

The result of both tensile and compression load show that the tensile and compression load of TWADI is higher than TWDI (Holding Time = 0’). This result indicates that the austempering process is running and change in microstructure occur.

CONCLUSIONS

The liquid metal used in this work fulfilled the CE requirements for TWDI and TWADI. Nickel deficiency give no effect since the austempering temperature is 350^{0}C.

Austempering process is running and has changed the microstructure of TWDI. The differences seen clearly in rod-end. The matrix of rod-end changes from ferrite-pearlite to 100% pearlite. Austenitizing times used in this work have not able to produce ausferrite matrix, but they turned the matrix in rod-end to match the I-beam.

The tensile loads for austenitizing time of 15, 30, 45 and 60 minutes show that the highest load is found in austenitizing time of 15 minutes. While in compression load and strength for austenitizing time of 45 and 60 minutes show the highest load and strength is in 45 minutes. Based on this austenitizing time should be shorten.

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 which is 15 kg/mm^2.

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