Thin Wall Ductile Iron Castings

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Abstract

The use of austempered ductile iron (ADI) as an alternative material has increased, and it is predicted that it will reach 300,000 tons by the year of 2020 due to its characteristics especially design flexibility. When the reduction in weight is considered as a parameter for energy saving, ADI is presented as thin wall austempered ductile iron (TWADI). To produce a good quality TWADI, a good quality thin wall ductile iron (TWDI) must be used as a raw material. Good quality TWDI is produced by casting design. This chapter discusses the production of thin wall ductile iron, including its characterisation and defect. The discussion includes the background of thin wall casting (TWC) and TWDI, applying TWC in general casting, the problems in producing TWDI, characterisation of the TWDI and specific defects.

Keywords: thin wall casting, ductile iron, austempered ductile iron, vertical casting, ingate position, premature solidification, single matrix for microstructure

1. Introduction

Thin wall casting (TWC) is developed to produce lighter casting products. The weight reduction in TWC is gained by thinning out the wall thickness of products in whole like plates or partially. Thinning of the cast product will disturb the pouring time and speed up the solidification rate. The pouring time will shorten since the volume of the cast product is decreased due to depletion process. To overcome this, foundrymen tends to increase the pouring temperature. The increase in pouring temperature will expand the temperature differences, which will result in higher solidification rate.

Increasing pouring temperature could not be applied while producing ductile iron (FCD) since the process includes liquid treatment processes, known as inoculation and nodulation. Both processes are limited by temperature and time. The effect of liquid treatment will reduce if the limit of temperature and time is exceeded. This condition will disturb the formation of spheroidal graphite and cause failure in production.

Thin wall ductile iron (TWDI) is ductile iron casted in TWC. The thicknesses of some products of FCD were reduced in certain parts. Caldera defined TWDI as ductile iron casting with wall thickness below 5 mm [1], while Stefanescu limited its thickness below 3 mm [2]. But the properties of TWDI should fulfil the properties of FCD. TWDI has made it possible for ductile iron to compete with aluminium in terms of weight [3]. The size of the thinnest TWDI plate is 1 mm [4–7].

2. Problems in producing thin wall ductile iron

Problems in producing thin wall ductile iron occur due to its thickness. In general casting, to avoid premature solidification, pouring temperature is raised when the casting product is thin. Premature solidification will lead to defects as presented in **Figure 1**. However, this method cannot be applied in producing TWDI since there is temperature limitation for liquid treatment process. Liquid treatments, i.e. inoculation and nodulation (Mg treatment), are applied to liquid metal to produce nodule graphite. Liquid treatment will fail if the temperature limit is exceeded.

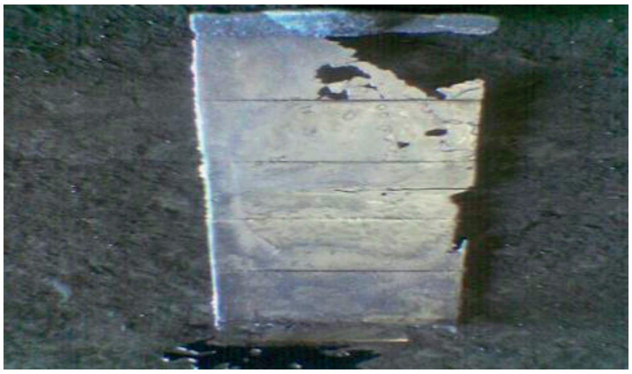


Figure 1. Shrinkage defect formation due to premature solidification [8].

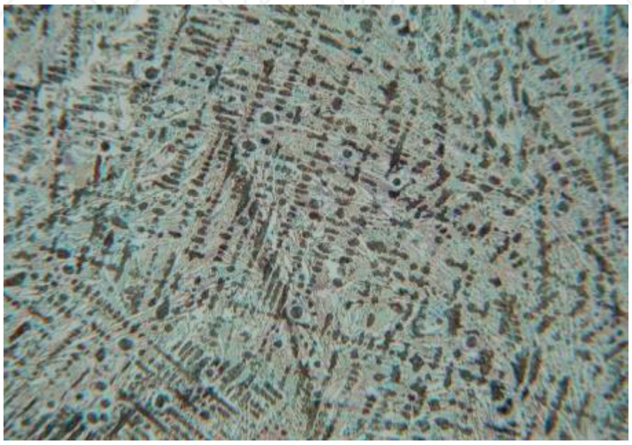


Figure 2. Carbides formation in TWDI [8].

Another issue that should also be considered is the formation of carbides as shown in **Figure 2**. Carbides form as a result of high solidification rate, and solidification rate increases when the thickness of the casting product decreases. Carbides formation in TWDI is to be strongly avoided. To deal with it, solidification rate should be maintained.

3. Designing TWDI products

As mentioned previously, the classification of TWDI is made based on the thickness of casting products which can be applied either in the whole part of product such as plate as shown in **Figure 1** or in just some parts such as in the connecting rod invented by Martinez [9] as shown in **Figure 2**. The thickness of the casting products should not exceed 5 mm.

Soedarsono, Soemardi and Sulamet-Ariobimo have designed two series of plates. In the first series, they designed five plates with the same length and width but different thicknesses. The length is 150 mm while the width is 75 mm. The thicknesses are varied from 5 mm to 1 mm with 1 mm interval. As in the second series, they designed also five plates with the same length, width and thickness. The length and width are still the same as the first series, and the thickness is 1 mm. Since it is just plates, designing the product is not challenging but designing the gating system will be challenging since the design of gating system determines the plates formation. The gating system design made by Soedarsono, Soemardi and Sulamet-Ariobimo is discussed in the following section (**Figure 3**).

Contrary to the plates' design, applying thin wall casting in components are challenging since the part or parts of component being modified should be carefully selected to ensure that the thinning process will not disturb the function and properties of the component. Martinez invented TWDI connecting rod by modifying the I-beam part. I-beam is not a critical part in connecting rod. Martinez modified the solid I-beam to hollow I-beam as presented in **Figure 4**. The wall thickness of the hollow I-beam is 4 mm. The hollow I-beam reduces 100 g of weight of the connecting rod.

Figure 3. TWDI plates [8].

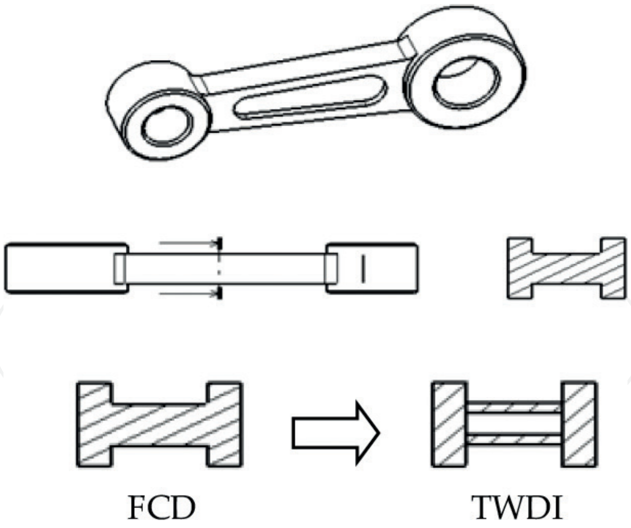


Figure 4. TWDI connecting rod invented by Martinez [9].

4. Casting design for TWDI

There are several ways to maintain cooling rate, but among all of them, casting design is the easiest one. Casting design covers the cast products, gating system and risers. Casting design is important since it determines the quality of the products and their production cost. Regarding TWDI, the casting design should consider fluidity, pouring temperature, pouring time and solidification rate of the molten metal. The casting design should ensure that premature solidification does not occur [10]. The main cause of premature solidification is pouring disruption. To deal with this, pouring stability should always be maintained.

Many researchers used steps design to produce TWDI plates. Javaid [11] designs are presented in **Figure 5**. Javaid used this design to study the effects of chemical composition and process parameters on tensile and impact properties, while Showman [12–14] used groove steps design as shown in **Figure 6** for studying the effects of cooling rate on skin effect formation. Pedersen used both horizontal and vertical steps design, as shown in **Figure 7**, to gain cooling rate from various plate thicknesses. Javaid also modified steps design as presented in **Figure 8** to analyse the effects of position on plates.

Besides the steps design, Stefanescu used horizontal and vertical design as shown in **Figure 9a** and **b**. The vertical design was made after unsatisfactory data gained from its horizontal design [18, 19]. Stefanescu defined his vertical design as gating system, casting products and risers. The casting products were plates of 250 mm in height and 1000 mm in length. The thicknesses of the plates were 6.0, 2.5 and 3.5 mm, which were arranged vertically with cylindrical risers in between. The diameter of the riser is 25 mm, and the number of risers is four [19]. Stefanescu used counter gravity system to maintain the filling rate.

Schrems developed a horizontal design as shown in **Figure 10**, and INTEMA team developed several designs as shown in **Figure 11**. From his design, Schrems found that the condition of the plates together with their thickness affects mechanical properties and reducing cooling rate will make TWDI characteristic equal to general casting. INTEMA used the design shown in **Figure 11a** and **b** to evaluate the graphite characterizations. The results obtained from the

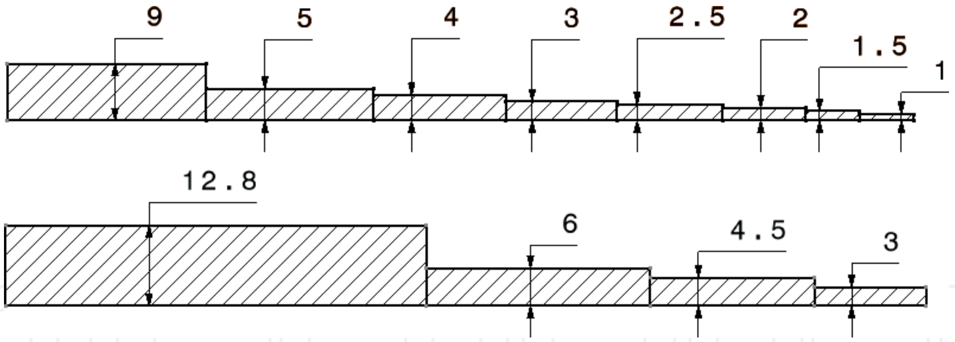


Figure 5. Javaid designs [11].

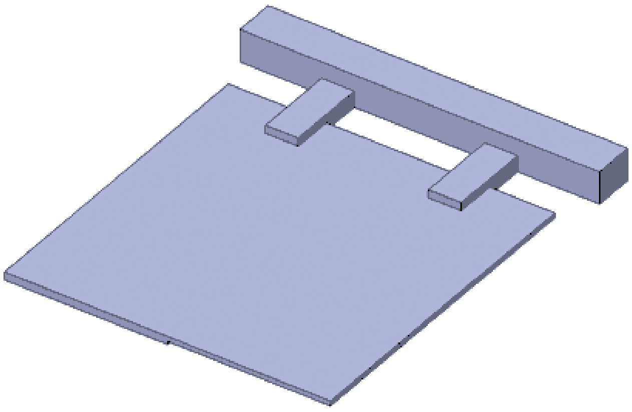


Figure 6. Showman designs [12–14].

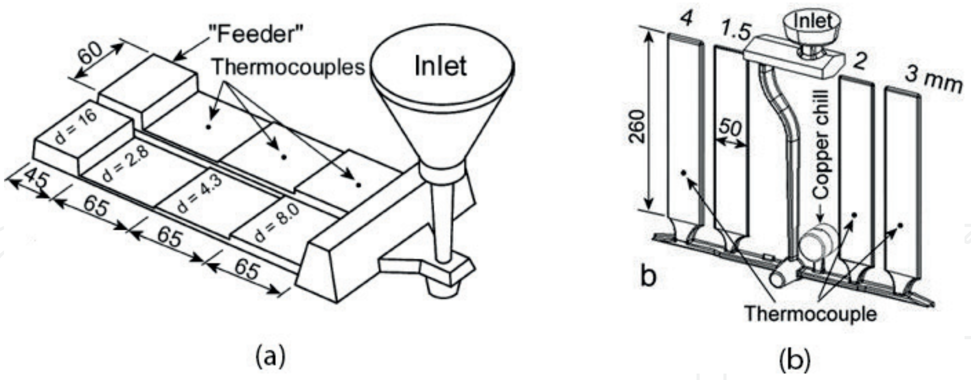


Figure 7. Pedersen designs [15–17]. (a) Horizontal design; (b) vertical design.

first two designs were used to develop the other designs as shown in **Figure 11c** and **d**. The new designs were used for further research.

Labreque used the design shown in **Figure 12** to study the effects of cooling rate on microstructure and mechanical properties of TWDI. The design developed by Labreque resembles industrial condition. Filling process was maintained by using pouring basin, while the adjustment of undercooling temperature and cooling rate was controlled by using material known as low-density alumina silicate. This combination leads to the similarity of TWDI with the specification of ductile iron.

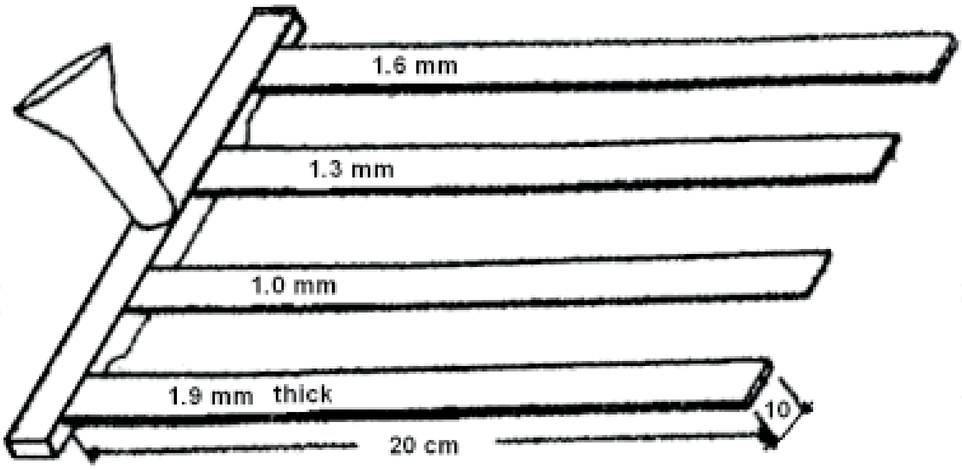


Figure 8. Javaid designs [11].

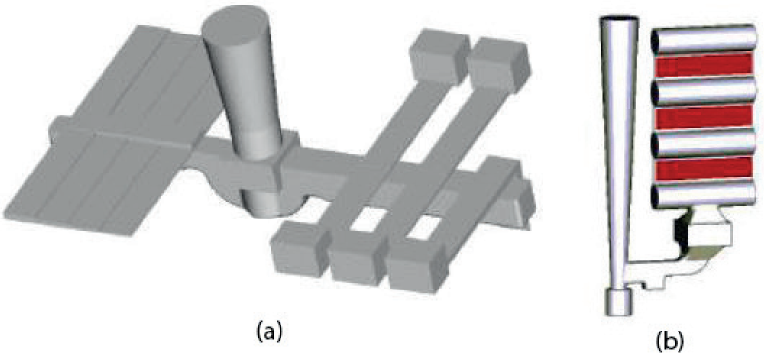


Figure 9. Stefanescu designs [2, 18–20]. (a) Horizontal design; (b) vertical design.

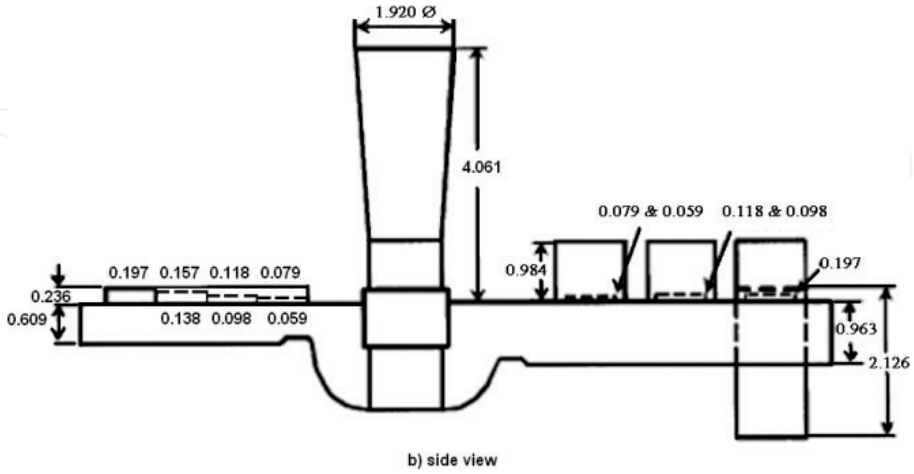


Figure 10. Schrems design [21, 22].

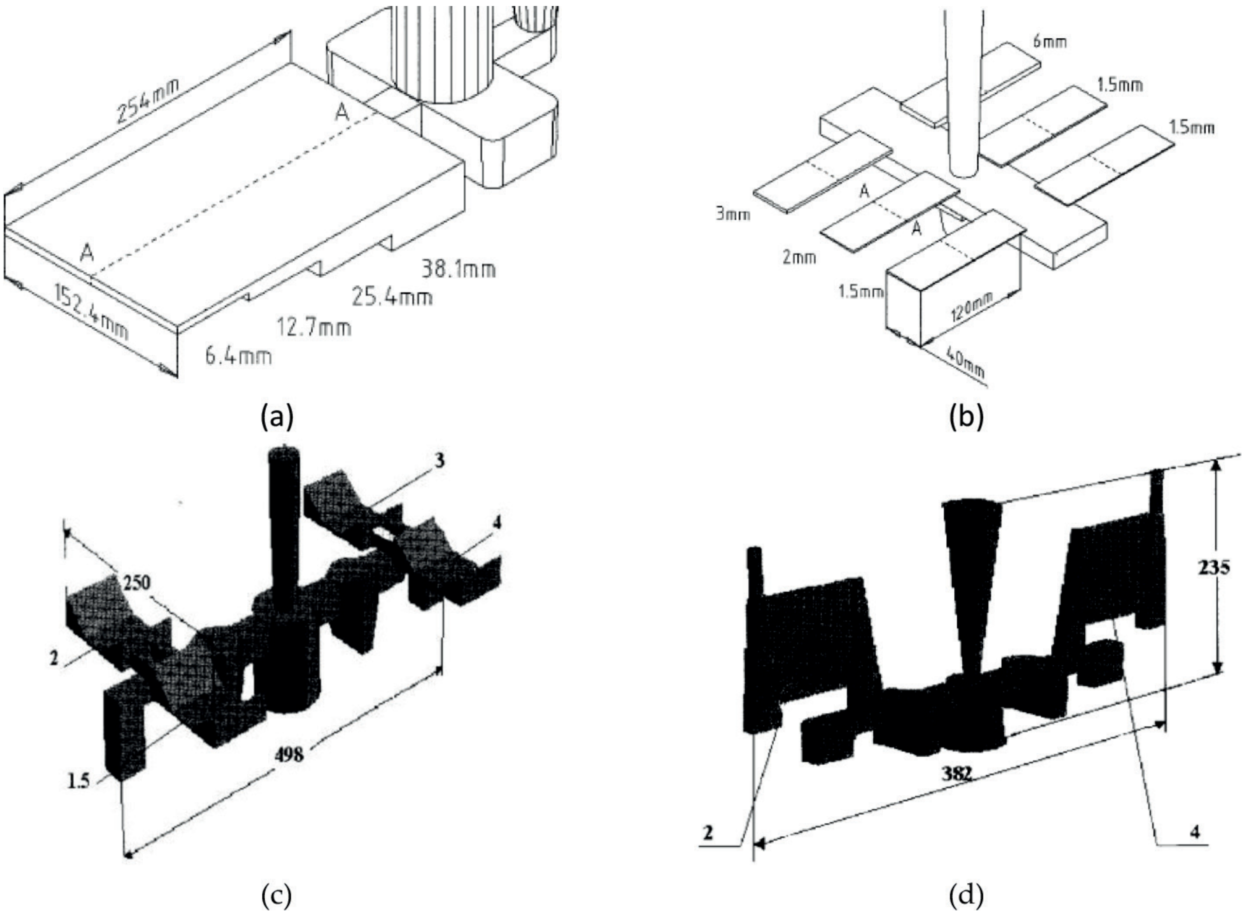


Figure 11. INTEMA designs [23–27].

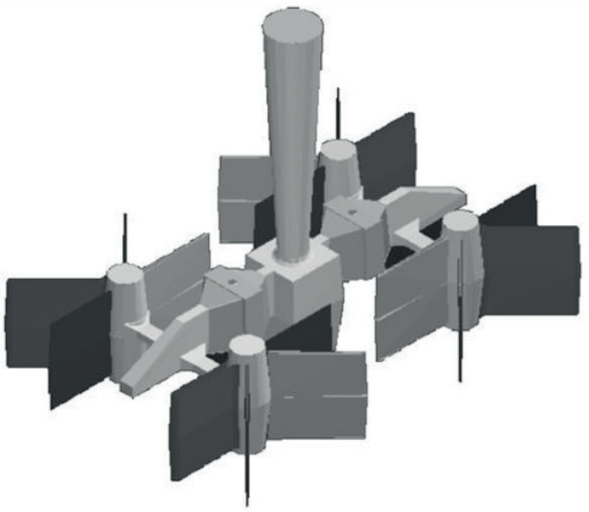


Figure 12. Labreque design [28–30].

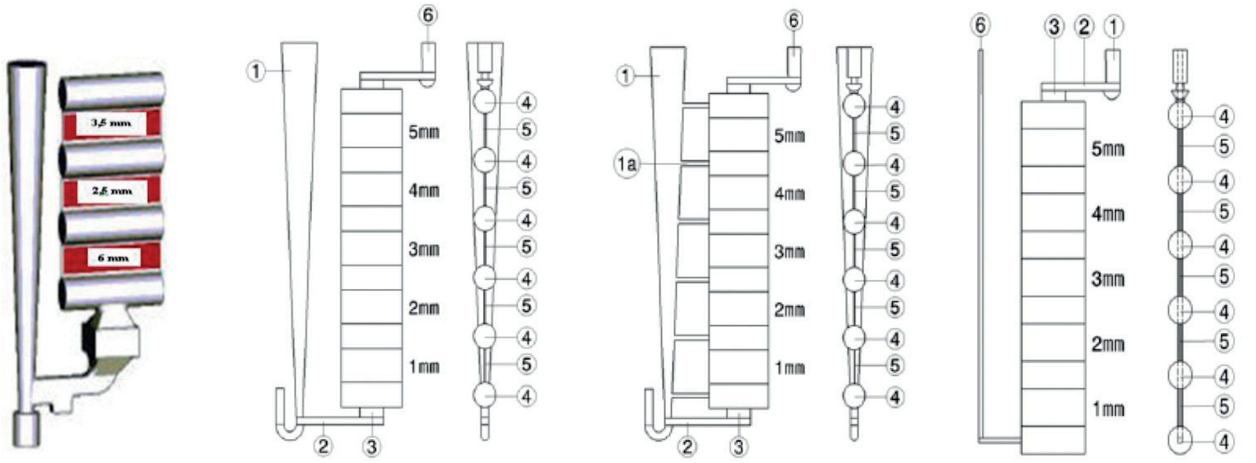
This section shows that all researchers are producing their TWDI plates using varied casting designs in horizontal and vertical casting position. This demonstrates how important is an appropriate gating system design to produce TWDI products, whether plates or components.

5. Purposed casting design for TWDI plates

As mention previously, Soedarsono, Soemardi and Sulamet-Ariobimo in their works developed vertical casting designs to produce their plate series. They developed two models of vertical casting design. The first model was based on Stefanescu vertical casting design which used gating system and risers as presented in **Figure 13**.

Soedarsono, Soemardi and Sulamet-Ariobimo modified the Stefanescu design in the number, dimension and thickness of the plates produced. Stefanescu design produced three plates with the dimension of 100 mm × 25 mm and thicknesses of 2.5, 3.5 and 6.0 mm. The design purposed by Soedarsono, Soemardi and Sulamet-Ariobimo produced five plates with the dimension of 150 mm × 75 mm and thicknesses of 1.0, 2.0, 3.0, 4.0 and 5.0 mm. The casting design consists of down sprue, runner, ingate, risers and plates. Every plate is clamped by risers.

Soedarsono, Soemardi and Sulamet-Ariobimo also modified the arrangement of the plates. Since it is a vertical casting design, they placed the thinnest plate near the ingate. This is contrary to the general rule of casting. In the general rule of casting, ingate should not be placed in the thinnest part since it could block the filling process due to first place to solidify. But Soedarsono, Soemardi and Sulamet-Ariobimo assumed that the heat in the running liquid metal will prevent the thinnest part of the casting to solidify or known as premature solidification. Therefore, as long as the liquid metal runs along the system, the thinnest part will not solidify and premature solidification



Stefanescu Design

a.

b.

c.

Figure 13. Soedarsono designs [3–8, 31–33]. Vertical casting. 1—Down sprue; 1a—supporting gate; 2—runner; 3—ingate; 4—riser; 5—plate; 6—gas tunnel.

will not happen so the liquid metal can fulfil the mould. This assumption was verified during the casting process. A minor disturbance during the pouring process resulted in defective products.

Soedarsono, Soemardi and Sulamet-Ariobimo proposed three types and all of them produced TWDI plates with ferrite matrix. After evaluating the microstructures and tensile properties of every plates resulting from every types [3, 4, 31–33], they chose the first type which is presented in **Figure 13a** for further developments.

Soedarsono, Soemardi and Sulamet-Ariobimo also developed vertical casting design to produce TWDI without using gating system as the second model shown in **Figure 14**. The dimension and thickness of the plates produced are same as the previous designs. In this model, they proposed two types of design. These designs produced TWDI plates with perlite matrix.

Both models were able to produce TWDI plates. This showed that the casting design proposed were able to produce TWDI plates. Comparing the design of both models revealed that the advantage of the second model is high casting yield, while the first design tends to reduce the casting failure. Both models have their own solidification rate as shown by the microstructures. The first model has ferrite as a matrix, and the second one has perlite. Microstructures represent solidification rate. The conclusion made based on the microstructure formation is that the second model has higher solidification rate than the first one.

Later Soedarsono, Soemardi and Sulamet-Ariobimo modified the chosen design presented in **Figure 13a** for further development. They changed the thickness of the plate from 1 to 5 mm to only 1 mm in all position to discover the ability of the casting design. Experimental studies showed that all plates were formed during the casting process and presented with ferrite matrix.

Based on the latest design, Sulamet-Ariobimo and Gumilang modified the design of vertical casting. They reduced the number of the plates and minimised the dimension of the gating system to gain higher casting yield. The improved design is presented in **Figure 15**. This design produced TWDI in perlite matrix.

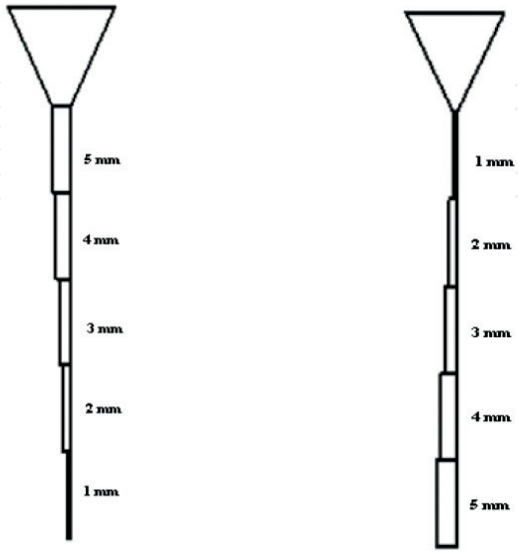


Figure 14. Soedarsono designs [6]. Vertical casting without gating system.

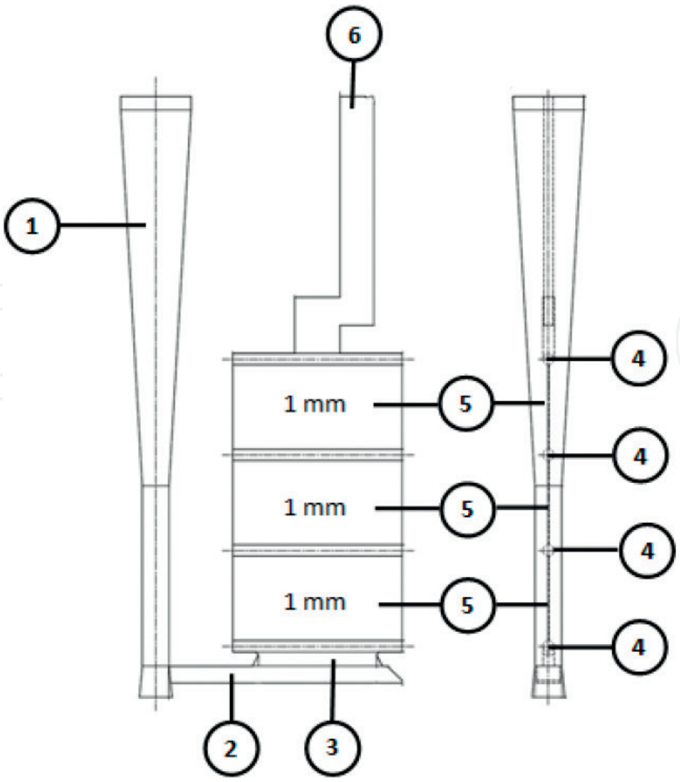


Figure 15. Improved design [34]. 1—Down sprue; 1a—supporting gate; 2—runner; 3—ingate; 4—riser; 5—plate; 6—gas tunnel.

6. Characterisation

Characterisation, especially tensile test, become an important issue in TWDI production since TWDI properties should be same as FCD and thinning process should not change the material properties. ASTM has determined the tensile specimen for TWDI or TWADI, but JIS has not determined which kind of specimen should be used for TWDI or TWADI.

Referring to ASTM Standard, researchers tended to use ASTM E8 [35] as shown in **Figure 16**, for the tensile specimen. While in JIS, several types of tensile specimens can be applied in plate. However, each type of this specimen gave different results. Sulamet-Ariobimo et al. investigated this [36] and decided to use JIS Z2201 No. 5 [37], shown in **Figure 17**. This decision was made based on the findings that fracture propagation in TWDI and nonferrous metals needs wider width.

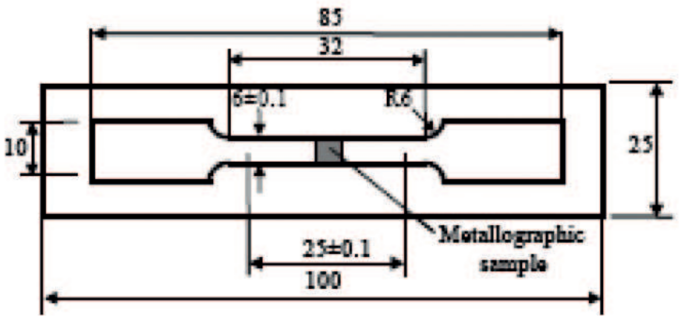


Figure 16. Tensile specimen of ASTM E8 [35].

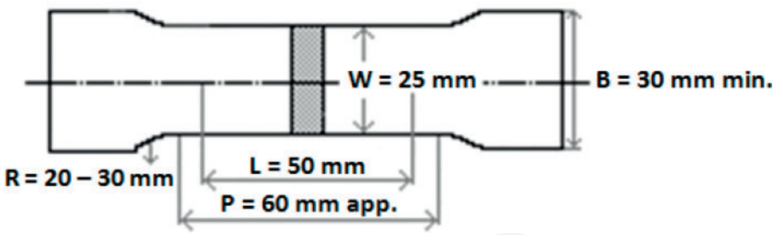


Figure 17. Tensile specimen of JIS Z2201 No. 5 [37].

7. Skin effects

Skin effect [13] or flake graphite rim anomaly [18] is a layer of flake or vermicular graphite formed in outer layer of ductile iron microstructure. This layer tends to appear in sand casting products. The formation of skin effect occurred due to magnesium malfunction. The malfunction of magnesium is caused by several things such as the presence of sulphur or oxygen. Magnesium tends to bind with sulphur which produce MgS or with oxygen which produce MgO. Ruxanda [18] assumed that skin effect was formed due to different level of magnesium content. Aufderheiden [13] found that besides magnesium content, the type of sand also contributed to the formation of skin effect. Sulamet-Ariobimo [38] found that besides magnesium content, cooling rate also influences the formation of skin effect.

Goodrich in Dix [19] stated that skin effect tends to disturb the tensile properties. Ruxanda [18] found difference of magnesium content between bulk and rim area. He concluded that skin effect was formed due to the lack of magnesium. Boonmee [39] supported the Ruxanda’s conclusion and concluded that skin effect is formed due to depletion of magnesium. The magnesium depletion is caused by the reaction of magnesium with sulphur and oxygen. Labreque [31] found that although skin effect is detrimental to mechanical properties but up to certain limit, it supports the homogenization of microstructure. Skin effect is an acceptable defect in general casting since it will vanish during the finishing process, but it is vice versa for TWDI. The thickness of TWDI makes it impossible to apply machining process to dispose skin effect. This is the reason why the formation of skin effect in TWDI should be avoided.

8. Conclusion

Light weight components are produced to answer the needs of lower energy consumption. TWDI is produced by applying TWC to ductile iron casting. This will enrich the material preference for lighter weight. TWDI has higher design flexibility than aluminium, which is one of the reasons to choose TWDI rather than aluminium.

During TWDI production, problems occur due to its thickness and liquid treatment process. A vertical design has been made and is able to produce TWDI plates with 1 mm thickness. This design puts the ingate in the thinnest part, which is controverted to the general rule of casting. The casting will be succeeded if the pouring process runs smoothly, while slight interruption will cause failure.

Apart from the regular casting defects, the presence of skin effect is also detrimental to TWDI. In general casting, skin effect can be removed by machining process. This removal process cannot be applied in TWDI.

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