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The Effect of Vertical Step Block Casting to Microstructure and Mechanical Properties in Producing Thin Wall Ductile Iron

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Abstract

Thin wall ductile iron (TWDI) is introduced to fulfill the needs of lighter material in automotive parts that will reduce fuel consumption. Problem occurs during the production of TWDI due to the casting thickness. TWDI casting thickness classified to below 5 mm. Many designs have been made to answer the problem in producing thin wall ductile iron. Soedarsono et al established vertical step block casting design. This design based on Y-block principle that allows direct pouring of liquid metal to the mold without passing any gating system. This design will increase casting yield. The parameter of this research is pouring basin placement to study the effect of plate arrangement to filling and solidification. This research is conducted to see the effect of pouring basin placement to microstructure and mechanical properties of TWDI. The Design is made to produce 5 plates with different thickness that is 1, 2, 3, 4, and 5 mm. All of the plates arranged parallel in line. Pouring basin located in 2 ways. The first type located pouring basin above the plate of 5 mm thickness while the second one located it above the plate with 1 mm thickness. The first type coded as T4 while the second coded as T5. The moulds made from furan sand. The result shows although cold shut occurred in both pouring basin placements due to pouring discontinuity but shrinkage only formed in T5 on its plate with 1 mm thickness. Microstructure of all the plates presented nodule graphite in pearlite matrix. Carbide and skin effects also detected. Average nodularity is above 80% while the nodule count is between 614 to 1269 nodule/mm^2. Most of the Brinell hardness number exceeded maximum limit given by JIS G5502 but the UTS is below the minimum limit except for 3 mm plate thickness of T5. All elongation values below the minimum standard. The results confirm that pouring basin location is important in casting design following Y-Block principle.

Introduction

Energy crisis has force human kind to change the way they consume it. Lighter materials are applied to machine components to reduce the energy consumption during the operation. Since reducing 100 kg of car’s weight will reduce 0.5 liter of fuel for 100 km [1]. Unfortunately, light materials such as aluminum consume a lot of energy during their production. Thin wall ductile iron (TWDI) is developed to combine superior ability owns by ductile iron with lightweight characteristic. Apart from that TWDI is energy friendly during the production. These combinations will form a material with the ability to fulfill the needs. The main problem in the producing TWDI is the cooling rate; since the thickness of TWDI is classified to be below 5 mm. [2-5].

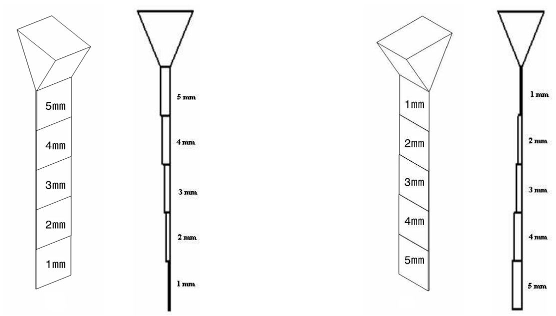
Researches take casting design to deal with TWDI cooling rate since casting design is a free parameter. Changing in casting design will not disturb material supplies, equipments, and process that have been established. Javaid et al. [6] used a step block casting design while Showman et al [7] introduced modified and horizontal groove step block casting designs and Pedersen et al used stepped block with feeder [8]. Beside the step block designs specific casting designs also introduced in producing TWDI. Stefanescu and his research group [4,9] have used special horizontal and vertical gating designs. Followed by Schrems et al. [1] who created horizontal casting design, INTEMA group developed special horizontal and vertical gating system [2,3,13]. In addition, Labrecque and his associates [10-12] created their own casting design as well as

Soedarsono et al [5,14-19] together with his colleagues developed several special vertical casting designs which can be classified into 2 groups. In the first group, the designs were developed from Stefanescu et al vertical casting design [3]. Soedarsono et al modified the gating system designs purposed by Stefanescu et al with three variations, that are: the bottom gating, the bottom gating with supporting gates, and the top gating gravity [5,14-19]. While in the other groups Soedarsono et al applied the Y-block principle, which can improve the casting yield. Y-block principal is a casting method without using gating system. Soedarsono et al introduced a new concept of plate arrangement based on its thickness, which contradicted the general principle of casting. This concept puts the thinnest plate near to ingate. The result of both the simulation and the experiment emphasizes that there was no trace of premature solidification, the filling process was successful, and all the plates were fully cast. [5,14-19].

This paper discusses the effect of Y-block principle casting design to microstructure and mechanical properties in producing TWDI plates.

Experiment Methods

Casting designs used in this work is represented by Figure 1. Two designs were built and coded as T4 and T5. The dimension of the plates is 75 X 150 mm with the thicknesses of 1, 2, 3, 4, and 5 mm. Every mould produces five plates. The plates are arranged in sequences. In T4 the pouring basin was put directly above the plate with 5 mm thickness while in T5 the pouring basin was placed above 1 mm thick plate.



T4 T5

Figure 1. Casting Design

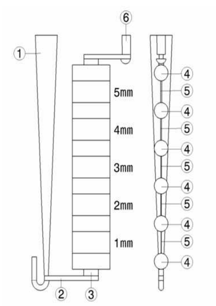


Figure 2. Casting Design of P1T1 [4,14-19]

The work was done in both simulation and experiment. Simulation on casting designs used Z-Cast program version 2.5. It ran for flow, solidification, and shrinkage analysis. Z-Cast is casting process simulation system developed by KITECH for over 20 years and fully verified at real manufacturing fields for various casting processes. The simulation was made base on assumptions that the process will be held in equilibrium condition since the molten metal used is ductile iron. The solidification process was assumed as alloyed solidification process with phases changing. The heat transfer dominant in the process will be convection ($\partial T/\partial x$) and every calculation were made base on it [18].

The experiment was done on the foundry scale and the moulds were made from furan sand. The metal cast was Ferro Casting Ductile (FCD) within the grade of 450 (JIS 2000). There was a chemical composition examined before conducting the liquid treatment process. The liquid treatment used was 12 kg Fe-Si-Mg with 6%Mg as the nodularising agent in the sandwich method with a tapping temperature of 1500^{O}C. Inoculants were also placed in the ladle. The inoculant used in this research was S70 with the composition of 1.5%Ca; 72.95%Si; 0.86%Al; 2.1%Ba. Pouring temperatures were 1450^{O}C and 1445^{O}C. The observations made included carbides appearance, nodule count, nodularity and nodule diameter uniformity. The calculations of nodular graphite characteristics were made by using manual calculation based on American Standard Testing Material (ASTM) A427 and also by using Cyuuzou Kun. Cyuuzou Kun is an imagine analyses software used in Iwate University.

Discussion

The chemical compositions of molten metal shows by Table 1 are all in range. There are some differences but the differences are not significant. Chemical composition of the molten metal fulfilled the requirements of FCD450.

Table 1. Chemical Composition – weight, [%].

Element/Pouring	C	Si	Mn	P	S	Cu	Ni	Cr	Mg
P1	3.8	2.6	0.37	0.02	0.02	0.04	0.03	0.04	0.04

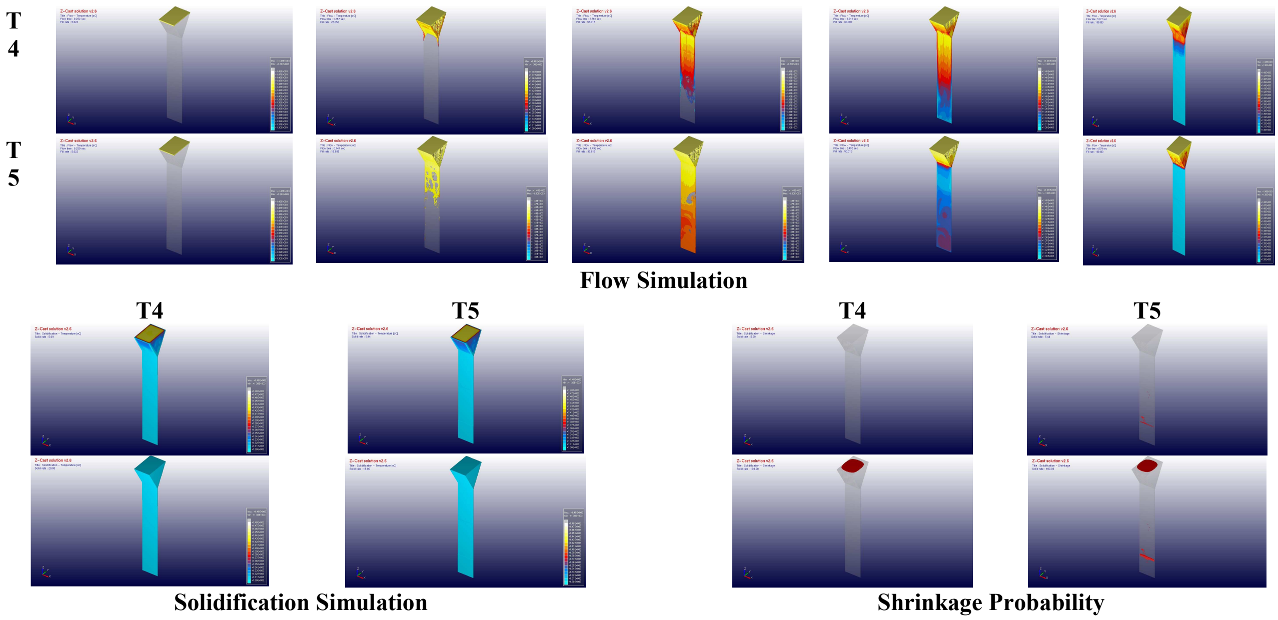


Figure 3. Simulation Result of T4 and T5

Simulations of both designs present different flow patterns (Fig. 3). Mould filling process is faster in T5 (0.75 s) than T4 (1.25 s). Filling process in T4 begins from both side of mould opening. Molten metal fills the mould with left and right side flows. The molten metal stream is smooth and still. Small turbulence occurs and temperature drops happens but localize when the mould full. The filling pattern in T4 is one direction flow. As for T5, the molten metal enters the mould through the whole opening with heavy stream. Heavy turbulence happens and the filling pattern is two ways direction. Although temperatures gradation missing when the mould full but during the filling heavy temperature gradation happens in several areas. This might cause different development of microstructure.

Results of solidification simulation (Fig. 3) show same pattern for T4 and T5. All plates already have blue color in the beginning of the simulation. When simulated the solidification only happens in pouring basin with the same pattern for both designs. Results of shrinkage (Fig. 3) presents different pattern for T4 and T5. In T4, shrinkage forms in the pouring basin area. This will do no harm to the cast plates. While in T5, shrinkage also forms in the bottom of 4 mm plate thickness.

During pouring process, discontinuity happens. This might cause defects in macro or micro condition. Both T4 and T5 show cold shut defects (Fig. 4) but discontinuity effects T5 more than T4. Beside cold shut, shrinkage also forms in T5. This is happen because T5 has smaller opening, which acts as an ingate. Simulation of T5 has predicted the formation of shrinkages and shrinkages do formed in the cast but the positions are not the same. Analysis result of shrinkages in T5 show that the shrinkages form due to discontinuity of molten metal during pouring.

T4 T5

Figure 4. Casting Result of T4 and T5

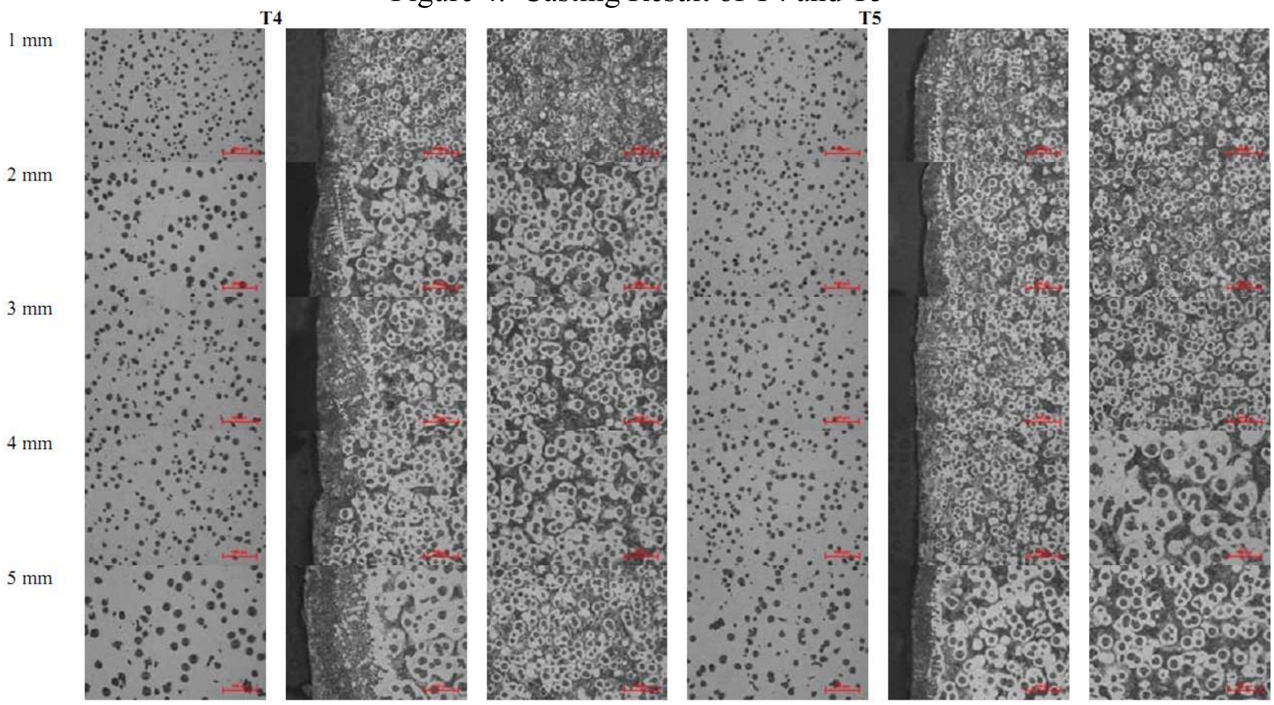
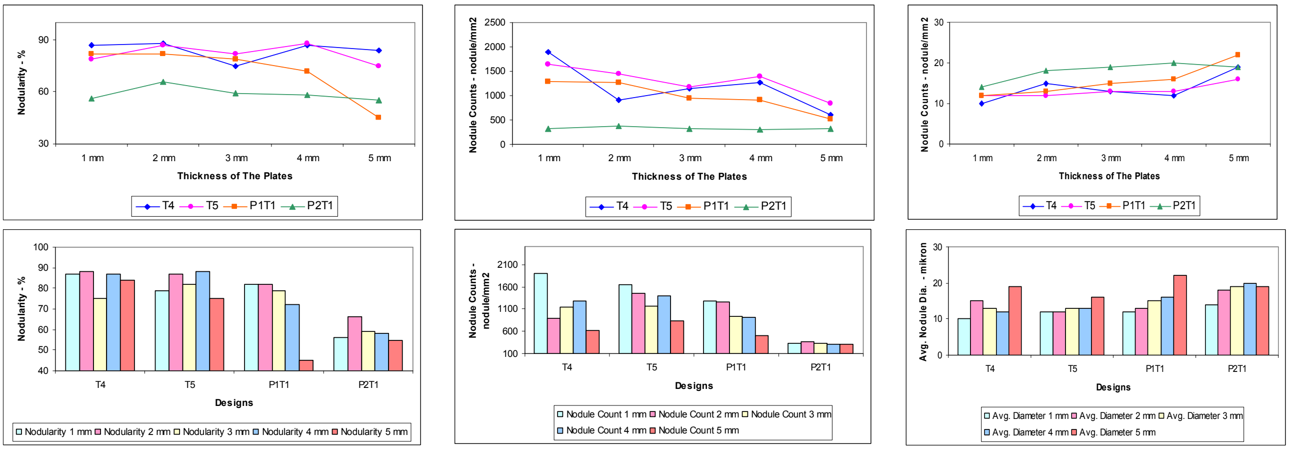


Figure 5 Microstructure of T4 and T5

Metalographic examinations of non-etched microstructures show same result for T4 and T5 that is nodule graphite (Fig. 5). Defects form in T5 and seen clearly in 3 mm plate thickness. Qualitatively, nodule graphite in T5 is smaller than T4. The nodule graphite of T5 appears to be similar in all thickness and distributes evenly except for plate with 5 mm thickness. This proves that temperature gradation (Fig. 3) happened during the filling process do not affects the final result. The nodule graphite in T4 look bigger in plate thickness of 2 mm and 5 mm look bigger compared to the other plates. T4 seems to have higher nodularity than T5. The etched microstructures show that the matrix is pearlite for both designs. Carbides also form in both designs and so do skin effects. Heavy carbide is show by plates with the thickness of 1, 3, 4 mm for T4 and 1, 2 mm for T5. The pearlite composition looks decrease as the thickness of the plate increase. In plate with 5 mm thickness, the matrix becomes pearlite/ferrite. A same thing happens to carbide. The composition of carbide seems to decrease as the thickness of the plate increase. Skin effects do not form in all plates. Plate with the thickness of 1 mm in T4 and 4 mm in T5 do not show any presence of skin effects. The qualitative analysis of microstructure confirms the simulation result. Simulation shows that T5 does not have temperature degradation when the filling process finished while T4 has localized one. This situation suspects to be the caused of nodule graphite condition. The designs of T4 and T5 give different matrix compared to previous research done by Soedarsono et al using the design of T1 (Fig. 2). The microstructure resulting from T1 for both plate arrangements (P1T1 and P2T1) is nodule graphite in ferrite matrix [19].

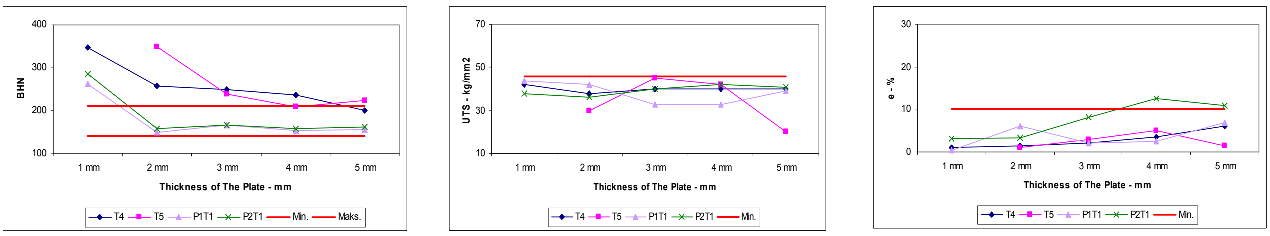


a. Nodularity b. Nodule Counts c. Average Nodule Diameter

Figure 6 The Characteristic of Nodule Graphite for T4, T5, P1T1 [19] and P2T1 [19]

Quantitative examination of nodule graphite presents average nodularity of T4 is 84% while T5 is 82%. This confirmed that T4 has higher nodularity than T5. Nodularity of T4 is between 75 to 88%, while T5 are between 75 to 88%. Nodularity in T4 plates is distribute evenly more than T5. The trend of nodularity for T4 and T5 do not show any similarity if compares to P1T1 and P2T1. Averages nodularity gain by T4 and T5 are higher than P1T1 and P2T1, even when the nodularity of plate with 5 mm thickness from P1T1 excluded.

Average nodule counts show that T5 (1302 nodule/mm^2) has higher nodule count than T4 (378 nodule/mm^2). Range of T4 nodule counts are from 614 to 1898 nodule/mm^2. While in T5, the nodule counts are from 840 to 1649 nodule/mm^2. This confirmed the qualitative examination made previously. Nodule counts in T5 plates show more similarity than T4. The difference between the highest and the smallest nodule count from plates in T5 is 49% while in T4 is 68%. T5 has higher nodule count compares to P1T1 and P2T1 [19]. Although nodule count in P2T1 is the lowest among others but the similarity of nodule count between plates in P2T1 is the highest. T5 has the smallest average nodule diameter (13.2 micron). This finding confirms T5 as the highest in nodule counts.



a. Brinell Hardness Number b. Ultimate Tensile Strength – UTS c. elongation – e

Figure 7 Mechanical Properties of T4, T5, P1T1 [19] and P2T1 [19]

Almost all of Brinell Hardness Number (BHN) of T4 and T5 exceeded the maximum limit of FCD450 (Fig. 7). This is happen because the presence of carbide and pearlite as the matrix. In T4 the BHN of plate with 5 mm thickness enters the standard of FCD450 because the matrix is pearlite/ferrite. While the BHN in T5 on its plate with 4 mm thickness close (0.5%) to the maximum limit because the composition of the matrix is all almost pearlite. Carbide is trace but very little. The BHN obtains by T4 and T5 confirmed the presence of carbide. When the BHN of T4 and T5 compare to P1T1 and P2T1, the BHN of P1T1 and P2T1 all are below maximum standard except for plate with 1 mm thickness. BHN of plates with 1 mm thickness from both designs also exceeded the maximum limit and carbide is present.

Ultimate tensile strength of T4 and T5 do not pass the minimum limit of FCD450, but T4 has higher and more even than T5. The smallest UTS achieve by plate produce in T4 design is 17% below the minimum limit. While for T5 is 57%. Based oh microstructures condition and analysis this failure suspects as the effect of defects that formed especially in on T5 where 2 kinds of defects are found. Same thing happens in elongation. The elongation of both T4 and T5 do not reach the minimum limit. Elongation of T4 exhibits its general that is elongation will increase with the increase of thickness, but this phenomenon is not happens in T5. Average UTS of T4 (40 kg/mm^2) is higher compare to P1T1 (38 kg/mm^2) and P2T1 (39 kg/mm^2) [19]. Reverse condition is happen for elongation. The elongation of P1T1 and P2T1 [19] are higher compare to T4 and T5.

Conclusion

This work finds that the designs made by Soedarsono et al have able to produce TWDI plates with different kinds of matrix. The designs of vertical step block casting following Y-block principle produce TWDI with the microstructure of nodule graphite in pearlite matrix while the gating system designs produce TWDI with the matrix of ferrite.

When cooling rate is determined by the presence of microstructure then designs of vertical step block casting following Y-block principle has higher cooling rate compare to the designs developed from Stefanescu vertical casting design.

The quantitative microstructures analysis shows high nodularity and nodule count owned by all of the plates but their mechanical properties have not fulfill the standard of FCD450, this is caused by the presence of carbide and defects in the plates.

Temperature gradation during filling process will not affect the development of microstructures but the temperature condition when the mould fully fulfill will. Stream turbulences are not always detrimental to casting properties.

Experiment results to a certain limit confirmed simulation results. Full confirmation cannot be established due to discontinuity that happened during the pouring process.

The highest nodularity is 88% achieve by 2 mm plate thickness produces by T4 and 4 mm plate thickness produces by T5. The highest nodule count is 1898 nodule/mm^2 achieved by 1 mm plate thickness produce by T4. The smallest average nodule diameter is 10 micron achieved by 1 mm plate thickness produce by T4. The highest average nodularity is 84% achieved by T4 while the highest nodule count is 1302 nodule/mm^2 achieved by T5. The smallest average nodule diameter is 13.2 micron achieved by T5. Compared to P1T1 and P2T1 the nodularity of T4 is the highest while nodule count of T5 is the highest among others.

Almost all BHN of T4 and T5 exceeded maximum limit due to the presence of pearlite matrix and carbide. The highest BHN is 350 achieved by 2 mm plate thickness produces by T5, the smallest is 201 achieved by 5 mm plate thickness produces by T4. The highest UTS is 45 kg/mm^2 achieved by 3 mm plate thickness produces by T5, the smallest is 20 kg/mm^2 achieved by 5 mm plate thickness produces by T5. The highest elongation is 6% achieved by 5 mm plate thickness produces by T4, the smallest is 1% achieved by 1 mm plate thickness produces by T4 and 2 mm plate thickness produces by T5.

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REFERENCE

[1] K. K Schrems, J. A. Hawk, Ö. N. Dogan and A. P. Druschitz, SAE Tech. Paper Doc. No. 2003-01-0828 (2003).

[2] M. Caldera, M. Chapetti, J.M. Massone, and J.A. Sikora: Mater. Sci. Technol, Vol. 23 No. 8 (2007), pp. 1000.

[3] R.A. Martinez, R.E. Boeri, and J. A. Sikora: Proceeding of 2002 world conference on ADI, AFS(2002).

[4] D.M. Stefanescu, L.P. Dix, R.E. Ruxanda, C. Corbitt-Coburn, and T.S. Piwonka: AFS Trans, Vol. 110 (2002), pp. 1149.

[5] J.W. Soedarsono and R. D Sulamet-Ariobimo: AMM, 415-417(2012), pp. 3301.
[6] A. Javaid, K. G. Davis, and M. Sahoo: *Mod. Cast.*, 90(2000), pp. 39.
[7] R. E. Showman, R. C. Aufderheiden and N. Yeomans: *Mod. Cast.*, 96(2006), pp. 29.
[8] K. M. Pedersen, N. S. Tiedjen: *Mater. Charact.*, 09(2007).
[9] L. P. Dix, R. Ruxanda, I. Torrance, M. Fukumoto, and D. M. Stefanescu: AFS Trans, Vol. 111 (2003), pp. 895.
[10] C. Labreque, M. Gagné, A. Javaid and M. Sahoo: *Int. J. Cast Metal Res.*, 16(2003), pp. 313.
[11] C. Labreque, M. Gagné, and A. Javaid: AFS Trans, Vol. 113 (2005), pp. 677.
[12] C. Labreque and M. Gagné: AFS Trans, Vol. 108 (2000), pp. 31.
[13] R.C. Aufderheide, R. E. Showman and M. A. Hysell: AFS, 113(2005), pp. 567.
[14] J.W. Soedarsono, B. Suharno and R. D Sulamet-Ariobimo: AMR, 415-417(2012), pp. 831-837
[15] J.W. Soedarsono, B. Suharno and R. D Sulamet-Ariobimo: AMM, 152-154(2012), pp. 1607.
[16] R. D. Sulamet-Ariobimo, J. W. Soedarsono and B. Suharno, “Effect of Casting Design to Microstructure and Mechanical Properties of 2 mm TWDI Plate” AMR, in press.
[17] R. D. Sulamet-Ariobimo, J. W. Soedarsono and B. Suharno: Solid State Phenomena, in press (2013).
[18] T.P. Soemardi, J.W. Soedarsono, and R.D. Sulamet-Ariobimo: International Symposium on Transport Phenomena, ISTP-22(2011).
[19] B. Suharno, J. W. Soedarsono, T. P. Soemardi, and R. D. Sulamet-Ariobimo: AMR, 277(2011), pp. 66.