Effect of Heat Treatment Parameters on the Characteristics of Thin Wall Austempered Ductile Iron Casting

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Abstract. The technology of thin parts is necessary steps to designers for energy consuming equipment to choose accurate material based on material properties. Here austempering treatment process was utilized to acquire thin wall austempered ductile iron castings. The plate thickness (2-5) mm were austenitized at 900 °C for, 30 minutes took after by holding at 350°C, 400°C and 450°C inoculated by Ce-Ca-Al-S-O-FeSi,Zr-Mn-Ca-Al-Ba-FeSi and Sr-Al-Ca-FeSi at 0.2wt%,0.4wt% and 0.6wt% for 2,5 and 10 minutes for every temperature.The austempered samples are comparatively harder than the as-cast ductile iron plates. The microhardness(HV20) also decreases with increase in austempering temperature for a given austempering time for thinner plates and also the micro hardness(HV20) is more for the samples treated at 350°C than those treated at 400°C and 450°C at 0.4wt% for a given austempering time. The yield strength and ultimate tensile strength of 2 mm thin wall austempered ductile iron are higher and ductility and impact strength are lower than that of as-cast 2 mm thin plate ductile iron inoculated by Ce-Ca-Al-S-O-FeSi compare to Zr-Mn-Ca-Al-Ba-FeSi and Sr-Al-Ca-FeSi at 0.4wt%. This may be attributed to the change in the structure change from ferrite-pearlite to austenite-bainite.

1. Introduction
Producing light weight ductile iron casting by decreasing the thickness of casting to approximately 2-5mm with high quality/weight proportion and better mechanical properties to make thin plate ductile iron casting an efficient other option to cast aluminium parts. It likewise makes conceivable transformation of many steel congregations to ductile iron because of its higher yield stress/cost ratio [1-3]. The solidification behaviour of thin wall ductile iron casting where studies by Several Investigators [4-6] they observed the directional growth of dendrites and graphite spheroids in the thin section and also found the segregation of Si and Mn.

X.Guo et.al [7] demonstrated that the amount of pearlite is influenced by both alloying elements and cooling rate. The Brinell hardness increases exponentially as the pearlite content is increased. Faster cooling rate results in higher nodule count. In other words, thinner sections will have higher nodule count [8]. Austempering heat treatment was generally done by heating the sample slightly above the austenitizing temperature and holding it in the austenitizing range for sufficient time. At that point the specimen is quenched in legitimate medium kept up at austempering temperature and holding it for adequate time for the isothermal transformation, and further cooled in air to room temperature. Austempering treatment was finished in a salt bath made up of KNO₃, NaNO₂ and NaNO₃ in the ratio 55 to 40 to 5 [9] which melts at 143°C and can be used at temperatures of up to 550°C[10-11]. Austempering should not be thought as medium to improve the properties of inferior quality castings, rather requires attention to produce a material having much superior properties than ductile iron.
Production of good quality ductile iron is the primary step followed by austempering to get the desired properties of thin wall austempered ductile iron casting.

2. Experimental Details
To acquire the thin plate austempered ductile iron castings, the heat were taken in Induction furance (1 ton) at a foundry unit. Liquid metal was tapped into the hot ladle at 1400°C-1450°C. The final chemistry of heat was obtained by spectrometer as given in Table 1.

**Table 1. Charge Chemistry for heat**

| Elements | C   | Si  | Mn  | P   | S    | Cr  |
|----------|-----|-----|-----|-----|------|-----|
| Wt %     | 3.75| 2.43| 0.32| 0.095| 0.013| 0.043|

Nodularizing treatment was done by sandwich method. Table 2 enlists the composition of the nodularization treatment alloys used.

**Table 2. Composition of nodularization treatment alloy FeSi-(6-7%) Mg**

| Elements       | Mg  | Ca  | TRE | Al  | Si  | Fe  |
|----------------|-----|-----|-----|-----|-----|-----|
| Wt %           | 6-7 | 1-1.5 | 1-1.5 | 1.2 Max. | 43-48 | Balance |

The Mg treated melt was poured in the mould, where in-mould inoculation was done. The thin wall ductile iron casting obtained as shown in Figure 1.

**Figure 1. Thin Plate Ductile Iron Casting**

Three types of inoculants were used for in-mould inoculation. Table 3 enlists the composition of inoculants used.

**Table 3. Composition of Inoculants**

| Inoculants         | Si  | Zr  | Ba  | Ce  | Mn  | Sr  | Ca  | Al  | S   | O   | Fe  |
|--------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Ce-Ca-Al-S-O-FeSi(wt%) | 70-76 | Nil | Nil | 1.5-2.0 | Nil | Nil | 0.75-1.25 | 0.75-1.25 | <1.0 | <1.0 | Bal. |
| Zr-Mn-Ca-Al-Ba-FeSi(wt%) | 62-69 | 3.0-5.0 | 0.3-0.7 | Nil | 2.8-4.5 | Nil | 0.6-1.9 | 0.55-1.3 | Nil | Nil | Bal. |
| Sr-Al-Ca-FeSi(wt%) | 73-78 | Nil | Nil | Nil | 0.6-1.0 | 0.10max | 0.50max | Nil | Nil | Nil | Bal. |
3. Results and Discussion

3.1 Microscopic Observation

By observing the microstructures in Figure 2 (a)-(c), it may be noted that the microstructures mainly consist of ausferrite and feathers of bainite with different volume fraction. The observe microstructures show slight difference in the volume fraction of bainite and ferrite. To further analyze, SEM photographs were taken for 2 mm thickness plate austempered at 350°C and for kept for 2 min. which are shown in Figure 3. It can be found from these SEM micrographs (Figure 3) that they bainitic feathers are uniformly distributed around nodules and in matrix. From comparing the Figure 3 and by observing the microstructures in Figure 2 (a)-(c), it may be noted that the microstructures mainly consist of ausferrite and feathers of bainite with different volume fraction.

Figure 2. Microstructure of 2 mm section thickness plate, austempered at 350°C and hold for (a) 2 min. (b) 5 min. and (c) 10 min. inoculated by Ce-Ca-Al-S-O-FeSi at 0.4%

Figure 3. SEM micrograph of the 2 mm thick plate austempered at 350°C and kept for 2 min. (a) at around nodules and (b) in matrix inoculated by Ce-Ca-Al-S-O-FeSi at 0.4%
3.2 Hardness results
Microhardness testing was conducted using a Vickers microhardness tester (OMNI-TECH, Model: MVH-AUTO). Table 4 enlists the micro hardness (HV$_{20}$) data of thin plates and respective plot made is shown in Figure 4. The hardness value remains more with austempering temperature at 350°C for 2 min., for 2 mm thick plate compare to 3 mm thick plate with austempering temperature at 400°C and 450°C for 2 min. This may result due to comparatively finer bainitic structure.

Table 4. Micro hardness(HV$_{20}$) value of (TWADI) samples of
2 and 3 mm Plate inoculated by
Ce-Ca-Al-S-O-FeSi at 0.4% inoculation

| Austempering Temp.(°C) | Austempering Time(min.) | Micro hardness (HV$_{20}$) 2mm Plate | Micro hardness (HV$_{20}$) 3mm Plate |
|------------------------|-------------------------|-------------------------------------|-------------------------------------|
| 350                    | 2                       | 395                                 | 370                                 |
|                        | 5                       | 380                                 | 355                                 |
|                        | 10                      | 365                                 | 345                                 |
|                        |                          | 380                                 | 365                                 |
| 400                    | 5                       | 375                                 | 345                                 |
|                        | 10                      | 360                                 | 330                                 |
|                        |                          | 365                                 | 350                                 |
| 450                    | 5                       | 345                                 | 335                                 |
|                        | 10                      | 320                                 | 310                                 |

Figure 4. Effect of austempering temperature and section thickness on Micro hardness (HV$_{20}$) inoculated by Ce-Ca-Al-S-O-FeSi at 0.4% inoculation
3.3 Tensile results
A tensile test specimen was set up as per ASTM E8, which were machined to 6 mm gage diameter and 25 mm gage length. Test was led by utilizing universal testing machine as per ASTM standard. From Table 5, the measured value of yield strength and ultimate tensile strength of thin wall austempered ductile iron (TWADI) are around 815 MPa and 1210 MPa respectively. However the same for as-cast is 410 MPa and 620 MPa respectively. The thin wall austempered ductile iron also have lower ductility in comparison to as-cast plate (Table 5). The increase in both strength value and decrease in ductility of thin wall austempered ductile iron in respect to as-cast thin wall ductile iron (TWDI) may be attributed to the change in the structure from ferrite-pearlite to ausferrite-bainite.

Table 5. Tensile properties data of as-cast TWDI and TWADI inoculated by Ce-Ca-Al-S-O-FeSi at 0.4% inoculation

| Tensile Test Specimen | Percentage Elongation (%EL) | Yield Strength (MPa) | Ultimate Tensile Strength (MPa) |
|-----------------------|----------------------------|----------------------|--------------------------------|
| As-cast TWDI (2 mm)   | 6                          | 410                  | 620                            |
| TWADI (2mm)           | 4                          | 815                  | 1210                           |

3.4 Impact results
The impact strength test was completed utilizing a charpy impact tester with the strain rate of $10^3$s$^{-1}$. The test was set up as indicated by the ASTM standard E327M. It can be noted from Table 6, the thin wall austempered ductile iron (TWADI) have lower impact strength in respect of as-cast thin wall ductile iron (TWDI). This may be due to the structural change of thin wall austempered ductile iron i.e. ferrite-pearlite to ausferrite-bainite.

Table 6. Impact test data of as-cast TWDI and TWADI inoculated by Ce-Ca-Al-S-O-FeSi at 0.4% inoculation

| Impact Test Specimen | Impact Strength (J/cm²) |
|----------------------|-------------------------|
| As-cast TWDI (2 mm)  | 75.28                   |
| TWADI (2 mm)         | 40.21                   |

4. Conclusions
Effect of austempering variables was successfully studied. The hardness, tensile strength, impact toughness and microstructure were evaluated. The following conclusions are derived from the present study.
• The austenizing followed by austempering of thinner plates at different temperatures and times leads to change in the structure ferritic-pearlitic to ausferrite-bainite.

• The hardness value remains more with austempering temperature at 350°C for 2 min., for 2 mm thick plate compare to 3 mm thick plate with austempering temperature at 400°C and 450°C for 2 min. This may result due to comparatively finer bainitic structure.

• The yield strength and ultimate tensile strength of thin wall austempered ductile iron (TWADI) inoculated by Ce-Ca-Al-S-O-FeSi at 0.4 % inoculation are higher and ductility and impact strength are lower than that of as-cast thin wall ductile iron (TWDI) plates. This may be attributed to the change in the structure change from ferrite-pearlite to austenite-bainite.

References

[1] John R. Brown, B. Heinemann 2000 Foseco ferrous foundry man’s handbook 78-79.
[2] K. Strauss 1970 Appl. Sci. Casting Metals 1 195-205.
[3] P. David, J. Mossone, R. Boeri and J. Sikora, Gating system design to cast thin wall ductile iron Plates 2009 Found. Trade journal 119-126.
[4] H. Morrogh, Production of nodular graphite structure in gray cast irons 1948 AFS Trans 56 72-87.
[5] A. G. Fuller, Evaluation of the Graphite Form in Pearlitic Ductile Iron by Ultrasonic and Sonic Testing and the Effect of Graphite Form on Mechanical Properties 1977 AFS Trans 85 509-526.
[6] C. Labrecque, M. Gagne, Development of carbide free thin-wall ductile iron castings 2000 AFS Trans. 108 31.
[7] X. Guo, D. M. Stefanescu, L. Chuzhoy, A mechanical properties model for ductile iron 2000 AFS Trans. 47-54.
[8] D. Venugopalan, A. Alagarsamy, Effect of alloy addition on the microstructure and mechanical properties of commercial ductile iron 1990 AFS Trans. 98 395-400.
[9] J. Achary, Tensile properties of austempered ductile iron under thermomechanical treatment 2000 J. Mat. Engg. and Performance 9(1) 56-61.
[10] R. A. Martinez, R. E. Boeri, J. A. Sikora, Impact and fracture properties of ADI compared with SAE 4140 steel 1998 AFS Trans 106 27-30.
[11] E. Fras, M. Gorny, H. F. Lopez, Thin wall ductile iron and austempered ductile iron castings 2008 AFS Trans 601-609.