A study on The Production and Characterization of Carbidic Austempered Ductile Iron

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Abstract

Austempered ductile iron (ADI) is the family of ductile iron with wide range of mechanical properties. This material is known for its higher toughness, wear resistance and the ductility. This ADI will replace the steel forgings with low production cost and aluminium components where higher strength-to-weight ratio is required. The properties of this material are improved by alloying and also by varying the austempering heat treatment process parameters. The microstructure of ADI contains ausferrite matrix and graphite nodules. The ausferrite matrix gives higher wear resistance due to its strain hardening effect during the wear applications. The wear resistance of this ADI is further improved by introducing carbides because carbides are wear resistance compounds. ADI with carbides are called as carbidic austempered ductile iron (CADI). The production process, characterization and optimization of mechanical properties of CADI are done in this research work.

Keywords:-Austempered ductile iron (ADI), carbidic austempered ductile iron (CADI), heat treatment process, ausferrite matrix.

I. Introduction

This section of the research work describes the method of production of ductile iron and carbidic ductile iron, its heat treatment process and standards of different characterization. The experimental work and characterization is done in two phases. An austempered ductile iron is produced and analyzed in the first phase of the work. The production of austempered ductile iron is done in two steps. One is the production of ductile iron castings and the second is the austempering heat treatment of the specimens. Then the austempered specimens are subjected to various mechanical tests like tensile, hardness, impact and abrasion wear test. Microstructure analysis is carried out and SEM analysis is also carried out on the impact and the wear test specimens.

In the second phase of the research, the carbidic ductile iron is produced by melting route. Different levels of chromium alloyed carbidic ductile iron are produced with high chromium ferro-chrome as alloy addition. Tensile, impact, hardness and wear test specimens are machined from the casted Y-blocks. The carbidic ductile iron specimens are austempered to form the carbidic austempered ductile iron. Mechanical properties of the CADI specimens are measured, SEM analysis of impact fracture and wear surfaces are also carried out.

2. Melting and Composition Control

An electric induction furnace is used for melting the base metal. The basic melting processes are furnace operations including charging, melting, composition analysis, composition adjustment, slag removal and superheating. The raw materials are added to the melting furnace directly and heated. The molten metal is tapped by tilting and pouring through the spout for the magnesium treatment.

2.1 Magnesium Treatment

It is the critical step in the ductile iron making. The amount of residual magnesium present in the melt during solidification is in the range of 0.03 to 0.05 weight percent. Magnesium contents less than this amount will result in flake graphite, and the amount more than this results in the appearance of exploded graphite. Either of the type contributes to degradation of the ductility of the cast iron.

The tundish cover ladle method is suitable for better magnesium recovery. Figure 1 shows the design of a tundish cover ladle suitable for the magnesium treatment. The use of a refractory dividing wall to form an alloy pocket in the bottom of the ladle gives an improved Mg recovery. The diameter of the filling hole is chosen to minimize the generation of fume while allowing the ladle to be filled quickly without excessive temperature loss. It is essential that the Fe-Si-Mg alloy is not exposed to the liquid iron until quite late in the filling procedure.

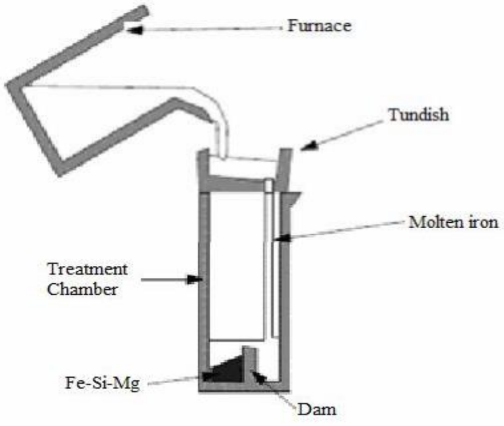

Figure 1 Magnesium treatment process

The calculated amount of magnesium alloy is kept in the alloy pocket and covered with steel turnings, Fe-Si pieces of size 25 × 6 mm. When the melt level in the ladle reaches the dividing wall, iron flows over and forms a semi-solid mass with the covered material allowing the ladle to be almost filled before the reaction starts, thus ensuring good recovery of Mg. This is done primarily to reduce the violence of the reaction that occurs when the molten iron contacts the magnesium. In order to minimize temperature losses during treatment, the ladle and cover should be separately heated with gas burners before assembly. The common magnesium treatment (Fe-Si-Mg) master alloy which is used in this process contains approximately 6-wt% Mg, about 45 wt% Si, with the balance Fe. About twice as much as magnesium is to be added during treatment and is required in the casting (this represents a 50% recovery) because of the oxidation losses during the violent treatment reaction..

During this time the magnesium reaction involves production of bubbles of magnesium vapour which proceeds to rise up through the molten iron bath which is now covering the pockets in the chamber. For successful treatment results, there should be a significant portion of the magnesium is dissolved into the molten iron, so that the correct conditions for graphite nodule formation are met in the solidifying melt. Typical “recoveries” of magnesium for the Tundish cover treatment facility are in the range of 50 - 60 percent. Successful nodularization requires a composition of about 0.03 to 0.05 weight percent elemental magnesium in the iron. It is necessary that sulphur content should be kept below 0.015% for successful treatment, because ability of the sulphur to react with the magnesium (forming Mg2S) removes elemental magnesium from the melt. Often the melt needs to be desulphurized before the treatment begins. It usually involves additions of Ca (calcium) to combine with the sulphur. The calcium sulphide will rise to the slag layer and be skimmed. Tapping time is usually around 40 seconds. The temperature loss during magnesium treatment is around 50°C, so the tapping temperature must be adjusted accordingly; treatment temperatures around 1540°C are commonly used. After treatment, the tundish cover is removed; the metal is transferred to a pouring ladle where inoculation takes place. The liquid metal must be poured within a short period of time after treatment, usually less than 5 minutes. Longer time may fade the magnesium in the liquid metal and lead to the formation of vermicular cast iron with poor mechanical properties.

Immediately after magnesium treatment, the iron must be inoculated. Graphitizing inoculant BACAL 25 is used. The inoculant manufactured and supplied by M/s SNAM alloy is used. The BACAL contains 25% barium and remaining calcium. Normally 0.3 wt percentage of inoculants is added into the melt. Inoculation treatment is not permanent. The inoculants effect starts to fade from the time it is added. Significant fading occurs within five minutes of inoculation. As the inoculating effect fades, the number of nodules formed decreases and the tendency to produce chill and mottled iron increases. In addition, the quality of the graphite nodules deteriorates and quasi-flake nodules occur.

3 Moulding, Pouring and Knockout

CO2 mould with designed runners and risers is prepared for the Standard Y-block pattern as per the ASTM A 370 standards and the dimensions are shown in Figure 2.3. Casting trials are done by filling the molten metal through the designed runners and risers and checked for its filling performance. This trial shows good filling performance of the mould. The same design of runner and riser is used for the Y-block casting production. The molten metal after treatment is poured into the mould within a short span of time to avoid the fading of magnesium. The mould is allowed to cool for a period of 12 hours and the casting is knocked off from the mould. The casting is shot blasted to remove the sand particles on it. The runner and the risers are removed from the casting using arc cutting. After cleaning, the visual inspection is carried out on the Y- block that reveals defect free cast surface. Cracks, blow holes, porosities are not observed on the surfaces.

4 Composition Analysis

The final composition of the specimen is analyzed using a vacuum spectrometer. The results of the composition are shown in Table 1.1. Specimens are machined from the lower part of the Y-block (Hatched lines shown in Figure 1.3) for the characterization. Melt 1 is the common unalloyed ductile iron (500/7) casting taken for the experimentation. Nodule count 80 should be the minimum requirement for effective austempering. Standard wire cutting, machining and grinding operations are employed for specimen preparation.

The microstructure of the melt 1 specimen is analyzed after austempering. The microstructure does not reveal any formation of ausferrite matrix. It contains graphite nodules in the pearlite and ferrite matrix. Literatures show that small quantities of alloying are necessary for best austempering. Hardenability elements are to be alloyed for the formation of ausferrite matrix. Copper, nickel, chromium, titanium and molybdenum are some of the hardenability agents used in ductile iron. In this study, copper and molybdenum are added to get the austempered ductile iron.

Table 1 Composition of alloyed DI

Composition	**Melt 2**	**Melt 3**

C	3.5862%	3.3652%
Si	2.4957%	2.8112%
Mn	0.4681%	0.2657%
P	0.0240%	0.0410%
S	0.008%	0.0070%
Mg	0.0490%	0.0320%
Cr	0.0256%	0.0410%
Cu	0.3145%	0.3600%
Mo	0.0000%	0.4200%

Selection of the raw material and the melting is carried out as in the previous case. Calculated amount of copper for melt 2, copper and molybdenum for melt 3 are added in the raw materials. Recovery of 60% of the alloying elements is considered. Weight of the melt is 50 kg. Addition of copper turnings for the melt 2 is 300 grams. 300 grams of copper turnings and 700 grams of HCFeMo are added to the melt 3 to increase the content of copper and molybdenum. The composition of the Y-block castings is checked using spectrometer and the same has been given in Table 1. Microstructures of the melt 2 and 3 are analyzed after austempering treatment. The microstructure reveals ausferrite matrix. The fact sheet of complete experimentation and characterization of austempered ductile iron

Specimens are machined from the lower part of the Y-block for the tensile test, hardness test, wear test and impact toughness test. The positions of the specimens in the Y-block are marked as hatching lines. 10mm x10mm size bars are cut from the Y-block casting by hacksaw cutting. These bars are milled to the Charpy impact test specimen of dimensions 10mmx10mmx55mm as per ASTM A370 standard. The standard tensile test specimen, hardness test specimen and the wear test specimens are turned in lathe.

5 Austempering Heat Treatment Process

Austempered ductile iron is produced by heat-treating the cast ductile iron alloyed with small amounts of copper and molybdenum. The final properties of the material are determined by careful choice of heat treatment parameters. The austempering process improves the strength of the specimens with minimal distortion and stresses. Austempering heat treatment process is a two stage process. During the first stage the specimens are heated to austenitizing temperature and held for two hours. In the second stage, the specimens are rapidly cooled from the austenitizing temperature to austempering temperature and soaked for a long time.

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The steps followed in the austempering process are:

1. Heating to the austenitizing temperature (A to B) – 920°C.
2. Austenitizing (B to C) at 920°C for two hours.
3. Rapid cooling to the austempering temperatures (C to D) like
250°C, 275°C, 300°C, 325°C and 350°C.
4. Isothermal heat treatment at the austempering

temperature for two hours (D to E).

5. Air cooling to room temperature (E to F).

Two electrical resistance type salt bath furnaces are used for the austempering process. One is for austenitizing and another is for austempering. Furnace system and process are driven via a state-of-art human machine interface, which also provides access to the heat treatment programmes. Flexibility in the furnace and controller configurations allows the austempering process to be tailored to the part.

The specimens are immersed in the crucible containing the molten salt bath. The mode of heat transfer to the work piece is by convection through the liquid bath. These salt bath offers certain advantages over other quench medium. All work pieces are at uniform temperature and have identical surroundings. Such a condition results in better surface conditions and consistent and reproducible results.

6. Conclusion

Austempering of unalloyed specimen does not form ausferrite matrix but improves mechanical properties; 27% improvement in hardness, 12 % increase in impact toughness and 13% improvement in the ultimate tensile strength are achieved. Minimum amounts of hardenability materials are required for better austempering of ductile iron. Copper responds in a better way as a hardenability element.

A clear upper ausferrite matrix at higher austempering temperatures and lower ausferrite matrix at lower austempering temperatures are noticed on the microstructure of copper, copper and molybdenum alloyed ADI. The hardness of CADI mainly depends on the amount of carbides and the type of matrix. Decrease in austempering temperature, time and increase in chromium content increases the hardness.

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