A REVIEW OF AUSTEMPERED DUCTILE IRON, MECHANICAL PROPERTIES, WEAR AND CORROSION CHARACTERISTICS

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ABSTRACT

Austempered Ductile Iron (ADI) has found enormous applications in recent years due to its high strength and hardness, coupled with substantial ductility and toughness. This material has replaced steel in most applications. Corrosion studies play an important role in the field of mechanical industry. Various corrosion testing methods available are electrochemical test, salt spray test, total immersion tests etc. The choice of the corrosion testing method depends upon many factors such as nature of environment, nature of exposure, type of specimen etc. In the present investigation, ductile iron castings conforming According to the ISO-standard No. 1083 (1976) there are six main grades of as-cast ductile iron denoted as 800/2, 700/2, 600/2, 500/7, 400/12, and 370/17 grade were produced in a regular ductile iron production foundry in green sand moulds. The castings were then subjected to standard austempering heat treatment cycle to bring about the changes in the microstructure and hence the mechanical properties. Austempering temperatures selected were 320°C and 400°C.

KEYWORDS:- Austempered Ductile Iron (ADI), Ductile Iron (DI), Corrosion, Mechanical Properties.

1.1 INTRODUCTION

Austempered ductile iron (ADI) is considered to be an important engineering material because of its attractive properties such as good ductility at high strengths, good wear resistance and fatigue strength. ADIs are reported to have fracture toughness comparable to those of heat treated medium and low alloy steels. The attractive properties of ADI are related to their unique microstructure that consists of ferrite and austenite rather than ferrite and carbide as in steels. Large amount of silicon present in ductile ironsuppresses the precipitation of carbide during austemperingreaction, and retains substantial amount of stable highcarbon austenite. Small amounts of alloying elements such as copper, nickel and molybdenum are generally added to ductile iron so that it has sufficient hardenability to be quenched to the austempering temperature without forming pearlite.

The mechanical properties of ADI can be tailored to suit particular applications by adjusting heat treatment parameters or material compositions. This has the effect of altering the proportions of the major phases present in the microstructure: bainitice ferrite, carbide, high carbon austenite and nodular graphite. The process comprises the production of a ductile iron casting, austenitization (800- 950°C), subsequent quenching to a temperature (250- 400°C), suitable for the final stage, the isothermal transformation (austempering) of some of the austenitic matrix to other phases, prior to subsequent cooling to room temperature. Addition of alloying element may also be the main factors of the changes in Microstructural and mechanical properties. Obviously, the combination of alloying composition together with the austenitization and austempering heat treatments, determines the microstructure produced and subsequently the dominant mechanical properties.

The explicitly study fatigue initiation and crack propagation of ADI found out that the crack propagations of ADI is much associated with tabulation of graphite and types of microstructures. Decohesion of graphite nodules and subsequent initiation and growth of micro-cracks may lead to deflection of the dominant crack system as they approach coalescence.

1.2 Type of Cast Iron

1.2.1 GRAY CAST IRON Gray cast iron is produced from the foundry pig, scrapped casting and coke which is melted in a cupola blast furnace. Grey cast iron derived its name from the grey color obtained when it is fractured. The carbons in gray cast iron are in graphite form, so its microstructure is full of graphite flakes but this is not always desirable. About 0.8% of the carbon is in the form of iron carbide Fe3C, and the rest 2 to 4% are in the form of graphite. It is possible for gray cast iron to have all its carbon inform of graphite. Such gray cast iron will be soft and easy to machine.(A). This type of cast iron will have high damping capacity and high compressive strength. The tensile strength, ductility and impact strength are much lower than steel due to the weakening effect of the graphite flakes but it has a high resistance to corrosion . On the other hand, the gray cast iron having the carbon content in the form of carbide is usually very hard, brittle and not easily machined. There are two main factors that determine which type of gray cast iron will be formed. These are (i) the chemical composition of the desired gray cast iron; (ii) the cooling rate from the molten state. Gray Cast Iron is used for cylinder blocks, Piston rings, Internal Combustion engine.

1.2.2WHITE CAST IRON This iron derived its name from its color which is white and dull. The carbon content of this type of cast iron is in the form of free cementite. White cast iron is produced either by casting the gray cast iron but rapidly cooled it or by adjusting the carbon content in the composition and makes it low.White cast iron is very hard, but wear resistant and very brittle. White cast iron can be used for the production of malleable iron castings and manufacture of components requiring hard and abrasion resistant surface

1.2.3 MALLEABLE CAST IRON Malleable cast iron is obtained from the white cast iron. To do this white cast iron is annealed. The white cast iron is heated slowly to 8700C. It is then homogenized for 25 to 60 hours depending upon its size. It is then cooled slowly in the furnace. This process is called malleabilizing heat treatment. Malleable cast irons are tougher than gray cast iron and more resistant to bending and twisting. It is used for various automobile, tractor and plough parts, gear housing et al.

1.2.4 DUCTILE CAST IRON The ductile cast iron is another type of iron that can be obtained from grey cast iron. This is obtained by the addition of magnesium to the melt of grey cast iron. This will result in the production of nodules in the microstructure of the ductile cast iron and therefore called Nodular Cast Iron Ductile iron contains 3.2 – 4.2%C, 1.1 – 3.5%Si, 0.3 -0.8%Mn, 0.08%P and 0.02% - 0.05%S(3,8,20).Ductile cast iron possesses a good ductility.

It has good machinability, wear resistance and very good castability (3)

1.2.5 AUSTEMPERED DUCTILE IRON Austempered ductile iron is obtained by heat treating the ductile iron in salt bath of sodium chloride, potassium chloride and barium chloride at the temperature of 8300C. It was austempered at 350 - 420^{O}C and later salt bath using sodium nitrate and potassium nitrate.

2. LITERATURE REVIEW

Shakir K.A, Ahamed Aahraf, Vijay Kumar(2015) Austempered Ductile Iron (ADI) is replacing steel and it is finding applications in agriculture, mining construction and automotive sector due to its superior mechanical properties and cost-effectiveness in manufacturing. In this study IS500/7 grade ductile iron castings were made subjected to austempering heat treatment to get ADI i.e., to bring about changes in microstructure and hence therefore mechanical properties. Austempering heat treatment involves arsenisation at 9000C temperature for 2 hours duration, austempering temperatures selected was 3600C and 4300C and austempering duration selected were 50,100,150,200 and 250 minutes. Ultimate Tensile strength and Hardness of the ADI specimens were analysed and compared with as cast condition specimen. The results of the investigation indicate that the ADI castings possess better tensile strength and hardness compared to as cast specimens [3].

TFH Mohamed, SS Abd El Rehim (2017) Ductile cast iron (DCI) possesses several engineering and manufacturing advantages when compared with cast steelsThese include an excellent damping capacity, better wear resistance, 20-40% lower manufacturing cost andlower volume shrinkage during solidification. The combination between the good mechanical properties and thecasting abilities of DCI makes its usage successful in structural applications especially in the automotive industry.However, DCI suffers corrosion because of the free graphite content (2-4% by weight); an insoluble graphitic layer ofcorrosion products is left behind in the process of corrosion . These corrosion products are very dense, adherent,have considerable strength, and form a barrier against further corrosion. In comparison with steel corrosion, becauseof the absence of free graphite in steel, the corrosion products have little or no strength or adherence and flake off asthey are formed, thus presenting fresh surfaces for further corrosion [4].

OlasupoOgundare, Babaniyi Babatope (2012) This research presents the corrosion characteristics and the accompanying changes in the microstructure of unalloyed ductile iron (DI) and austenitic stainless steel (ASS) in table salt medium representing an upper limit in an extreme marine environment. The individual corrosion rates of DI and ASS was evaluated for the maximum time period of 1200 hr. Using the immersion test technique, the corrosion rate of DI was evaluated and found to be four-orders of magnitude greater than that of ASS. The corrosion product morphologies of the DI showed that the nodular matrix was gradually covered up as immersion time progressed while the corrosion channels and volume of pits that initially formed in ASS respectively deepened and increased with increased exposure time. This work is important as a reference point for the quantification of the corrosion effectiveness of alloying DI. The microstructures of the corroded samples showed corrosion initiation and gradual accumulation of corrosion products [5].

Shuai Han, Qingmin Li (2014) The hot spot temperature inside the windings of the oil-immersed power transformersmay exceed 200C due to some winding deficiencies, posing negative impact on the research insulation. A series of heating experiments are deliberately conducted withoil-research insulation samples to study the influence of the hot spot temperatureranging from 120 to 280 C, and the insulation degradation is characterized by thebreakdown voltage (BDV) and the degree of polymerization (DP). Furthermore,surface morphology, water content and cellulose degradation mechanism areanalyzed so as to reveal the causes of the above phenomena. The experimental resultsindicate that with increase of the hot spot temperature, the breakdown voltageincreases after the first drop, while the DP continues to decline in the testedtemperature range. No obvious linear relationship is observed between the hot spottemperature and the DP or the BDV. Regarding the test samples the authors havestudied, the inflection point of the hot spot temperature for the insulationdeterioration is found to be between 240 and 260 C. The proposed research presentsa fundamental reference for assessment of the winding insulation degradation fromthe viewpoint of hot spot temperature [6].

V. D. Shinde, B. Ravi (2012) Achieving the desired mechanical properties in thin wall ductile iron castings poured in industrial production foundries is a challenge. In this work, the effect of copper addition (up to 0?74%) and melt processing (Ba based stream inoculation) on the matrix structure, mechanical properties and fracture behaviour of ductile iron castings with varying section thickness (4–16 mm) were investigated in a regular jobbing foundry. It was possible to obtain 80% pearlitic structure without carbides in 4 mm sections, giving a tensile strength of 658 MPa with 2?5% ductility and 264 Brinell hardness. The solidification behaviour represented by the cooling curves helped in checking the effectiveness of the melt treatment by observing the amount of undercooling. Fractography studies of tensile specimens showed the change in fracture mechanisms due to increase in copper content on fracture paths. The increased amount of pearlite in the matrix exhibited brittle fracture with river pattern [7].

C. Labrecque, M. Gagné (2013) The use of Ductile Iron for light weight automotive components has been limited in the past by the capability of the foundries to produce as-cast, carbide free, thin wall (2-3 mm) parts. For almost a decade, the Ductile Iron industry has invested significant amounts of money and time to develop a technology that would allow the manufacture of such castings. A key parameter for the production of thin-wall casting is to control the nodule count in a range of 500-700 for which the mechanical properties and the microstructure are optimum. This is obtained by controlling the cooling rate of the parts and by optimizing the inoculation process. This paper presents the results of a study carried out in an experimental foundry in which the following parameters were studied: I) optimization of the addition of an insulating material to the mould to control the heat exchange at the mould/metal interface and then, the undercooling level to avoid carbide formation; ii) selection of the appropriate inoculation practice to control the nodule count in the selected range; iii) to determine a minimum silicon content required to optimize properties and cost [8]

Dr. T. Skaland (2013) The objective of the present paper is to give an overview of various commercial ductile iron treatment processes available and in particular, major advantages and disadvantages of the various methods. The addition of nodularizing agents to molten iron is probably the most important single step in the production of ductile iron. Magnesium is the most widely used spheroidizing element, and it is frequently added with cerium and other rare earth materials. The objective of the founding business is to produce the quality required at the lowest possible cost. Recovery of the treatmentmethod and alloy are key factors in this respect.BThese are known as the sandwich process, the tundish cover process, the flow through process, the in-mould process, and the cored wire process [9].

Vaibhav sharma (2015) Study on the corrosion characteristics of ascast ductile iron in lime juice was conducted using the common weight loss method. Five standard tensile samples were prepared from the ascast condition of the alloy. One of them was taken to be for control, while the others were labeled A, B, C, and D. These labeled samples were then immersed in freshly extracted lime juice for a period of four weeks, having noted their respective initial weights. A sample was withdrawn from the medium at the end of each week for microstructural and tensile properties (using INSTRON 1195 at a fixed crosshead speed of 10mm min-1) examination for comparison with those of the control sample. It was observed that the mechanical properties of the alloy were deteriorating due to pitting corrosion and that the corrosion rate increases with increase in the pH of the medium. It was concluded that corrosion rate can be kept to the minimum by controlling the pH of the media within the range 2.0 to 3.05.[10]

HaMiD PourAsiabi , and Hamed PourAsiabi(2012) Austempered Ductile Iron (ADI) has unique microstructure of ferrite and austenite known as ausferrite which givesa remarkable wear resistance and mechanical properties to it . These considerable mechanical propertiesresulted in a daily increasing use of ADIs in fabrication of industrial components like gears, pinions, crankshafts,bearings, grader blades and similar parts that require improved wear resistance There are a lot ofinvestigations in literatures about the wear resistance behavior of ADIs in a variety of abrasive mediums. Thereported properties include sliding wear resistance, impact wear resistance and rolling wear resistance Fordyce and Allen have showed that ADI has such a high un-lubricated sliding wearresistance that its wearresistance is equal to high hardness steels especially at high sliding velocities. [11]

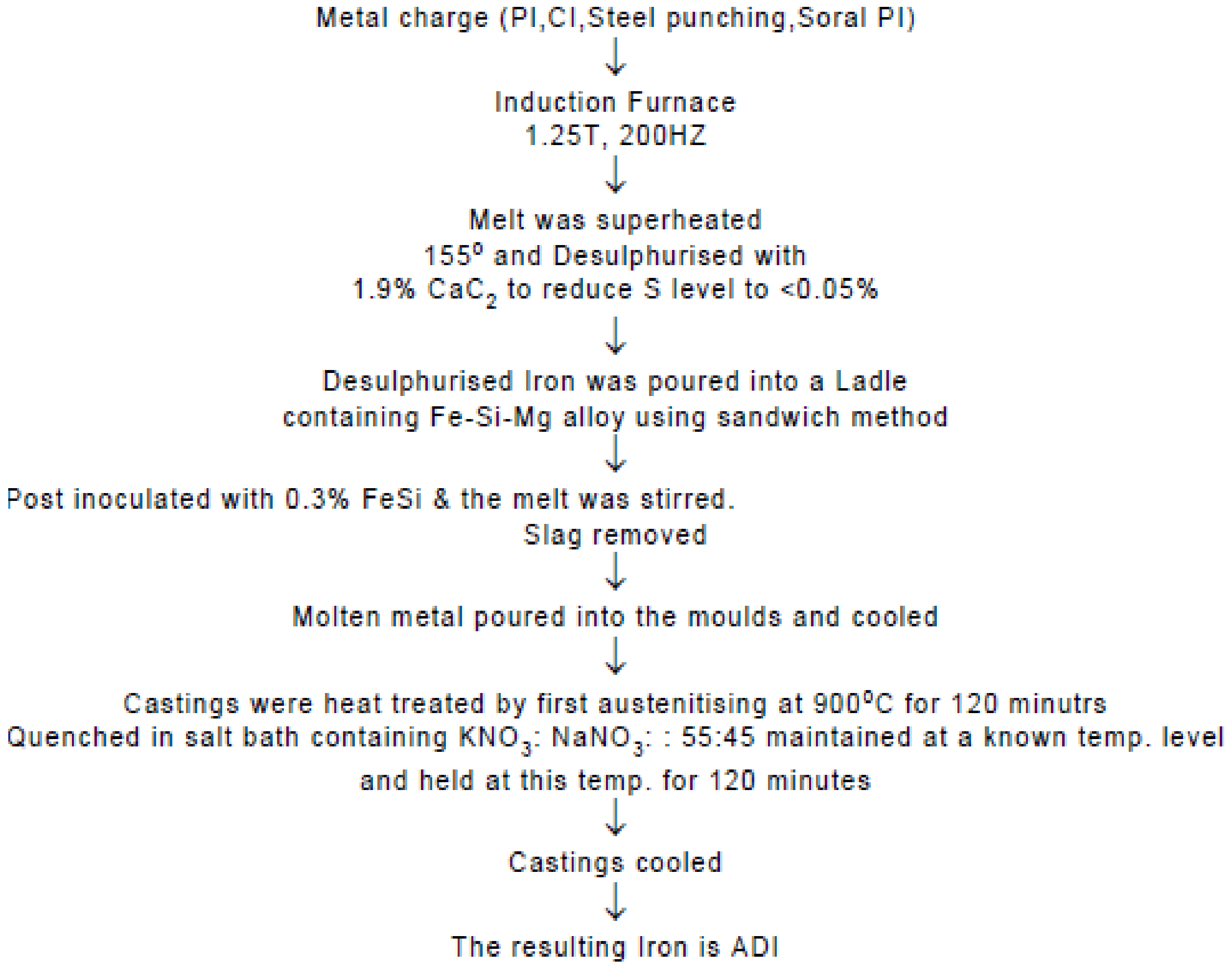

Fig (1) Flow chart for ADI casting production.

3. RESEARCH METHODOLOGY

3.1 Mechanical Properties Testing

3.1.1 Microstructure Examination: Standard metallographic procedures like grinding and polishing were done for microstructure examination. Standard test procedures were employed for structure examination and mechanical property assessments.

3.1.2 Hardness Test

Hardness is a characteristic of a material, not a fundamental physical property. It is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation

3.1.2 Tensile Test

Tensile testing, also known as tension testing, is a fundamental materials science and engineering test in which a sample is subjected to a controlled tension until failure. Properties that are directly measured via a tensile test are ultimate tensile strength, breaking strength, maximum elongation and reduction in area From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics

3.1.3 Impact Test

The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition. It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. A disadvantage is that some results are only comparative.

3.1.4 Percentage of Elongation

Percent elongation is a measurement that captures the amount a material will plastically and elastically deform up to fracture. Percent elongation is one way to measure and quantify the ductility of a material. The material's final length is compared with its original length to determine the percent elongation and the material’s ductility.

3.2 Corrosion Test

Polarization is the displacement of an electrode potential from its equilibrium value as a result of current flow. Gamry Instrument was used to measure the polarization test. Three compartment cells with a saturated calomel reference electrode and a platinum auxiliary electrode was used. Polarization data was analyzed using Gamry software.

3.3 Wear Test

3.3.1 Dry Sliding Wear test

The specimens in the form of 5mm pins were prepared in a lathe and used as a sample for dry wear test. A hardened circular disc having hardness of 64HRC was used as counter face. The testing was carried out by allowing the specimen to rub against hardened disc for a given normal load and speed condition. Making use of pin on disc machine test was carried out. The specimens were taken out at regular intervals and the weight was recorded. The experiment was conducted for different load, speeds and different conditions of metal (as-cast or heat treated).

5. CONCLUSIONS

The investigation carried out on as-cast ductile iron and austempered ductile iron indicate the following:

- Graphite nodules are more or less uniform and are evenly distributed; upon austempering the structure shows bainitic matrix in the iron.
- Mechanical properties such as ultimate tensile strength, percentage elongation and hardness values are enhanced compared to the as-cast condition.
- Impact test shows that impact energy decreases on heat-treating of the specimen.

- Dry sliding wear shows that on heat treating the specimen shows higher resistance to wear
- Wet abrasive wear also shows higher resistance to wear in the heat-treated condition.
- Studies on corrosion shows that the weight loss is more in as-cast condition compared to heat-treated condition. It was also observed that corrosion is more at higher temperature of the bath.
- The corrosion (rate) of the heat-treated specimen is less/reduced compared to the as-cast conditions.

Hence, it is clear that by austempering the ductile iron castings, better mechanical properties and corrosion resistance properties are realised.

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