IMPROVING NODULAR CAST IRON MECHANICAL PROPERTIES THROUGH AUSTEMPERING IN PALM KERNEL OIL

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ABSTRACT

Austempering of nodular cast iron in palm kernel oil bath medium was carried out. Samples of nodular cast iron were heated at 900^0C in a metallurgical furnace for 1hour and quenched in hot palm kernel oil at 270^0C for 0.5hour, 1hour, 1.5hour, 2hour, 2.5hour and 3hours after which the samples were subjected to hardness test, ultimate tensile strength test, and micro structural analysis. The hardness was improved from 14.8HRC to 27.5HRC, the ultimate tensile strength was improved from 697×10^6 to $911 \times 10^6 N/m^2$ and the toughness was also improved. Bainite structure was also obtained in the microstructures thus, suggesting that palm kernel oil is a suitable medium for austempering nodular cast iron.

Keywords: Austempering, cast-iron, hardness, tensile-strength, toughness, test.

INTRODUCTION

The importance of metals in modern world cannot be over emphasized; a day does not pass without us interacting with metals. Because of this there are many ways in which metals (ferrous and non ferrous) influence our daily life. Steel and cast iron are extensively utilised in some vital areas such as the automobile, construction, manufacturing industries, agriculture, power industry, water supply piping and many more. Conventionally, machines, agricultural tools and automobile parts are produced from alloy steel material by drop forging in dies or machined out from alloy ingots and heat treated to resist wear. These processes are however very expensive because of high initial capital investment and machining cost, so casting as an alternative process has been introduced. However, casting from steel has disadvantages of poor casting properties: rough looking casting, high solidification shrinkage and thermal contraction as the casting cools to room temperature. Therefore nodular cast iron is believed to be a good substitute (Falalu, 2003).

Nodular cast iron is one of the recent additions to cast iron family. A modification of cast iron using magnesium or cerium which precipitates graphite as nodules gives a first class nodular cast iron which has excellent properties. Ductile cast iron has properties of castability, machinability, reliability in service, vibration damping, hardenability and wide range of strength (Khurmi and Gupta, 2004). Improvement of some of these properties of nodular cast iron is possible, such that it can exceed steel in some mechanical properties (Uma *et al*., 2011; Chan-yun *et al*., 2013). The half-life span of any machine component or tool in service depends on good mechanical properties acquired. One way of improving the desired properties is by heat treatment, for example the abrasion wear resistance of irons is improved by carbidic austempering which involves the incorporation of an extra phase to a nodular cast iron (Laino *et al.*, 2008). This paper is a report of how the mechanical properties of nodular cast iron were improved through austempering heat treatment in palm kernel oil. Austempering is a special heat treatment process in which a metal is heated to austenitizing temperature (900^0C -950^0C) and then quenched in a bath content of a constant temperature above the martensite start (Ms) and within the bainite range (200^0C - 400^0C in general) as shown in Figure 1. The heated metal is quenched and maintained at a constant temperature in the bath till all the austenite is transformed into bainite, after which it is taken out of the bath and cooled in air to room temperature. Because the process involves transformation at constant temperature, it is also known as isothermal quenching. According to Rajan *et al*. (1988) two important parameters which control the process are cooling rate for the first quench and holding time in the quenching bath.

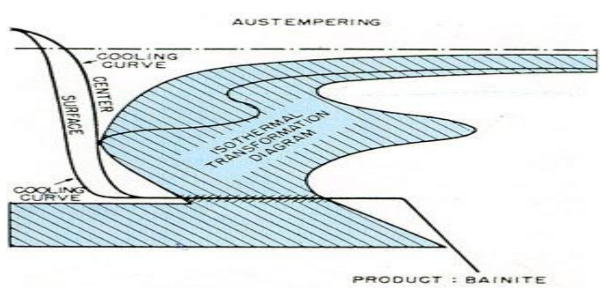

Figure 1: Isothermal transformation diagram for austempering process. Source: Oloche *et al.* (2003).

The history of austempering began in 1930 when Grossman and Bain were evaluating the metallurgical response of steels cooled rapidly from 788^0C to intermittently high temperature and held for various times, in the United States Steel Laboratory (Keough, 1998). When a stronger and tougher metal is required austempering is used as conventional heat treatment processes cannot produce a combination of strength and toughness (William, 1997; Adewuyi, 2004).

Isothermal quenching transforms austenite to bainite during austempering. Bainite is a structure made up of ferrite and metal carbide. Austempering temperature is between 250^0C - 450^0C. The isothermal transformation of austenite to bainite during austempering is divided into two regions: upper and lower bainite, when austempering is carried out between 330^0C – 450^0C the structure obtained is called upper bainite while lower bainite is obtained between 250^0C – 330^0C (Adewuyi and Afonja, 2000; Oloche and Ause, 2003). According to Baumeister et al. (1979)

austempering temperature and time is the main determinant of the final microstructure and consequently the mechanical properties of austempered products. Thus it is possible to obtain various combinations of high strength, high hardness, limited ductility or lower strength, lower hardness and high ductility by varying the austempering temperature (Rollason, 1985). Austempered Nodular cast iron therefore offers the design engineer the best combination of low cost, good machinability, high ductility, high strength, good toughness, wear resistance and fatigue strength (Adewuyi, 2004). The austempered ductile iron microstructure is compossed of graphite nodules floating in a matrix composed of a mixture of the ferrite and austenite lamellae otherwise called ausferrite (Myszka, 2006).

MATERIALS AND METHODS

The materials and equipment used to achieve the aim of this research as well as the detail experimental procedure that was carried out are as follows:

Experimental Procedure

Some quantity of palm kernel oil was poured into a steel pot and progressively heated on the big stove until boiling at 270^{0}C. A piece of nodular cast iron was dipped into the boiling oil and held for five minutes then removed to be observed for the presence of staining. After cooling nodular cast iron piece was washed in kerosene. Eight pieces of nodular cast iron samples of standard dimensions 25x15x5 mm were heated to 900^{0}C and left to soak for 1hour in the heat treatment furnace after which one sample was quenched in water, one sample quenched in water but tempered at 350^{0}C and the remaining six samples were austempered in a five litre volume steel pot containing two litres of boiling palm kernel oil at 270^{0}C for 0.5hour, 1hour, 1.5hour 2 hour, 2.5hour and 3hours respectively (Adewuyi and Afonja, 2000; Oloche *et al*, 2003 and Adewuyi, 2004). During the austempering in boiling palm kernel oil, more oil was added and the heat reduced whenever there was inflammation while also ensuring that the temperature was maintained at 270^{0}C, fire extinquishers and sand were also handy and personal protective equipments (PPE) were also used for safety purposes. The austempered samples upon cooling in air were subjected to Rockwell hardness test along with the water quenched, water quenched but tempered and as- cast samples. These nine samples were also etched using 5% nital and their micrographs taken. Details of the mechanical properties test procedure and microscopic examination procedure are outlined below.

Mechanical Properties Test Procedure

Each of the 9 heat treated samples and the control (as cast) sample were cleaned and freed from oxide that formed as a result of heating using acetone and cotton fabric. The Rockwell diamond pyramid cone (HRC) identer with a pre-load of 10kg and a major load of 150 kg was selected for the hardness test since it is the most suitable for cast iron (Kumar *et al*, 1983). These parameters were entered into the Rockwell testing machine and the samples were placed on the anvil of the elevating screw while the hand wheel was turned to bring the samples in contact with the indenter. Then the major load was applied and removed and the Rockwell hardness was read from the C scale and recorded. The ultimate tensile strength and Brinell hardness (BHN) equivalent was determined using the American Society of metals (ASM) hardness conversion table (American Society of Metals, 1987).

Microscopic Examination Procedure

The samples surfaces were finely ground using silicon carbide abrasive paper and all dirt were washed away with water, then the samples were polished using electric circular disc (nylon polishing cloth) with alumina polishing reagent while the final polishing was done using cerium oxide to give a mirror like shining scratch free surface. The polished samples were etched using 5% nital, washed with water jet and dried. The dried samples were mounted on the slide of metallux 3L microscope for viewing, then the observation of the image of the microstructure was carried out and the micrograph was taken.

RESULTS AND DISCUSSIONS

The result of both the Rockwell hardness test and its Brinell equivalent as well as the ultimate tensile strength are as shown in Table 1. The variation of hardness with austempering time is shown in Figure 2 while the variation of ultimate tensile strength with austempering time is shown in Figure 3. Detail discussion of the result is as follows.

Table 1: Combined result of hardness and ultimate tensile strength

Type of heat treatment	As-cast	Water quenched	Water quenched tempered at 350^{o}C	Austempered samples* with their holding time					
				0.5hr	1.0hr	1.5hr	2.0h	2.5hr	3.0hr
Average RHC (hardness) number	14.8	31.0	27.3	27.5	22.0	22.5	33.5	23.8	25.8
Equivalent BHN (hardness) number	205.0	294.0	261.0	268.0	237.0	240.0	245.0	246.0	257.0
Ultimate tensile strength(MPa)	697.0	999.6	904.4	911.2	805.0	816.0	833.0	836.4	873.8

Effect of austempering in hot palm kernel oil bath on hardness of nodular cast iron

Considering Figure 2, 0.5hour holding time gave the highest hardness of 27.5HRC for the austempered samples. This could be due to the un-transformed austenite which upon cooling to room temperature transformed into martensite (hardest austenite transformed structure); this is in agreement with the findings on austempering of steel (Rajan, Sharma and Sharma, 1988; Adewuyi and Afonja 2000; Oloche and Ause, 2003). The hardness decreased sharply from 27.5 to 22.0 HRC as the holding time increased from 0.5 to 1hour, this is due to retained austenite (a soft structure) becoming stabilized such that it did not transform to martensite when cooled to room temperature, this retained austenite reduces hardness.The hardness continues to increase as the holding time increased from

1hour through to 3hours. This is because increasing holding time increased bainite structure formation, thus increase in holding time leads to increase in hardness of nodular cast iron austempered in palm kernel oil bath.

Effect of austempering in hot palm kernel oil on ultimate tensile strength of nodular cast iron

The graph of ultimate tensile strength against time; Figure 3 shows that 0.5hour holding time gives the highest ultimate tensile strength of 911.2 MPa. As holding time increased from 1hour through to 3hours the ultimate tensile strength increased as well. Thus increasing the holding time increases the ultimate tensile strength of nodular cast iron austempered in hot palm kernel oil bath.

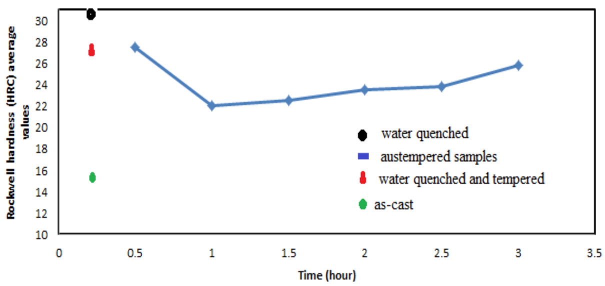

Figure 2: Variation of hardness with quenching time

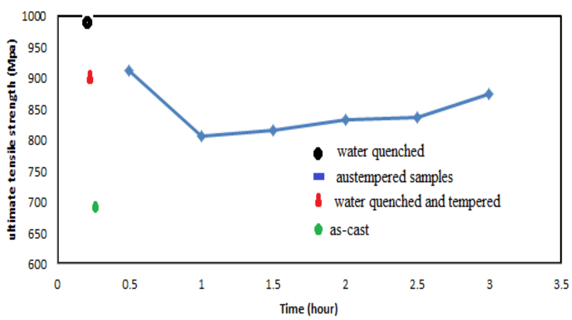

Figure 3: Variation of ultimate tensile strength with quenching time

Comparison of austempering in hot palm kernel oil with other heat treatment in relation to mechanical properties of nodular cast iron

Comparing the hardness of water quenched, water quenched but tempered, as cast and austempered samples shows that water quenched gives the highest hardness of 31HRC. This is because the water quenched has a martensitic microstructure which is the hardest austenite transformed structure. The water quenched but tempered sample has the hardness of 27.3HRC which is less than that of both water quenched and austempered for 0.5hour, as the latter are martensitic; tempering generally reduces hardness but increases toughness. The as cast sample has the lowest hardness, this is because it has a pearlitic microstructure; the lowest in hardness as compared to martensite and bainite (Angus, 1979). Thus austempering in hot palm kernel oil improves the hardness of nodular cast iron. Similarly, the water quenched sample gave the highest ultimate tensile strength of 999.6MPa followed by the austempered sample and then the water quenched but tempered sample while the as cast sample has the least value of 697MPa. Therefore austempering in hot palm kernel oil bath improves the ultimate tensile strength of nodular cast iron.

Microstructural analysis

The as-cast sample micrograph shows a purely pearlitic matrix with graphite nodules scattered in between the alternate lamella of ferrite and cementite as shown in Figure 4. This structure is obtained by the transformation of austenite during normal cooling in the mould or in the air through the critical range. The micrograph of the austempered sample reveal bainitic structure as shown in Figure 5 and Figure 6; this is a combination of ferrite and carbide with the graphite nodules scattered in the matrix. Austempering in hot palm kernel oil bath was able to effect the formation of bainite, thus palm kernel oil is a good medium for austempering. The formation of bainite structure upon austempering indicates that the toughness of the nodular cast iron has been improved. The presence of bainite structure is associated with improved toughness (Adewuyi and Afonja, 2000; Oloche and Ause, 2003). Unlike conventional heat treatment processes, austempering of nodular cast iron in hot palm kernel oil bath gave optimum combination of improved mechanical properties: hardness, ultimate tensile strength and toughness.

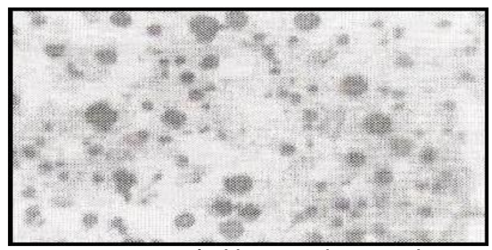

Figure 4: Microstructure of nodular cast iron; showing a pearlitic structure of as-cast sample (×250 etched in 5% nital).

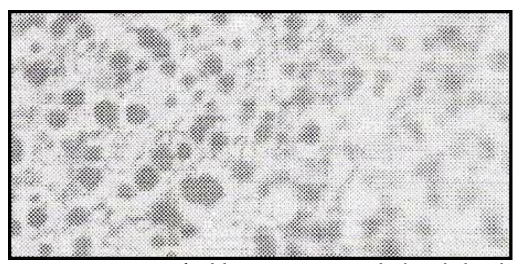

Figure 5: Microstructure of nodular cast iron austempered in hot palm kernel oil bath for 2.5 hours; showing bainite with retained austenite (× 250 etched in 5% nital).

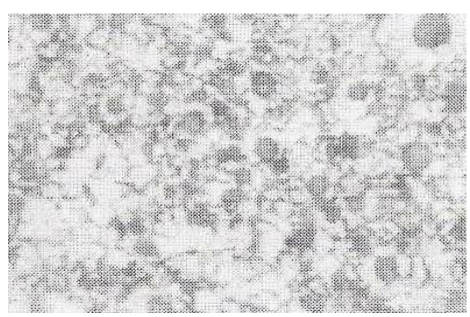

Figure 6: Microstructure of nodular cast iron austempered in hot palm kernel oil bath for 3 hours; showing a bainitic structure (× 250 etched in 5% nital).

CONCLUSION

The mechanical properties of nodular cast iron can be improved by austempering in palm kernel oil. Other oils like bitumen, used lubricating oil and the conventional molten salt used for austempering are expensive, not locally available and metal samples austempered in them requires further cleaning and surface treatment, thus palm kernel oil is an emerging best austempering medium. Holding time in palm kernel oil affects mechanical properties; hardness and ultimate tensile strength increases with holding time up to 3 hours. Austempering of nodular cast iron in palm kernel resulted to the formation of ausferrite (sometimes called bianite) microstructure which is better in mechanical properties than the graphite in ferrite microstructure of the as-cast ductile iron. Austempering in palm kernel oil gave optimum combination of mechanical properties and nodular cast iron austempered in palm kernel oil exceeded nodular cast iron subjected to other heat treatment processes like hardening through water quenching and tempering.

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