INTERNATIONAL JOUNAL OF: ENGINEERING RESEARCH AND TECHNOLOGY

TIMBOU-AFRICA ACADEMIC PUBLICATIONS
INTERNATIONAL JOURNAL, MAY, 2022 EDITIONS
VOL. 9 NO. 5 ISSN: 2707-5654

EFFECT OF ANNEALING TEMPERATURE AND SOAKING TIME ON THE MACHINABILITY CHARACTERISTICS OF NODULAR CAST IRON

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ABSTRACT

The machinability of nodular cast iron annealed at different temperatures and soaking times has been investigated. A total of nine samples were used for the experiment. Four of the samples were austenized at a temperature of 750°C, 800°C, 850°C and 900°C and then soaked for 30 minutes at the

Introduction

The term cast iron refers to an alloy of iron that contains more than 2.0 percent carbon (Jose, Wisley, Wilson and Alisson, 2018). Along with steels, cast irons are the most commonly used metals in various industries, not only because of their inherent properties, but also because of their immense versatility (Dawson and Schroeder, 2004). Cast irons are considered important materials as they generally offer good machinability, interesting properties and low production costs (Barbosa, Costa, Guesser and Machado, 2015). According to Grzesik, Rech, Zak and Claudin (2009) and Guesser (2009), research and development projects at foundries have helped cast iron

selected temperatures and then furnace cooled to room temperature. The other four samples were also austenized at the same temperatures mentioned above and soaked for 60 minutes. One sample was left in as-cast state. Orthogonal turning operation was carried out on the samples at different cutting speeds (30 – 500 rpm) where the feed and depth of cut were maintained constant and the surface finish produced were measured in terms of average surface roughness. The hardness and microstructure of the nodular cast iron were also conducted. From the results obtained, it was observed that at lower annealing teperatures (750°C – 800°C), the materials soaked for 30 minutes have a better surface finish whereas at higher annealing temperatures (850°C – 900°C), good surface finish was obtained for the material soaked for 60 at any cutting speed. The lowest hardness value (100BHv) was recorded for the material annealed at 900°C and soaking time of 60 minutes. It was further observed that the effect of annealing heat treatment is mostly to lower the hardness of metal so that they can be machined at a relative ease.

Keywords: *Annealing, machinability, hardness, microstructure, surface finish*

to compete better with steels. The substitution of continuously cast nodular iron rods with carbon steel represents an excellent alternative for companies that want to achieve lower manufacturing costs, produce more pieces per hour and off-take (Feres, 2011).

The brittle behaviour associated with cast iron is an antiquated and common misconception that implies that all cast irons are brittle and none of them are inherently ductile. Nodular cast iron, a form of cast iron that is ductile and offers the designer a unique combination of mechanical properties. The matrix can range from a soft ductile ferritic structure to a higher strength pearlitic structure to a hard and comparatively strong martensitic structure (Jose et al., 2018). Ghani, Choudhury and Husni (2002) warned that the increasing use of nodular iron in industry generates the need for major improvements in research and innovation aimed at better understanding the behaviour of these materials in different types of manufacturing processes. Nodular iron has better mechanical resistance and toughness than gray iron because the graphites are in the form of nodules and thus the continuity of the matrix is maintained, resulting in less stress concentration (Nayyar et al., 2012).

Nodular iron, in particular, offers a number of properties not found in other cast irons, such as high strength, wear resistance, fatigue strength, ductility and toughness as reported by Yigit, Celik, Findik and Koksal (2008). Nodular iron represents a significant part of the low strength steel market due to its versatile properties, making it suitable for the manufacture of crankshafts, pistons, gears, tubes, dies and molds (Toh, 2004).

Machining at best is an expensive procedure when compared in general terms to most other manufacturing processes making it necessary for an industry for proper evaluation and use of machining data. Machinability testing for an industry invariably begins with specific objectives such as the evaluation of the comparative machining performance of work materials, cutting tools or cutting fluids, the establishment of a set of machining conditions that will satisfactorily produce a part meeting the desired dimension, surface finish and functional integrity requirements, and the determination of most economic combination of machining conditions for a specific application.

Machinability is used to describe the relative ease with which a given material can be machined. It depends on such factors as the physical and metallurgical properties of the materials, speed of machining, feed, depth of cut, applied cutting fluid etc (Adepoju and Olatunbosun, 1985).

According to Nayyar, Kaminski, Kinnander and Nyborg (2012), the good machinability of nodular iron is ensured by the presence of free carbon in the form of graphite, which, in addition to improving chip breaking, acts as an efficient lubricant at the chip/tool interface. Brandenberg (2011) reported on the successful processing of austempered ductile iron. He recommended to use the larger depth of cut to overcome problems caused by the stress induced austenite to martensite transformation during machining. Grzesika, Kiszka, Kowalczyk, Rech and Claudin (2012) reported that the surface roughness decreases with increasing cutting speed, but this effect results from good rigidity and satisfactory thermal stability of the turning center used.

This research aims to investigate the influence of annealing temperature and soaking time on the machinability of nodular cast iron so as to ascertain the best quality of surface finish and the cutting speed to machine the material with relatively ease.

EXPERIMENTAL PROCEDURE

Materials

The materials used in this study is a nodular cast iron cast produced at Nigeria Machine Tools, Oshogbo in the form of cylindrical bar of diameter of 35mm. It was cut into an average length of 120mm using power arc saw. The chemical analysis was conducted using Optical Emission Spectrometer (OES). The chemical composition of the cast iron is given in table 2.1

Table 2.1: Chemical composition of ductile cast iron

Element	Fe	C	Si	Mn	Mg	P	S	Cr	Mo	Ni
Comp (%)	94.450	3.460	2.340	0.636	0.044	0.045	0.030	0.022	0.034	0.030

Experimental Procedures

Annealing Heat Treatment

A total of eight samples were austerized at different temperatures in an electric muffle furnace with maximum temperature of 1500°C. Four of these samples were subjected to annealing temperatures of 750°C, 800°C, 850°C and 900°C each, soaked for 30 minutes and then furnace cooled to room temperature. The same procedures were followed in the annealing of the other four samples at the same temperatures as mentioned above but for soaking time of 60 minutes. The time for temperature rise was 255 minutes at the heating rate of 200°C/hour. The last samples was left in as-cast condition.

Hardness Test

Hardness test was carried out on automated hardness testing machine using the Brinell Hardness Value (BHv) for all the samples. The test procedure consists of indenting the flat surface of the sample with a load of 100kg force applied for 15 seconds. The hardness value were read directly through a high powered microscope on the machine. The procedure was repeated three times for each sample and the average value was taking and recorded as the hardness value of each sample.

Machining Operation

The following parameters were maintained constant for all the samples during machining operation.

a) Rake angle = 10°
b) Depth of cut = 1mm
c) Feed rate = 0.08mm/rev
d) Length of each machined cutting speed = 5mm

The nine samples were orthogonally machined using automatic Centre lathe machine with a wide range of spindle speeds (40rpm, 60rpm, 114rpm, 148rpm and 325rpm). The first bar was turned on the lathe machine at five different steps, each step corresponds to each speed. The same procedure was followed in the machining of the remaining other bars. The machined sample is shown in Figure 2.1.

Figure 2.1: Machined sample of nodular cast iron

Surface Finish Measurement

Taylor Hobson Surface Texture Machine was used to determine the roughness average of the surfaces. The computerized instrument consist of stylus and in operation, the tip of the stylus is adjusted carefully and placed on the surface to be measured and moved a certain length over the surface depending on the adjustment set by the operator. In this work, the length moved is 5mm.

Three different measurements were made for every machining speed for each sample and the value of surface roughness is automatically displayed. The average of these three values was taken to represent the average surface roughness of the machined sample.

Metallographic Examination

A total of nine samples were prepared for microstructural examination. The samples were prepared for optical examination by cutting, successive grinding using silicon carbide grit paper of 240, 320, 400 and 600 microns following a standard guide for preparation of metallographic samples.

Polishing was carried out on a rotating cloth to ensure mirror-like surface. The samples were etched in a solution of 2%Nital agent. The Digital Metallurgical Microscope with an in-built camera was used to capture the micrograph of samples recorded at a magnification of 100X.

RESULTS AND DISCUSSIONS

Effect of Cutting Speed on Surface Finish

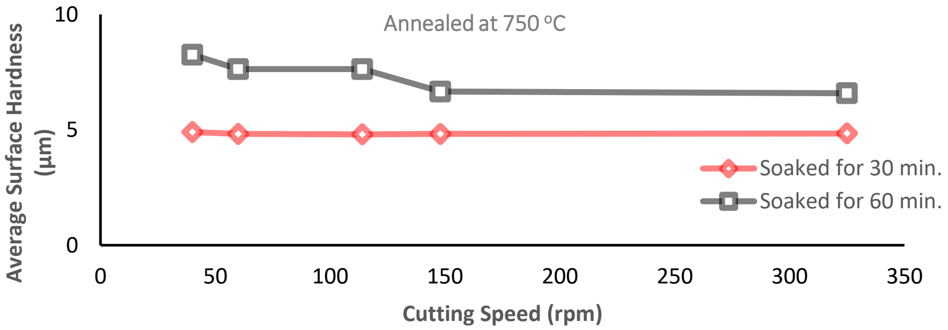


Figure 3.1a: Effect of cutting speed on the average sourface roughness of nodular cast iron annealed at 750°C

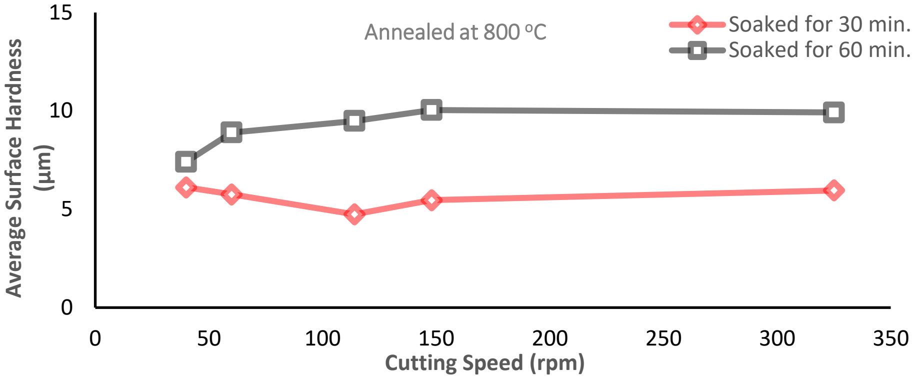


Figure 3.1b: Effect of cutting speed on the average surface roughness of nodular cast iron annealed at 800°C

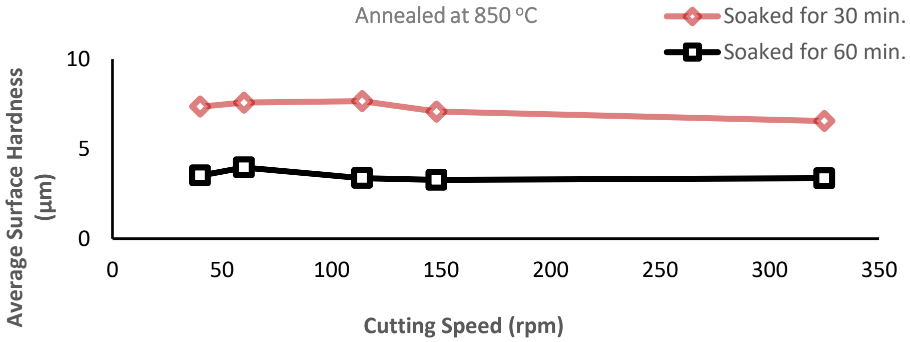


Figure 3.1c: Effect of cutting speed on the average surface roughness of nodular cast iron annealed at 850°C

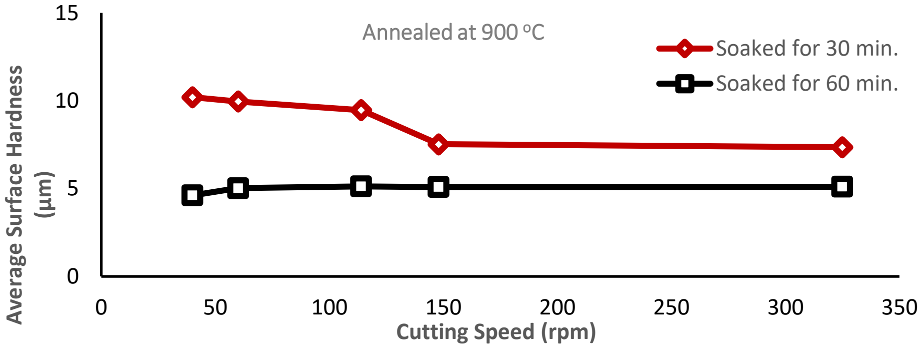


Figure 3.1d: Effect of cutting speed on the average surface roughness of nodular cast iron annealed at 900°C

The annealing heat treatment is mostly carried out to easy the machinability of metal. It does that by lowering the hardness of the material so that the tool can penetrate into the workpiece easily.

Figures 3.1a – 3.1d show the graphs of average surface roughness against cutting speed for nodular cast iron annealed at various temperatures and soaking times. It was observed that at lower annealing teperatures (750°C – 800°C), the materials soaked for 30 minutes have better surface finish compared to those ones soaked for 60 minutes at any cutting speed used. At this temperature and soaking time, the materials behaviour is closed to as-cast structure and the homogeniety of structure is yet to be fully attained and this may contributes to good surface finish due to pearlitic structure of the nodular cast iron and this is in agreement with Toktas, Tayan and Toktas (2006).

However, the best quality surface was equally obtained for the materials which undergone soaking time of 60 minutes at higher anealing temperatures (850°C – 900°C). This may be due to the fact that there was optimum homogenity in structure and soft ferrite have fulley developed and this will lower the hardness and easy the machinability which may contributes to the improvement in surface finish.

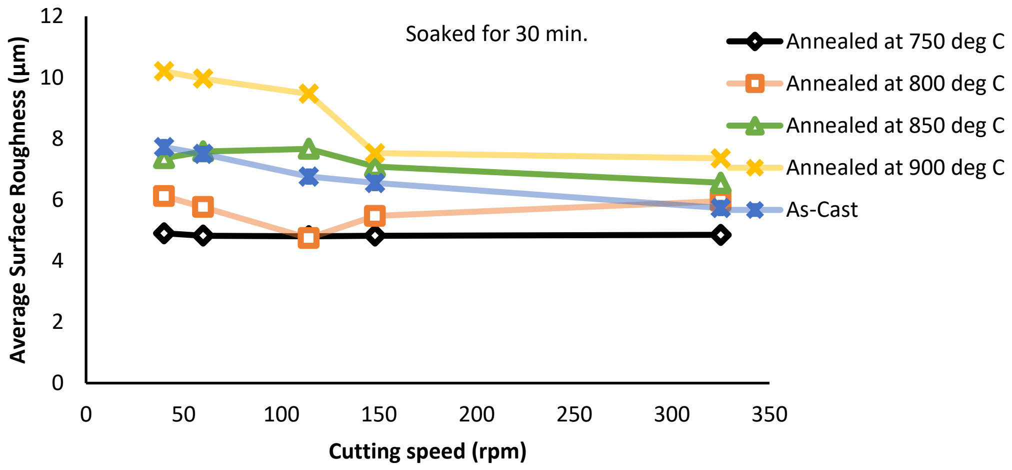


Figure 3.2: Effect of cutting speed on the average surface roughness of nodular cast iron annealed at various temperatures and soaking time of 30 minutes

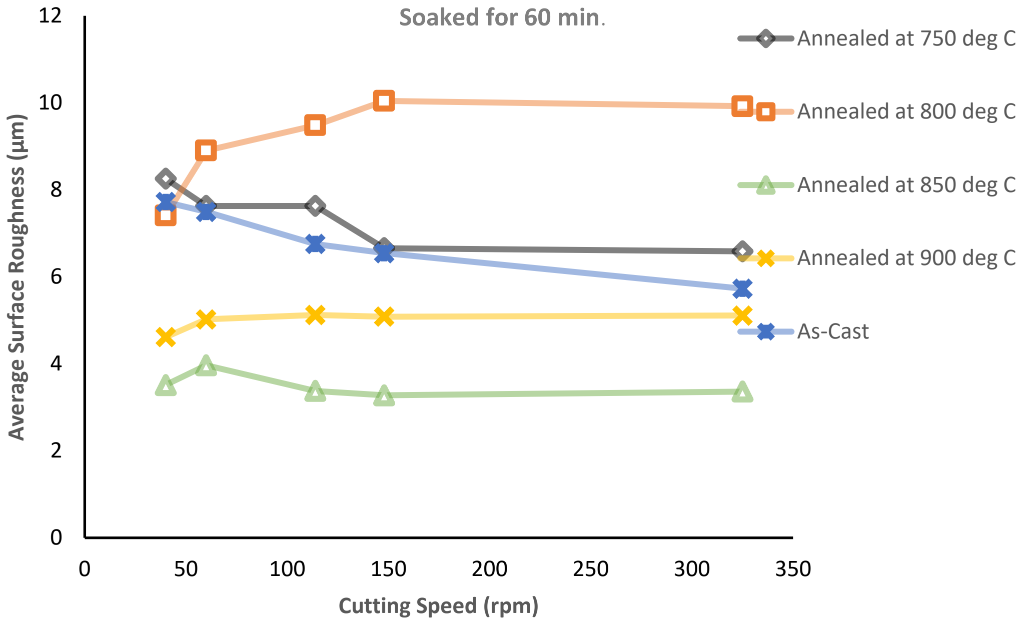


Figure 3.3: Effect of cutting speed on the average surface roughness of nodular cast iron annealed at various temperatures and soaking time of 60 minutes

At the initial stage when the speed was low, the surface finish were relatively poor. This is due to the fact that discontinuous chip were formed throughout the machining of the whole samples which resulted to bad surface finish particularly at low speeds (Figure 3.2 and 3.3). As the speed increases, the surface finish consequently improved and this in agreement with Omar, Veronica and Maria (2017) which affirmed that the surface roughness decreases with higher cutting speeds.

At higher speed, the surface finish slightly deteriorate due to the effect of built-up edge which occurred with increased cutting speed but this built-up edge is not as much as that which occurred in continuous chip formation because of the brittleness of the cast iron and this is accordance with Hassan, (2003). More also, machine vibration at higher cutting speed can also responsible for poor surface finish and this observation was previously reported by Grzesika et al. (2012).

3.2 Effect of Annealing Temperature and Soaking Time on Hardness

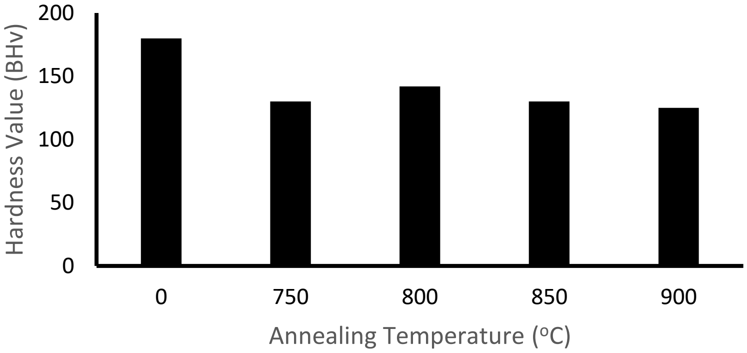


Figure 3.4: Effect of Annealing Temperature on the hardness of nodular cast iron annealed at various temperatures (30 minutes)

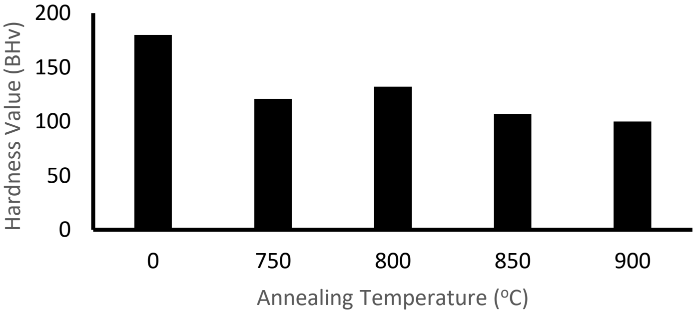


Figure 3.5: Effect of Annealing Temperature on the hardness of nodular cast iron annealed at various temperatures (60 minutes)

The hardness of the nodular cast iron in as-cast condition and after annealing heat treatment at various temperature and soaking time are depicted in Figures 3.4 and 3.5. From both Figures, the material annealed at 900°C have the lowest hardness values (100BHv) regardless of soaking time and this is followed by annealing temperature of 850°C. This attribute is due to the formation of soft ferrites microstructure as a result of heat treatment as reported in the research finding of Mirosław, Grzegorz, Tukasz and Tomasz (2020). The as-cast sample has the highest hardness (181BHv) and this is as a results of the presence of graphite nodules in pearlite matrix and this was previously affirmed by Hassan (2003).

Effect of annealing temperature and soaking time on the machined samples

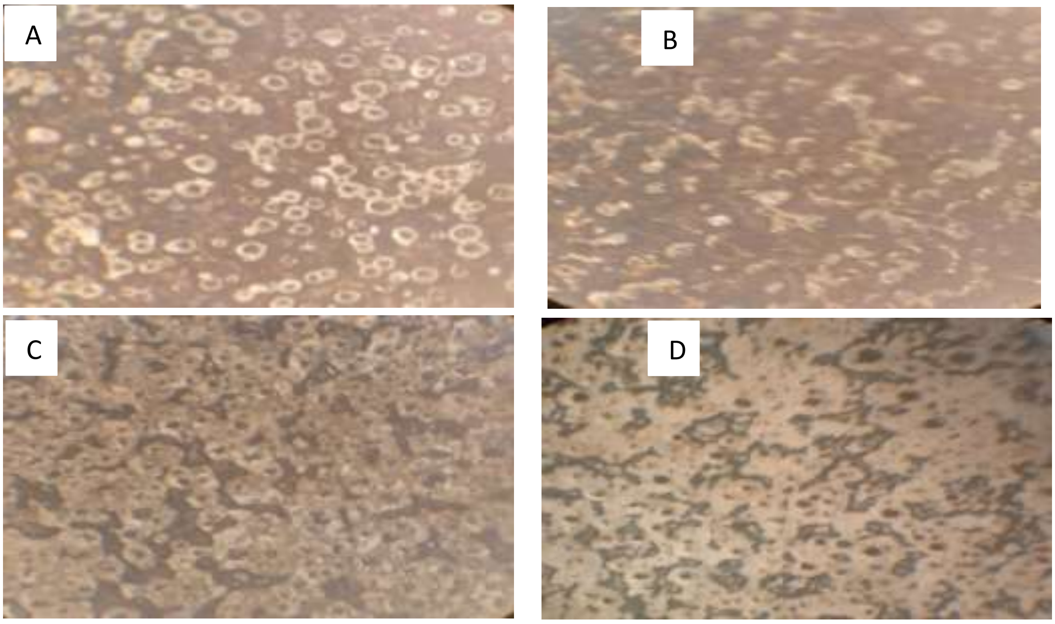
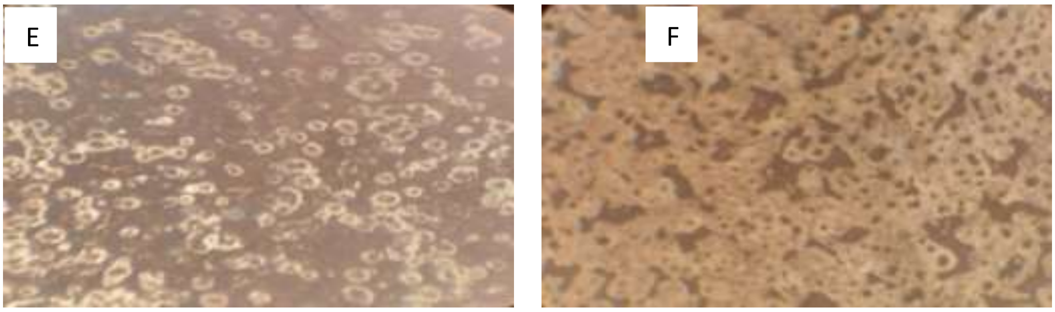


Plate 3.1: Optical micrographs of annealed nodular cast iron soaked for 30 minutes; samples A- annealed at 750°C, B- annealed at 800°C, C- annealed at 850°C, and D- annealed at 900°C. X100. Dissolution of ferrite in pearlite structure (dark back-ground), etched with Nital agent.



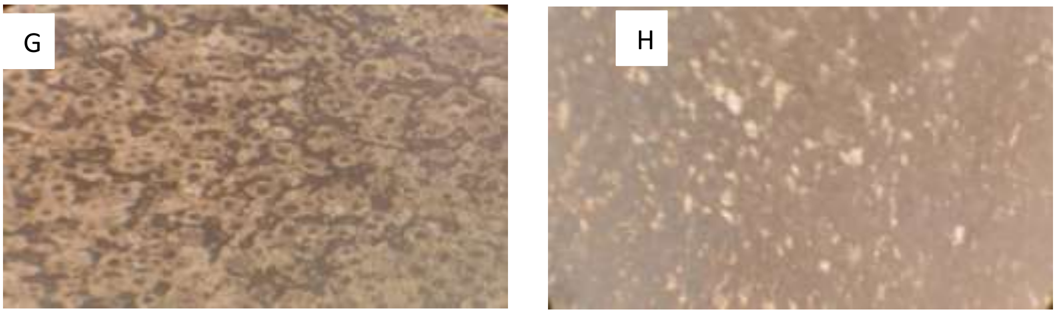


Plate 3.2: Optical micrographs of annealed nodular cast iron soaked for 60 minutes; samples E- annealed at 750°C, F- annealed at 800°C, G- annealed at 850°C, and H- annealed at 900°C. X100. Dissolution of ferrite in pearlite structure (dark back-ground), etched with Nital agent.

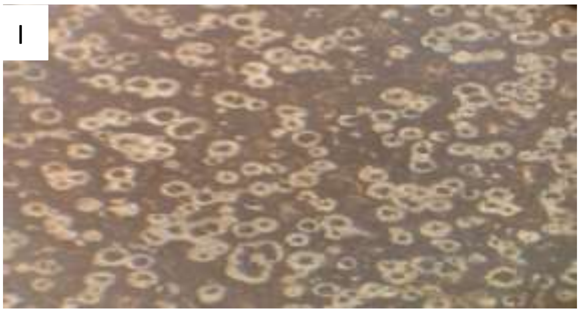


Plate 3.3: Optical micrograph of as-cast nodular cast iron. X100. Graphite nodules (yellow spot) in pearlite matrix (dark back ground), etched with Nital agent.

The annealing schemes have a crucial effect on the microstructure's morphology. The microstructure strongly develops owing to annealing and results in the evolution of soft microstructure as reported by Mirosław et al. (2020). The Plates 3.1 to 3.3 displayed the micrographs of nodular cast iron in as-cast and annealed condition. Nodular cast iron consists of graphite spheroids dispersed in a matrix of ferrite, pearlite, or both (Smith, 1981). The usual as-cast microstructure of nodular cast iron consists of graphite nodules which are surrounded by ferrite shell in a matrix of pearlite resulting in a "Bull's eye" structure (Hassan, 2003). These ferrite shells (yellow spots) and pearlite structure (dark background) can be observed in Plate 3.3.

When nodular iron is annealed, the pearlite structure dissolves to give ferrite structure (Mirosław et al., 2020). This can be observed in Plate 3.1 and 3.2 as more pearlite structure progressively dissolved to give soft ferrite structure and this resulted to lower hardness especially at higher temperatures as observed previously reported.

CONCLUSIONS

The quality of surface finish produced by orthogonal machining of nodular cast iron which has undergone annealing heat treatments for different soaking times has been quantitatively evaluated. From the obtained results, the following conclusions were made:

i. At lower annealing temperature (750°C – 800°C) and soaking time of 30 minutes, good quality surface finish can be obtained in the machining of nodular cast iron.
ii. By annealing nodular cast iron at higher temperature (850°C – 900°C) and soaked for 60 minutes, one can equally obtained a good surface finish at any level of machine spindle speed.
iii. The discontinuous chips are formed in machining of nodular cast iron regardless of the annealing temperature used during the heat treatment. This is attributed to high hardness of cast iron.
iv. Good surface finish can be obtained in machining of nodular cast iron in as-cast state but it is very difficult to machine due to its high hardness.

ACKNOWLEDGEMENT

The authors wish to acknowledge the technical assistance rendered by Chibogu Friday and other Engineers at Nigeria Machine Tools, Oshogbo.

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