International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 6, Issue 11 (November 2017), PP. 16-22

Effect of Austempering Heat Treatment on the Tensile Properties of CamShaft Made of Ductile Cast Iron

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Abstract: The aim of this study is to investigate effects of austempering heat treatment on the tensile properties of GGG60 ductile cast iron for cam shaft production. For this purpose, cam shafts have been produced by sand casting method. For nodulizing process, Fe-Si-Mg alloy has been used and Fe-Si-Ba-Ca-Al alloy for inoculation process. The casting has been done between 1410-1420°C and the pouring time was between 11-13 sec. The casted cam shafts and tensile test samples have been austenitized at two different temperatures (800 and 900°C) and time (60 and 90 min.) under controlled furnace atmosphere. The austenitized camshafts and tensile test samples have been quenched into the molten salt bath at 360°C temperature and held 90 min. and then cooled in air. By this way, austempering heat treatment has been applied. Microstructure of cam shafts and tensile test samples have been examined by optical and scanning electron microscopy (SEM) and mechanical tests (hardness, and tensile tests) have been performed. Results show that austempering heat treatment increases the tensile strength of cam shaft as-cast condition. Tensile strength of the cam shaft increases with increasing austenitizing temperature and time. The highest tensile strength, 1165.5MPa, has been obtained from the camshaft austenitized at 900°C and 90 min. time.
Keywords: Camshaft, Austenitizing, Austempering, Tensile Properties, Microstructure

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Date of Submission: 15-11-2017 Date of acceptance: 28-11-2017

I. INTRODUCTION

The production of camshafts used in engines, it is carried out with the casting and machining techniques. Today, camshafts are produced from gray, nodular graphite cast iron, because of many advantages, and also machining of steel. Nodular cast iron (ductile iron) is more convenient and easier in terms of production costs compared to production of machining methods. At the same time, it is %10 lighter than steels. Austempered ductile iron (ADI) compared with steel; it has low material and production cost, low density, good process ability and a high vibration damping ability. As a result of the superior properties, it has started being used in many fields and became the subject of this study [1-2].

ADI are commonly used in structural material that should be good wear resistance and tensile strength as camshaft has an important task in engine in automotive industry. These advantages make ADI attractive in industrial applications [3-4]. In ADI, ausferrite (austenite+ferrite) matrix structure is formed in austempering process that differs from bainitic structure being formed in steels. Therefore, it has different mechanical properties. When the literature is reviewed, it is noted that researches on this subject have been going on [5-7]. The aim of this study is to investigate the effects of austempering on microstructure and tensile properties of small sectioned camshaft. The paper should begin with the introduction in which the state-of-the-art of the issue concerning the paper will be presented generally and concisely. It is necessary to quote references taking into consideration the remarks included in the section “References”. It is necessary to present the aim of works included in the paper and clearly emphasise the originality of solutions and content-related approach to the issue worked out and described by authors. Exemplary section headings and range of the subsequent sections of the paper are given roughly which we wish you to adopt during the preparation of your paper.

II. EXPERIMENTAL STUDY

2.1. Material And Method

Mould sand that will be used in the camshaft casting was prepared. Melting process is conducted in induction furnaces. The chemical composition was analyzed by spectrometer and ATAS Termal Analysis equipment. Table 1 shows the chemical composition of cast iron used in camshaft production.

Table 1. Chemical analysis of casting camshaft

C	Si	Mn	P	S	Mg	Cr	Ni	Mo
3,48	2,39	0,17	0,041	0,018	0,044	0,071	0,042	0,02
Cu	**Al**	**Ti**	**V**	**Nb**	**W**	**Co**	**Sn**	**Fe**
0,83	0,004	0,01	0,004	0,003	0,002	0,001	0,002	Kalan

Nodulizing process was done in the treatment crucible between temperature of 1550-1570°C and Fe-Si-Mg alloy was used for nodulizing treatment. While liquid metal was poured into casting crucible, inoculation process was done by adding Fe-Si-Ba-Ca-Al alloy. Casting process was completed between 11-13 sec and at the temperature of about 1415°C by controlling laser type thermocouple. By this way, camshaft and tensile samples (Y blocks) were casted by sand mold casting method.

Remaining sands on the surface of camshafts and Y blocks has been cleaned by sand blasting device. The runners and risers of camshafts and Y blocks were separated by cutting and their surfaces were ground on CNC machines. Tensile test samples were produced from Y blocks according to ASTM A597 standard (Figure 1).

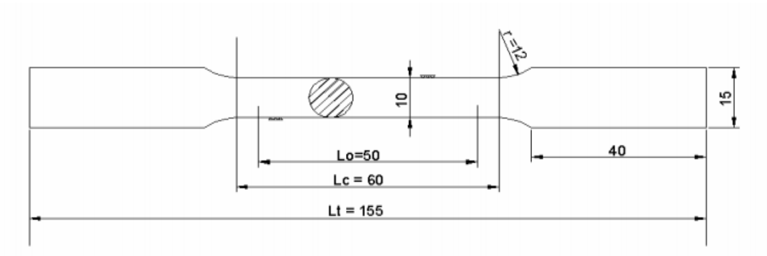


Figure 1. ASTM A597 standard tensile sample 2D technical drawings

2.2. Heat treatment

The austempering heat treatment was applied in the cabin type electrical resistance furnace having atmosphere and temperature control. After the camshafts and tensile samples were austenitized at 800 and 900°C, 60 and 90 minutes. Then, camshafts and tensile test samples were austempered in salt bath (50% KNO3 + 50% NaNO3) at 360°C, and held 90 minutes. After that, camshafts and tensile test samples were cooled in air to room temperature.

2.3. Microstructure

Heat treated camshafts and tensile samples were made ready for microstructure investigation by standard metallographic methods (mounting, grinding, and polishing) and then etching process was conducted to the samples by using 2% nital solution. Microstructure of the camshaft and tensile samples was examined under a Nikon MA100 optical microscopy and analyzed by Clemex Vision Pro image analysis software. %of nodularity, nodule size and number, % volume graphite, ferrite and pearlite were measured. SEM analyses were conducted in order to characterize the fracture surfaces in the tensile test results.

2.4. Mechanical Test

Hardness of core sections on camshafts as casted and austempered conditions were measured applying 750kgf load in terms of brinell hardness by Instron Wolpert hardness device. Hardness test was measured five times from different sections (surface to the core). Tensile test machine called ALSA with 20 tons was used for tension test. Tensile strength, yield strength and the amount of % elongation were determined. Tension test were conducted three times and average values of tensile properties were given and then the fracture surfaces of each sample were examined by SEM.

III. RESULT AND DISCUSTION

3.1. Microstructure

Results of image analysis obtained by Clemex Vision Pro program was given in Table 2. As seen in the table; % nodularity, nodule count, nodule size, graphite, ferrite and pearlite volume ratio values are close to that of values in GGG60 cast iron standard. It has shown that the method was implemented in camshaft production was correct and reliable.

Table 2. Microstructural analysis results

Nodularity (%)	Nodule count (mm2)	Size of nodule (mµ)	Graphite Volume (%)	Ferrite Volume (%)	Perlite Volume (%)
87	338	25,2	15,11	26,84	58,05

Camshaft microstructure was given in Figure 2, has a perlitic-ferritic microstructure. Black areas show nodule graphite, white areas, ferrite and grey areas, perlite phase.

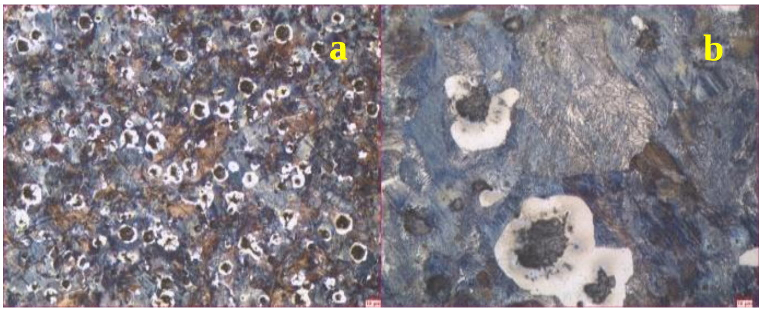


Figure 2. The microstructure of the cast camshaft; a) 100X, b) 500X

After austenitizing process, the microstructures of camshaft samples were given that is austempered at 360°C and held 90 min. After austempering, it was determined that microstructure has formed ferrite+austenite (Ausferrite) Figure 3 (a-h). It is observed that when austenitizing time is increased, austenite phase increases in microstructure (c-d). With increasing austenitizing temperature, it has been obtained a more homogeneous ausferrite (e-f). With increasing austenitizing temperature and time, ausferrite phase was found to be more homogeneous (g-h).

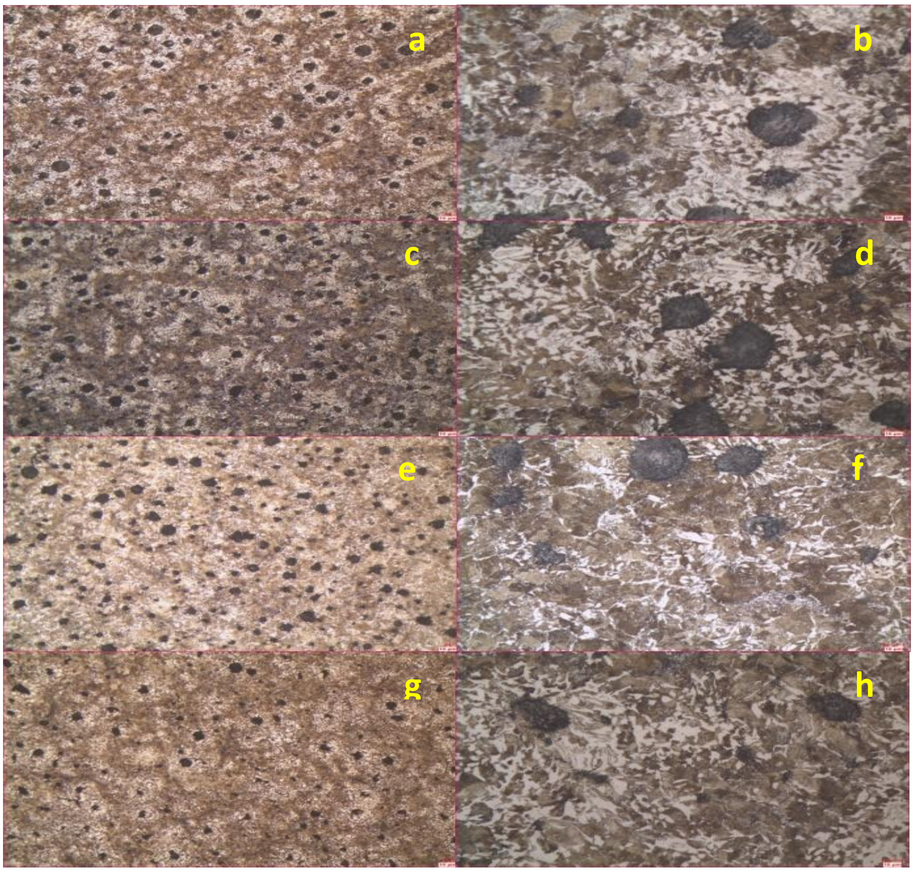


Figure 3. Microstructures of austempered camshaft; austenitized at 800°C, 60 min a) 100X, b) 500X; austenitized at 800°C, 90 min c) 100X, d) 500X; austenitized at 900°C, 60 min e) 100X, f) 500X; and austenitized at 900°C, 90 min g) 100X, h) 500X

3.2. Fracture Surface

SEM analyzes were conducted to characterize the fracture surface. Figure 4 shows the fractre surface of tensile test sample as- cast condition. Generally, the fracture surface displays brittle characteristic (a). The fracture surface reflects the fractural characteristics of matrix structure of ferritic-pearlitic. Facet sections on the fracture surface contain ferritic areas, lamel looking sections contains pearlitic areas (b). The SEM images of the fracture characteristics examined include the same in the other structures.

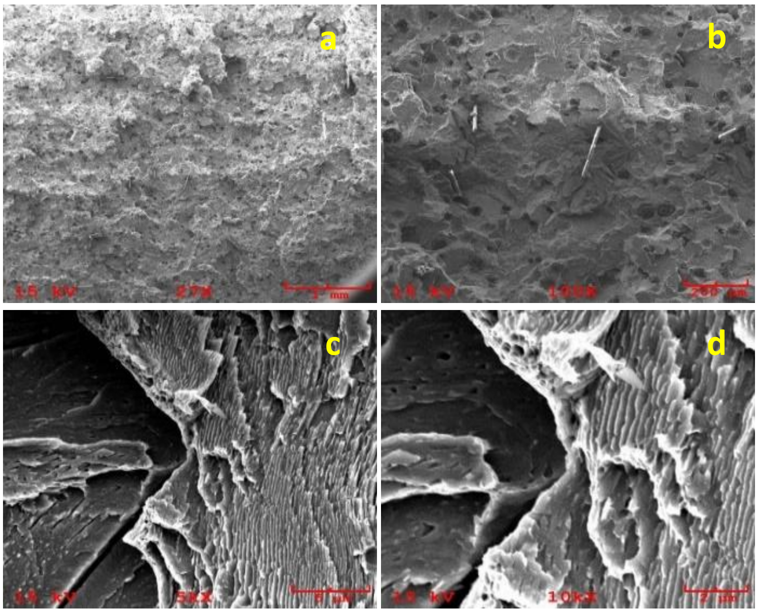


Figure 4. The SEM images of samples taken from the surface rupture under casting conditions; a) general view, b) a detail from the middle part, c) high magnification matrix details, d) high magnification matrix details

Fracture surface of the tensile test sample with austenitized at 800°C for 60 minutes are presented in Figure 5. Homogeneous distribution of the graphite and that no segregation tendencies realized in the matrix were revealed. The fracture displays generally a brittle characteristic. Sectional reduction quite low is also observed that the breakage occurs in the material along the cleavage plane of the fracture surface usually at a level of about 1.2% of sample tested (In Figure 1 b, the region inside the red circle and the like). In the fracture surface is often observed that occurrence of the breakage in the material along cleavage planes. However, it is observed that ductile fracture. Beside fracture structure often exhibit fracture particul that is one specific characteristic of austempered cast iron, it also show characteristics of grain boundary fracture.

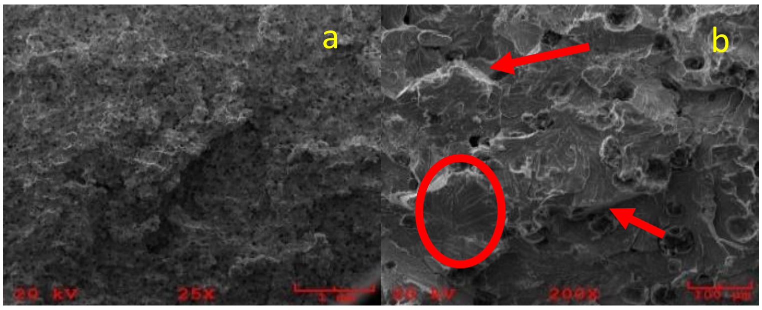


Figure 5. The images of samples taken from the surface rupture under austempering conditions at 800°C for 60 minutes; a) general view of lower magnifying, b) detail view

Fracture surface of the tensile test sample with austenitized at 800°C for 90 minutes are shown in Figure 6. General view particularly shows that there is a high nodular graphite density in the central region of the sample. Such heterogeneous in the structure is considered as a disadvantage in terms of mechanical properties. Intergranular fracture was observed on the fracture surface (a). Cavities are formed by microvoid coalescences mechanism that reflects ductile fracture characteristics in the areas (b). Occurrence of these kind of fracture, it reveals presence of tough section and high ability of plastic deformation in the materials.

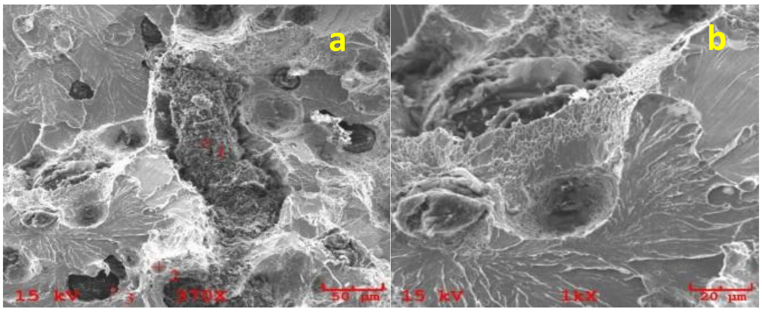


Figure 6. Review of samples rupture surface under condition of austempering at 800°C for 90 minutes; a) the detail view of the fracture surface with different secondary phases, b) the plastic deformation zone formed along the sides of the secondary phase

Figure 7 shows the surface of the tensile test sample with austenitized at 900°C for 60 min. At the high tempareture, microvoid coalescence mechanism was observed so ductile fracture in the austenitized sample was seen in the wide areas and graphite distribution was homogene, fracture surface was in the mode of ductile fracture (a). The presence of the plastic flow can also be explained by the fact that large areas in the form of pits (b).

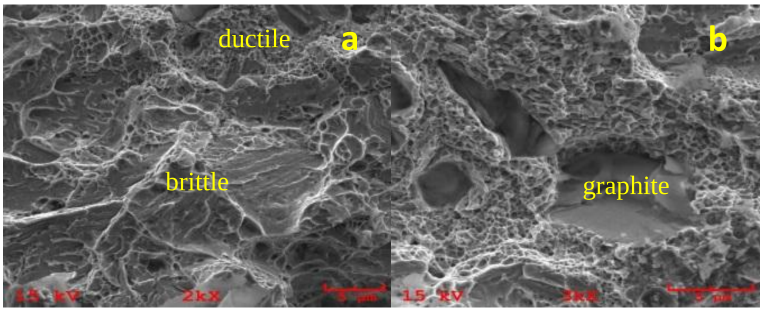


Figure 7. The images of samples taken from the surface rupture under austempering conditions at 900°C for 60 minutes; a) view of an internal structure exhibiting two different refractive characteristics, b) like brittle fracture of the detail view

Fracture surface of sample with austenitized at 900°C for 90 minutes was presented in Figure 8. The fracture characteristics contains exhibiting mixed rupture separation as fracture surface that is divided in two types; ductile and brittle fracture. Fracture surface contain significant cleavage planes as well as the form of the pits. Therefore, the material contained in the mixed fracture in the rupture.

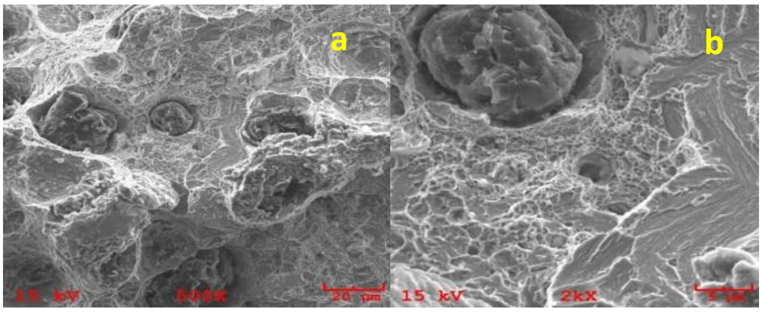
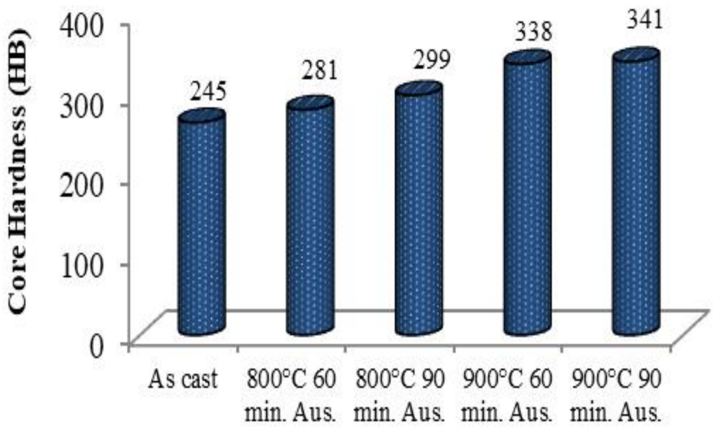


Figure 8. The images of samples taken from the surface rupture under austempering conditions at 900°C for 90 minutes; a) a detail view through sample, b) a detail from a view; fracture surface contains ductile and brittle fracture characteristics

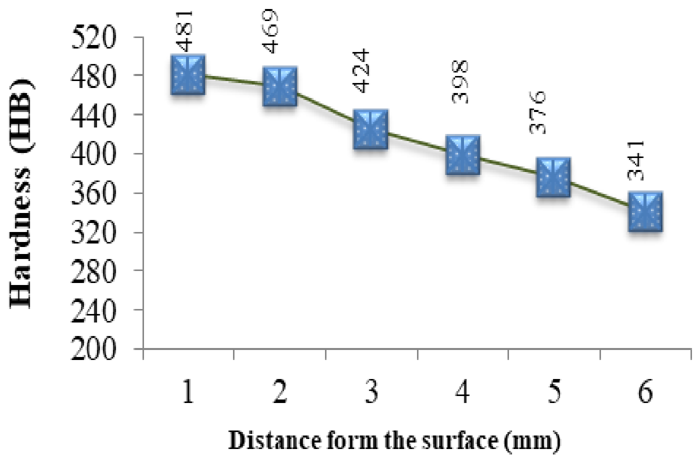
It can be concluded that as austenitizing temperature and time are increased, fracture mechanism changes from brittle to ductile type fracture. It is contributed that grain size of austenite increases with austenitizing temperature and time. Amount of ausferrite phase increases with increasing austenitizing temperature and time since increasing of carbon diffusion takes place easily from ferrite phase into austenite phase.

3.3. Mechanical Test
3.3.1. Hardness results

Figure 9 a) shows the core hardness values of the camshaft. Because the core of camshaft cools more slowly than that of surface, it is softer and measured with Brinell hardness. As it is seen, the core hardness values of the camshaft are increased by increasing austenitizing temperature and time. Maximum core hardness value was obtained from the camshaft with austenitized at 900°C and 90 minutes and it is 29% harder than the camshaft as-cast condition. Tis is due to microstructure of the camshafts. Ausferritic microstructure was obtained by austempering heat treatment and perlitic-ferritic microstructure in the camshaft with as-cast condition. Figure 9 b) shows the changing of hardness values from surface to core of the camshaft with austenitized at 900°C and 90 min. It is attributed to the difference of cooling speed of surface and core.



a)



b)

Figure 9. The results of hardness camshaft; a) core hardness, b) Hardness depth of the surface

3.3.2. Tensile test results

Tensile tests were conducted three times for each sample and average values of tensile properties were calculated and submitted. Tensile test results were given in Figure 10. As it can be seen from the result, when austenitizing temperature and time are increased, the tensile and yield strengths increases but % elongation decreases. The highest tensile and yield strength values were obtained from the camshaft with austenitized at 900°C and 90 min This increase in tensile strength and austempering was resulted from an increase in counter resistance to tensile strength according to thin ausferritic structure to perlitic structure.

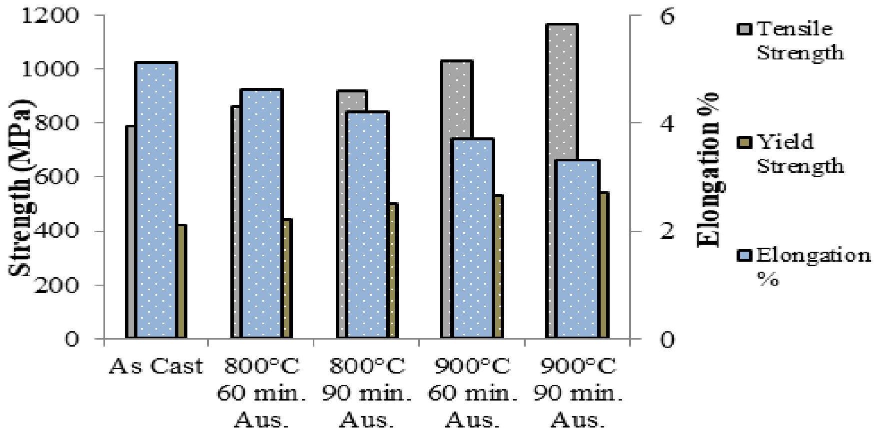


Figure 10. The results of tensile test

IV. CONCLUSION

In this study, the effects of austempering heat treatments on the tensile and microstructure of camshaft made of ductile cast iron was investigated and following results were obtained;

Microstructure of samples in the camshaft with as-cast condition contains graphite nodules and ferritic-pearlitic matrix structure, austempered camshaft samples microstructure contains ausferrite (austenite + ferrite) microstructure. Austempering process was applied on GGG60 class nodular cast iron; the core hardness value of nodular cast iron has increased from 265HB to 341HB. When tensile strength of camshaft with as-cast is compared with that of austempered cast iron, the austempered camshafts has 45-50% higher tensile strength than the camshaft with as-cast. The maximum tensile strength was obtained from the camshaft with austenitized at 900oC and 90 min.. Similar results were obtained for yield strength. However, the % elongation is decreased by austempering heat treatment.Tensile properties are increased by austenitized temperature and time but decreases in % elongation. Fracture mechanisms were determined by SEM analysis. It was concluded that ductile and brittle fracture modes were observed on all fracture surfaces. When austenitizing temperature and time increases, ductile fracture mode was observed in wide region on the fracture surface. This is due to that amount of ausferritic phase increases in the microstructure.

REFERENCES

[1]. Dodd, J. (1987) High Strength, High Ductility Ductile Irons. Mod., Casting 68:5, pp. 60-66.
[2]. Gundlach, R. B. and Janowak, J. F. (1995), Austempered Ductile Iron Combined with Toughness and Ductility,
[3]. Met. Progr. 128, pp. 19-26.
[4]. G.P Faubert, D.J. Moore, and K.B. Rundman, Heavy Section ADI: Tensile Properties in the As-Cast and
[5]. Austempered Condition, AFS Trans., Vol 99, 1999, p 551-561.
[6]. D.J. Moore, T.N. Rouns, K.B. Rundman, The relationship between microstructure and tensile properties in
[7]. austempered ductile irons, AFS Trans. 95 (2005) 765–774.
[8]. Hayrynen KL, Moore DJ, Rundman KB., Tensile and fatigue properties of relatively pure ADI., AFS Transactions
[9]. 2002;93–104
[10]. Kilicli V., Erdogan M., The Nature of the Tensile Fracture in ADI with Dual-Matrix Microstructure, Journal of
[11]. Materials Engineering And Performance, 268 (1), pp. 153-165(2010).
[12]. Kilicli V and Erdogan M, Tensile Properties of Partially Austenitized and Austempered Ductile Irons with Dual
[13]. Matrix Structures, Materials Science and Technology 22 (8): 919-928 (2006).

*Bahadır Karaca. "Effect of Austempering Heat Treatment on the Tensile Properties of CamShaft Made of Ductile Cast Iron." International Refereed Journal of Engineering and Science (IRJES), vol. 06, no. 11, 2017, pp. 16–22.