International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 6, Issue 11 (November 2017), PP. 34-40

The Effects of Heat Treatment on the Mechanical Properties of Camshaft Made of Ductile Cast Iron

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Abstract: The aim of this study is to investigate the effects of heat austempering and induction hardening on the wear properties of GGG60 ductile cast iron for cam shaft production. For this purpose, cam shafts have been produced by sand mould 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 900°C temperatures and 90 min. time 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 30-60-90 min's. and then cooled in air. By this way, austempering heat treatment has been applied. After that, surface hardening process was conducted by induction hardening machine with medium frequency. Microstructure of cam shafts and tensile test samples have been examined by optical and mechanical tests (hardness and wear tests) have been performed. Results show that austempering heat treatment increases the wear resistance of cam shaft as-cast condition. Wear resistance of the cam shaft increases with increasing austempering temperature, time and induction hardening. The lowest weight loss, 0.712mg/500m, has been obtained from the induction hardened cam shaft austempering at 360°C and 90 min. time.

Keywords: Camshaft, Austenitizing, Austempering, Mechanical Properties, Microstructure

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].

It is known from literature, mechanical properties of ductile iron are improved after applying austempering heat treatment [8-9].

However, the effect of induction hardening process on the properties of ADI was not seen in the literature. The aim of this study is to investigate the effects of austempering and induction hardening on microstructure and wear properties of small sectioned camshaft.

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
3,47	2,39	0,16	0,039	0,019	0,048	0,071	0,047	0,02
Cu	**Al**	**Ti**	**V**	**Nb**	**W**	**Co**	**Sn**	**Fe**
0,85	0,004	0,01	0,004	0,003	0,002	0,001	0,002	-

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. Camshaft casting process is done so casting time was taken 11-13 second, casting temperature1410-1420°C. During casting, molten metal temperature in crucible was obtained in the range between 1410±10°C by controlling laser type thermocouple. By this way, camshafts were produced by sand mold casting method.

2.2 Heat treatment

In the austempering heat treatments, cabin type furnace is used that works with electrical resistance and can go up to 1100 °C and has atmosphere and temperature control. After the camshafts were austenitized at 900°C, 90 minutes, camshafts austempered rapidly in salt bath (%50KNO3+%50NaNO3) at 360°C, 30-60-90 minutes duration. After that, camshafts were cooled in air to room temperature. When surface hardening heat treatment was conducted with medium frequency induction machine, it was obtained temperature control by thermal cameras for the samples of camshafts. Surface microstructure was changed by induction heating between 3-4s times.

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.

2.4 Mechanical Test

2.4.1 Hardness 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).

2.4.2 Wear test

For wear tests, wear test sample were prepared by taking cut views from cam sections on the camshafts under casted and heat treated conditions (austempering, austempering+ induction hardening). UTS T10/20 brand pin-on disc type test apparatus (tribometer) was used for wear test. Wear test was conducted in accordance with ASTM Standard G99-05, with various loads, constant distance and at a constant RPM.

Then, weight loss was measured by sensitive balance and wear surfaces were examined by optical microscope either on sample or on ball bearing that is wear counterpart. Because of ASTM G99-05 standard is based on the measurement of wear volume, wear on ball bearing was calculated by using mathematical relationship and direct measuring volumetric loss. Wear test parameters used in this study are shown in Table 2.

Table 2. Wear test parameters

Test Parameters	Test 1	Test 2
Wear Ball Bearing	100Cr6	100Cr6
Ball Bearing Hardness (HRc)	65	65
Ball Bearing Diameter (mm)	5	5
Nominal Load (N)	10	30
Disc Rotating Speed (rpm)	300	300
Sliding Speed (m/s)	0,095	0,095
Sliding Distance (m)	500	500
Test Temperature (°C)	RT	RT

III. RESULT AND DISCUSTION

3.1 Microstructure

Results of image analysis obtained by Clemex Vision Pro program was given in Table 3. 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 3. Microstructural analysis results

	Nodularity (%)	Nodule count (mm2)	Size of nodule (mμ)	Graphite Volume (%)	Ferrite Volume (%)	Perlite Volume (%)
ASTM A247	Type 1/2 Class 4-6	20-600	100-10	-	10-90	Ferrite Ferrite+Pearlite Pearlite
Measured	91 (Type 1/2) (Class 6-7)	341	27,5	16,61	24,51	58,88 Ferrite+Pearlite

Camshaft microstructure was given in Figure 1, has a perlitic-ferritic microstructure. Black areas show nodule graphite, white areas, ferrite and grey areas, perlite phase.

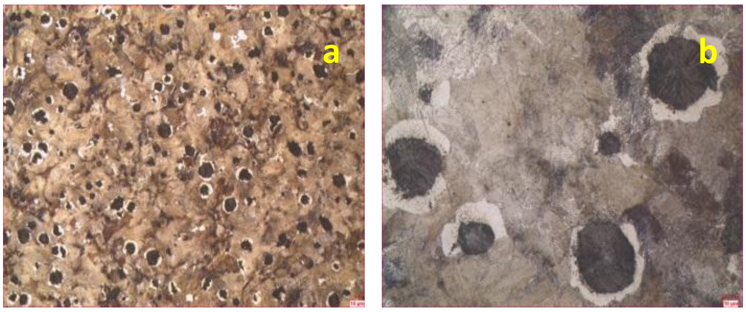


Figure 1. The microstructure of the cast camshaft; a) 100X, b) 500X

After austenitizing process, the microstructures of camshaft samples were given that is austempered at 360°C and held 30-60-90 min's. After austempering, it was determined that microstructure has formed ferrite+austenite (Ausferrite) Figure 2 (a-h). It is observed that when austempering time is increased, austenite phase increases in microstructure (c-d).

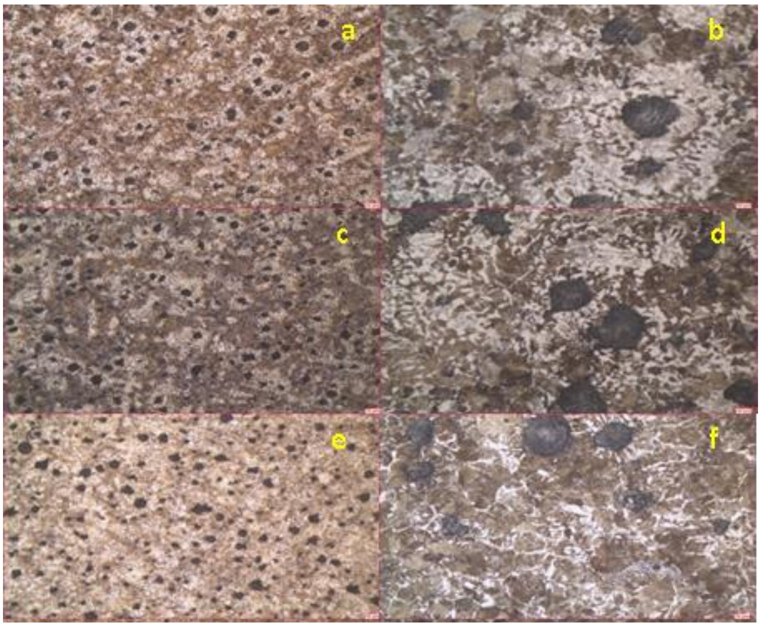


Figure 2. Microstructures of austempered camshaft; austempering at, 30 min., a) 100X, b) 500X; 90 min., c) 100X, d) 500X; 90 min., e) 100X, f) 500X

At the Figure 3 microstructure of the camshaft with austempering at 360°C, 90 min was applied by induction hardened. It was seen that with induction hardening heat treatment, nodular graphite has not changed and the core of camshaft has still austenite- ferrite structure. It was found martensitic structure only 3.0 to 4.5mm thick on the surface. In addition to this, untransformed residue austenite and partly needle ferrite in the matrix structures.

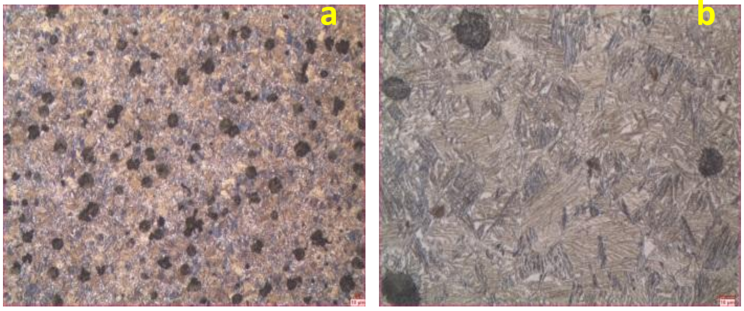


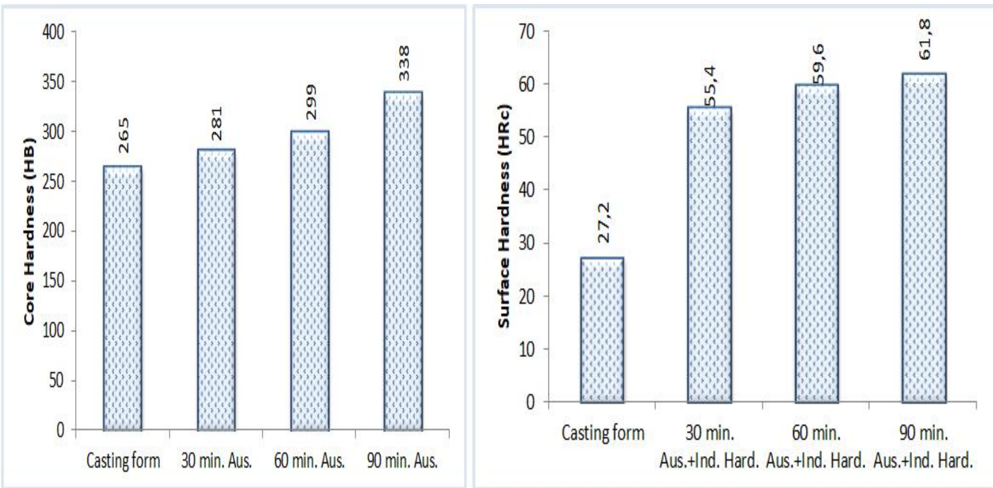
Figure 3. Surface microstructure of induction hardened camshaft with austempering and induction at 360°C, 90 min., a) 100X, b) 500X

3.2 Mechanical Test

3.2.1 Hardness results

Because the core of camshaft cools more slowly than that of surface, it is softer and measured with Brinell hardness. Depending on heat treatment applied in Figure 4.a, Figure 4.b shows the core and the surface hardness values. As it is seen, the core hardness values of the camshaft are increased by increasing austempering time. The results show that the core of austempered camshaft is 24% harder than that of casted camshaft.

The surface hardness of camshaft with austempered + induction hardened is 36% higher than that of casted camshaft. This is due to that cooling rate of core of the austempered camshaft and induction hardened camshaft is higher than that of camshaft with as-cast condition. When their surface hardness values are compared, it is seen that their microstructures were formed differently. With induction hardening heat treatment, martensitic microstructure was obtained on the surface of the camshaft; ausferritic microstructure in austempered camshaft and perlitic-ferritic microstructure in the camshaft with as-cast condition.



A B

Figure 4. The results of hardness camshaft; a) core hardness, b) surface hardness

3.2.2 Wear test results

Three tests were conducted for each load (10N and 30N) and their average was calculated. Wear test results were shown in Figure 5. As seen from results; when load increases, friction coefficient, weight loss in camshaft and ball bearing increases for all camshaft with as-cast, austempered, and induction hardened. However, it is observed that at the austempered+induction hardened surface of camshaft, weight loss is minimum. The reason is that an increase in the surface hardness is resulted from being martensite phase on the surface and ausferrite phase in the core. The surface hardness is lower and weight loss is much in casted camshaft. Minimum abrasion quantity was found in the camshaft that austempered+induction hardened under 10N load. Maximum weight loss was measured in the camshaft that casted under 30N load.

Maximum wear on the ball bearing under 30N load was obtained in wear of casted camshafts because of the high friction coefficient. Therefore, the amount of wear increases as the friction coefficient increases. The lowest coefficients of friction were found in the austempered+induction hardened camshaft test that was conducted under 10N applied load.

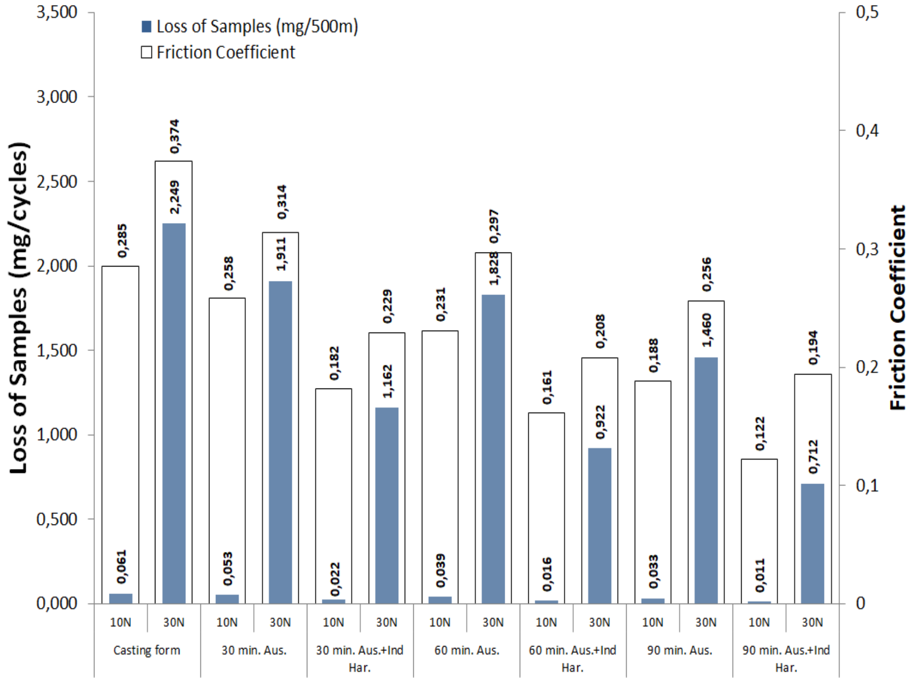


Figure 5. The results of tensile test

Optical microscope images of the sample are given in Figure 6. The trace of wear on the sample under 10N load is shown in Figure 6.a and ball bearing Figure 6.b. Wear trace width of the sample surface is relatively small, the thing that is seen as gray colored layer, adhesion layers formed by coating the wear particles to the interface between the two surfaces. They are generally known to be oxides and contribute to the reduction of the friction coefficient, acting as a protective barrier. They may be fallen down from the surface and some of them may be held on the surface. Slight wearing trace is found on a size that can be identified difficultly on the ball bearing surface (see Figure 6.b). The trace of wear on the sample under load of 30N is shown in Figure 6.c and in the bearing ball is shown in Figure 6.d. It is possible to seen partly the presence of adhesive layer and scratching trace together. The track width has expanded significantly. Friction and wear are seen to be more severe. There are abrasive wear marks on the surface of the ball bearing. It can be said that the bearing ball interface is subjected.

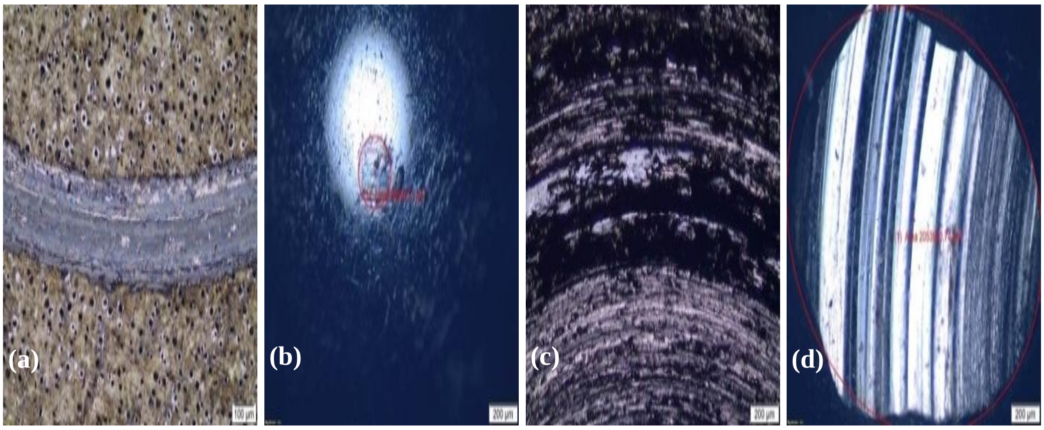


Figure 6. The worn surfaces under as-cast condition; under a load of 10N a) sample b) ball bearing; under load of 30N c) sample, d) ball bearing

Optical microscope images of 360°C, 90min. austempered spheroid casting sample are given in Figure 7. The trace of wear on the sample after abrasion test under 10N load is shown in Figure 8.a and ball bearing Figure 7.b. Sample surface with adherent and abrasive wear marks shows a mixed wear characteristic. An image with abrasive wear marks spread over a very small area was captured on the ball bearing surface. After the abrasion test under 30N load, on the sample surface that abrasion intensified an image of abrasive and adhesive wear marks was obtained together (Figure 7.c). Abrasive wear marks are intensively present (Figure 7.d.) and the diameter of the worn out section is enlarged on the ball bearing surface.

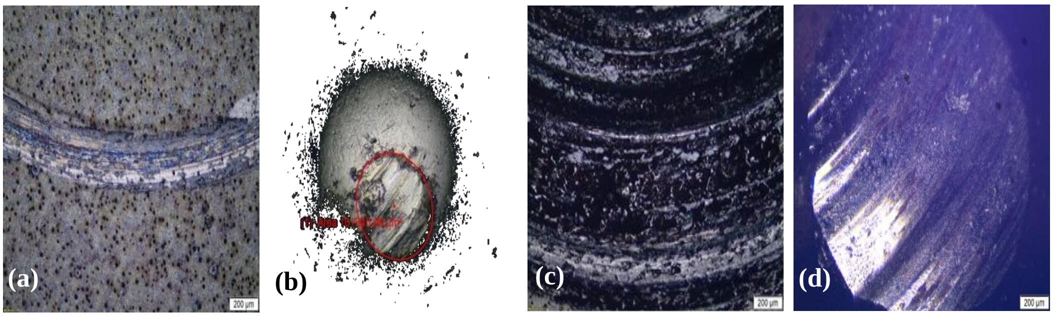


Figure 7. The worn surfaces under austempered conditions; applied load 10N a) the sample, b) ball bearing; applied load 30N c) the sample, d) ball bearing

Optical microscope images of the austempered and induction hardened sample are given in Figure 8. The trace of wear on the sample after abrasion test under 10N load is shown in Figure 8.a and ball bearing Figure 8.b. At the same time, there are adherent and abrasive wear marks on the sample surface. There are intense abrasive marks on the surface of the ball bearing. After the abrasion test under 30N load the marks on the sample surface and ball bearing area seen in the Figure 8.c and Figure 8.d. The type of abrasion is same on the sample surface and mix of abrasion and adhesive wear mechanism and mark width has increased by intensifying of the friction. In the same way, abrasive wear mechanism is seen on the surface of the ball and the wear trace diameter is increased.

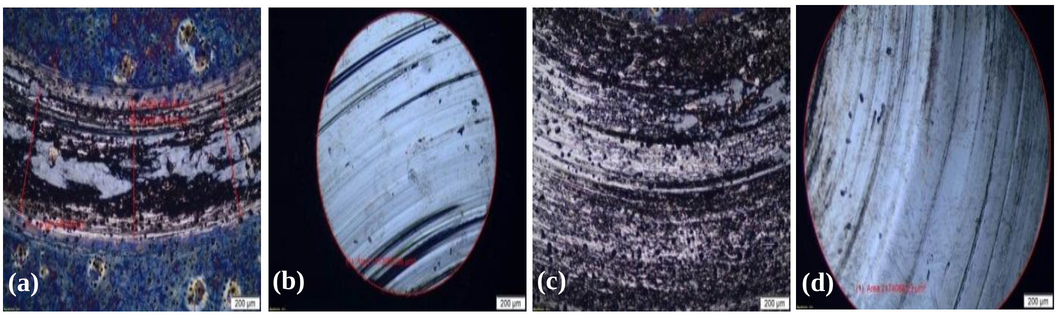


Figure 8. The optical microscope images of abrasion surfaces under austempered+induction hardened conditions under 10N load; a) sample b) ball bearing; 30N load c) sample, d) ball bearing

IV. CONCLUSION

In this study, the effects of austempering and austempered+induction hardening heat treatments on the wear and microstructure of camshaft made of ductile cast iron were investigated and following results were obtained;

1.When microstructure of samples in the camshaft under casting conditions contain graphite nodules and ferritic-pearlitic matrix structure, austempered camshaft samples microstructure contains ausferrite (austenite + ferrite) microstructure. The core of microstructure of camshaft with austempered + induction hardened contains nodule graphite and keep its ausferrit microstructure. The surface of microstructure of that consists of nodule graphite, fine martensite, some untransformed austenite and some needle ferrite.

2.Austempering and induction hardened heat treatment process applied on GGG60 class nodular cast iron, the core hardness value of nodular cast iron has increased from 265HB to 338HB, surface hardness value from 27.2HRc to 61.8HRc.

3.When compared wear resistance of produced camshaft samples, the wear resistance of the camshaft with as-cast cast condition has increased 35-40% by austempering heat treatment. After applying induction surface hardening heat treatment, the wear resistance of camshaft has increased 75-85% of wear resistance of as-cast camshaft.

4.While adhesive wear mechanism was seen under 10N loads in as-cast camshaft, after increased the applied load, wear mechanism changes to abrasive wear. Wear mechanism for austempered and induction hardened camshafts is abrasive wear mechanism regardless of applied load.

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International Refereed Journal of Engineering and Science (IRJES). “The Effects of Heat Treatment on the Mechanical Properties of Camshaft Made of Ductile Cast Iron.” International Refereed Journal of Engineering and Science (IRJES), vol. 06, no. 11, 2017, pp. 34–40.