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Property Improvement of Subzero/Cryogenic Heat Treated Camshafts made of 8620H, 16MnCr5 and 100Cr6 Steels

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Several types of camshafts that made of 8620H, 16MnCr5 and 100Cr6 steel were subzero/cryogenic heat treated and the effect of these heat treatment parameters such holding duration and temperature on the microstructure, retained austenite volume ratio and hardness. 8620H and 16MnCr5 grade camshafts were carburized at 925 °C in endogas atmosphere (20% CO, 40% N_2, 40% H_2) for 1440 min. At the end of carburing process the diffusion temperature was decreased to 840 °C, which is the austenizing temperature, and held for 90 min. Next the samples were hardened in oil at 60 °C (held for 30 min). Samples were subzero treated at −100 °C for 210 minutes and were tempered at 185 °C for 120 minutes. The microstructure was revealed that the subzero/cryogenic heat treatment increased the hardness up to 62 HRc and increased the wear resistance of camshafts surface. The decrease in the retained austenite ratio was observed from 25% to 5–10% after cryogenic heat treatment. All of steels the hardness values were increased with the transformation of retained austenite into martensite. This increase is the result of the transformation of martensite from retained austenite and the carbide precipitation mechanism. In this study, the wear strength values of the hardened camshaft have been brought from the level of 2.2851 mg to 0.5239 mg and SEM analyzes were performed.

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PACS/topics: machining, subzero/cryogenic heat treatment, retained austenite, wear, hardness

1. Introduction

The freezing of the metals has been acknowledged for many decades as an effective method for increasing the "period of wear resistance" and decreasing residual stress in tool steels [1]. Cryogenic treatment is an inexpensive one-time permanent treatment affecting the entire volume of the component unlike the coatings. The treatment is an add-on process to conventional heat treatment in which the samples are cooled down to prescribed cryogenic temperature level around 93 K at a slow rate, maintained at this temperature for a long time and then heated back to room temperature. Researchers have been skeptical about the process because it imparts no apparent visible change in the material and the mechanism is also unpredicted [2]. Deep cryogenic treatment in the range −125 to −196 °C improves certain properties beyond the changes obtained by ordinary cold treatment [3–6].

The main result for this treatment is the complete transformation of austenite into martensite and the formation of very small carbide grains dispersed in the tempered martensitic structure [7]. Cryogenic treatment is not, as it is often mistaken for, a substitute for good heat treating, rather it is an add-on or supplemental process to convertional heat treatment to be done before tempering. However, it has been reported that some improvement can be obtained by carrying out the treatment at the end of the usual heat treatment cycle i.e. on the finished tools [8]. In this study, we investigated the effects of different temperature and duration of the process on the microstructure, retained austenite, hardness and abrasion resistance properties of the camshaft samples produced from 8620H, 16MnCr5 and 100Cr6 steel.

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2. Materials and equipment

2.1. Materials and methods

For the elimination of possible faults before manufacturing and the determination of the cutting tools to be used, the simulation was carried out in the machine with the Esprit manufacturing simulation program. The process flow diagram is organized in the form of turning, milling and grinding, respectively. The steel cam was first turned into a lathe by cutting the front/back sides of the mill and the milling process was completed with the threading process. Finally, the production of the cam is completed by grinding of the outer corner and the grinding of the bearings. The chemical composition of the cam shaft produced from steels is shown in Table I.

TABLE I

Chemical composition [%] of 8620H, 16MnCr5, 100Cr6 steels

Material	C	Mn	Ni	Cr	Mo	Si	S	P	Cu
8620H	0.2	0.75	0.45	0.52	0.17	0.22	0.03	0.028	–
16MnCr5	0.18	1.15	–	0.95	–	0.23	0.02	0.02	–
100Cr6	0.97	0.36	–	0.43	0.08	0.28	0.01	0.02	0.25

2.2. Heat treatment

Camshafts for all kind of steels were grinded and different heat treatment cycles have been applied. 8620H, 16MnCr5 grade camshafts were carburized at 925 °C in endogas (20% CO, 40% N_2, 40% H_2) atmosphere for 1440 minutes. The camshaft made of 100Cr6 was not subjected to carbon diffusion because it has enough carbon content. 100Cr6 camshafts were heated to austenitizing temperature only and held for 90 min. Then all samples (8620H, 16MnCr5, 100Cr6 camshafts) were hardened in oil at 60 °C (held for 30 min). After the hardening process, samples were subzero treated at −100 °C for 210 minutes in liquid nitrogen (N). Then the samples were tempered at 185 °C for 120 minutes to get the residual stresses in the camshafts. Table II shows the heat treatments applied to the cam shaft of different materials.

Heat treatment schedule

TABLE II

Material	Carburized (925 °C, 1440 min)	Austenitise (840 °C, 90 min)	Oil Quench (60 °C, 30 min)	Sub-zero (−100 °C, 210 min)	Tempered (185 °C, 120 min)
8620H	+	+	+	+	+
16MnCr5	+	+	+	+	+
100Cr6	−	+	+	+	+

2.3. Metallographic process

Heat treated camshafts samples were prepared for the microstructure investigation by standard metallographic methods (mounting, grinding, polishing) and then etching process was conducted to the samples by using 2% nital solution. Microstructure of the camshaft was examined under a Nikon MA200 optical microscopy and analyzed by Clemex Vision Lite image analysis software.

2.4. Mechanical tests

Hardness values were measured by taking sections from the camshaft. Micro hardness measurements were measured at 1 kgf load qness micro hardness tester. Hardness measurements were made from the surface to the center. Hardness measurement values are given separately for each heat treatment.

Test sample for wear tests were prepared by taking cut views from cam sections on the camshafts under untreated and heat treated conditions. 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 then the wear surfaces of each sample were examined by SEM. 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. At room temperature, under load of 30 N, rotation speed of 300 rpm, at 500 m and 1000 m distance, wear test with material 5 mm in diameter was performed.

3. Results and discussion

3.1. Microstructure

Figure 1 shows the metallographic structure of the samples after nital etching. After the heat treatment, microstructure studies revealed that martensite phase was formed on the material surface. The martensitic phase transformation occurs by diffusion-free phase transformation. Martensitic transformation is a diffusion-free, military-type phase transformation in which atoms move with slip-like mechanisms [9].

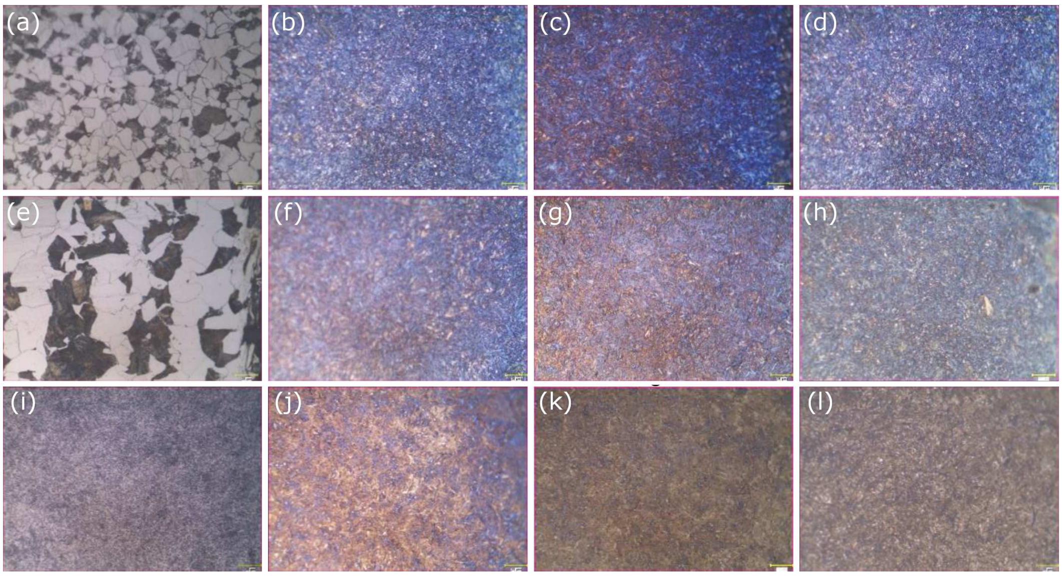

Fig. 1. Material microstructure before and after the heat treatment: (a) 8620H untreated, (b) 8620H hardened, (c) 8620H sub-zero, (d) 8620H tempered, (e) 16MnCr5 untreated, (f) 16MnCr5 untreated, (g) 16MnCr5 sub-zero, (h) 16MnCr5 tempered, (i) 100Cr6 untreated, (j) 100Cr6 hardened, (k) 100Cr6 sub-zero, (l) 100Cr6 tempered.

The residual austenite ratios of different steels after heat treatment are given in Table III. These alloys contain the austenite phase which is stable at high temperature and the martensite phase which is stable at low temperature phase. When the alloy is cooled below the martensite initial (Ms) temperature, the martensite begins the shift-like mechanism. When the temperature is increased, the martensite becomes unstable and the reverse conversion starts. If the conversion is crystallographically reversible, the martensite turns into the main facade in the same direction from the other [10]. In the measurements taken at the surface of the samples, a residual austenite of 15–25% was encountered. Residual austenite is called non-transformed martensite structure in quenched steel. According to the cryogenic treatment results, the amount of retained austenite in the 16MnCr5 steel is higher than that of 100Cr6 and 8620H.

TABLE III

Retained austenite [%] in 8620H, 16MnCr5, 100Cr6 steels

Material	Untreated	Hardened	Sub-zero	Tempered
8620H	50–60	20–23	5–7	6–7
16MnCr5	50–60	21–25	6–8	7–8
100Cr6	40–45	15–20	4–6	5–6

3.2. Mechanical tests

In these studies carried out with 3 different materials, the hardness of the samples increased after carbon impregnation to the sample surface. Figure 2 shows the results of hardness measurement of different steels from the surface of the sample to a depth of 1.9 mm. The surface hardness of the parts after the carburizing process is in the range of 780–810 Hv (red lines in Fig. 2a, b and c). After cryogenic treatment, the surface hardness of the sample has increased to 820–880 Hv (green lines in Fig. 2a, b and c). According to the results of the hardness measurements, the hardness of the cryogenic treated parts increased by 5%. Cryogenic treated specimens were tempered and as a result, 7% reduction in hardness was measured (purple lines in Fig. 2a, b). In Fig. 2a and b, 8620H and 16MnCr5 steels showed a decrease in hardness after a depth of 0.7–0.9 mm and a stable hardness distribution was observed due to the high carbon content in the 100Cr6 steel, as shown in Fig. 2c.

The reason for the high hardness of the 16MnCr5 steel is due to Manganese content. The effect of the applied cryogenic process on hardness is decreased at a depth of 0.9–1.1 mm.

The friction coefficient-wear distance graphs of the untreated and hardened samples of the cam against Al_2O_3 balls are given in Table IV. As a result of 500 m and 1000 m distances under 30 N load, the mean friction coefficients of the untreated samples were 0.79 and 0.99, respectively, while lower friction coefficients were observed in the hardened samples (Table IV). The reason for the high coefficient of friction is that it causes abrasive wear.

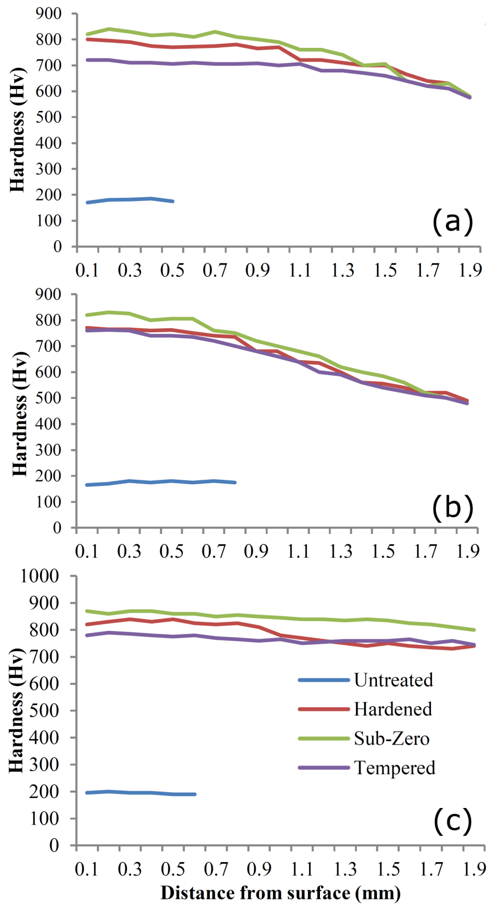

Fig. 2. Hardness obtained by heat treatments; (a) 16MnCr5; (b) 8620H, (c) 100Cr6.

TABLE IV

Wear test results

Material	Wear properties	Untreated		Hardened		Sub-zero		Tempered	
		500 m	1000 m	500 m	1000 m	500 m	1000 m	500 m	1000 m
8620H	loss of sample [mg]	1.9412	2.2851	0.3296	0.8601	0.2643	0.7485	0.4220	1.0415
	friction coefficient	0.7984	0.9997	0.4779	0.5481	0.3769	0.4327	0.4949	0.6158
16MnCr5	loss of sample [mg]	1.7208	1.9896	0.2985	0.6897	0.2423	0.5900	0.3962	0.8973
	friction coefficient	0.7120	0.9012	0.4131	0.5222	0.3065	0.4000	0.4312	0.5888
100Cr6	loss of sample [mg]	1.1531	1.5127	0.2332	0.5761	0.2118	0.5239	0.2985	0.6222
	friction coefficient	0.7120	0.9012	0.4131	0.5222	0.3065	0.4010	0.4312	0.5888

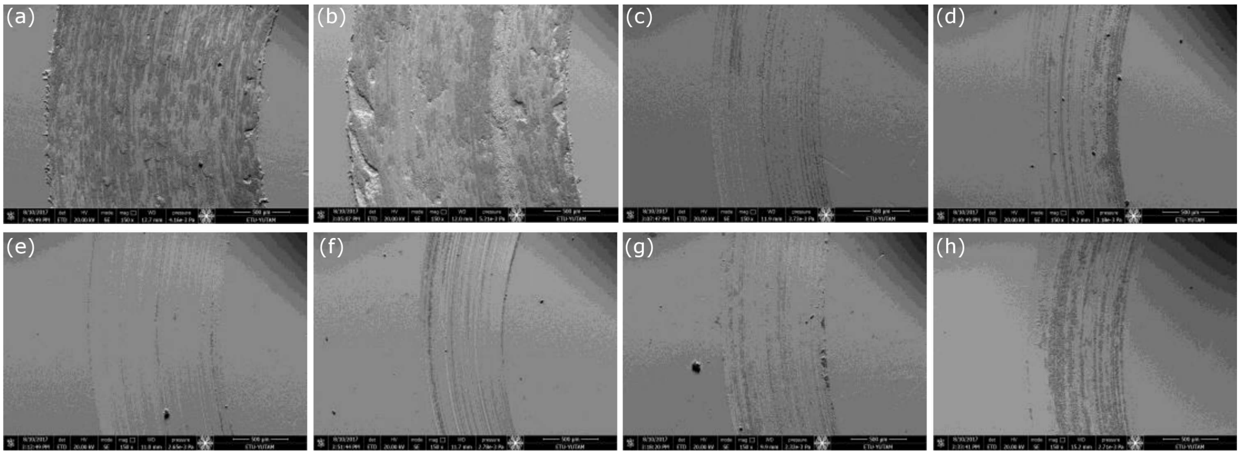

Fig. 3. Wear trace SEM images of untreated and hardened 100Cr6 steel camshaft specimens; (a) untreated 500 m, (b) untreated 1000 m, (c) hardened 500 m, (d) hardened 1000 m, (e) subzero 500 m, (f) subzero 1000 m, (g) tempered 500 m, (h) tempered 1000 m.

The surface hardness of the samples increased after the subzero treatment decreased the friction coefficient with increasing surface hardness. The lowest friction coefficients were determined as 0.30 and 0.40, respectively, in the in the at 500 m and 1000 m distances at 100Cr6 steel. After the wear test, wear volumes were determined with 3D contactless profilmeters.

Figure 3a–h shows wear SEM images of showing the best feature 100Cr6 steel camshaft specimens hardened operation in tested at different wear distances. When the images of the worn surfaces of the camshaft samples are examined, an adhesive wear mechanism is seen. When worn surface images are examined, it is seen that the non-treated and treated 100Cr6 steel exhibit different wear behaviors. In Fig. 3a and b the result of plastic deformation is clearly visible in the trace of wear of the non-processed sample. Moreover, the width of the wear trace is obviously widened. After the carburizing process, the trace width of the samples decreases (Fig. 3c and d). The narrowest trace of wear, obtained from cryogenic process samples, are shown in Fig. 3e, f. This situation can be explained by the reduction of the width of the wear allowance and the decrease in the surface roughness. Cryogenic treated specimens were tempered and the trace of plastic deformation is increased as seen in Fig. 3g and h with the decrease in hardness. When the wear distance is increased from 500 m to 1000 m, the width of the wear trace on the surface of both the cam and the machined cams increases. Partly abrasive scars of the presence of adhesive layers can be seen on the surface of the sample.

4. Conclusions

The deep cryogenic treatment ($-100\,^{\circ}$C) of quenched and tempered 8620H, 16MnCr5, 100Cr6 steels improves their properties; hardness, strength and microstructure properties. The amount of retained austenite is reduced by 60–65% after the sub-zero process following the carburizing process. It is observed that the increase in the amount of residual austenite adversely affects hardness. The maximum reduction in the amount of residual austenite was observed in the 16MnCr5 steel. Since high amounts of retained austenite in the carburized case decrease the wear resistance and fatigue limit of machine parts, it should be kept to a minimum. Consequently, the carbon contents of the machine parts must be lower than 0.7% C level, and quenching temperature (Tq) must be under the martensite finish temperature (Mf). The steel camshaft samples was subjected to a wear test at a distance of 500 m and 1000 m under a load of 30 N, and the hardening process was found to increase the wear resistance. The best wear resistance was observed as 0.21 mg at a distance of 1000 m at 100Cr6 steel.

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