The Characterization After Normalizing Treatment of Hot Forged 16MnCr5 and 20MnCr5 Cementation Steels

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Abstract
Low carbon steels such as 16MnCr5 and 20MnCr5 are a widely used grade of steel in almost every industry including aerospace, transportation, power transmission for manufacturing of gears, camshafts, piston, pins and bearing due to its suitable properties such as toughness, ductility, high tensile strength, good resistance to corrosion. In this study, different heat treatments have been applied to improve the properties of hot forged parts. The microstructure and mechanical properties of the hot-forged samples have been examined in three different processes; after normalizing was applied, cementation and tempering applied without normalizing, and cementation, tempering was applied on the normalized parts. As a result, when normalization is applied before the carburization and tempering processes an increase in core hardness and fatigue lives were observed for the examined parts.

1. Introduction

Cementation steels are defined as low carbon content structural steels containing 0.1 to 0.2 %C before carburizing. Due to its low carbon content, it has good toughness with the low hardness of steel before the thermochemical treatment. The carburization process is a surface hardening process to increase surface hardness and improve the wear resistance of steel but maintains the toughness and fatigue strength of the core. These steels are classified as unalloyed and low alloy steels (Cr, Mn-Cr, Mo-Cr, Ni-Cr, Cr-Ni-Mo etc.) according to different alloy compositions. The selection of proper alloying elements obtains the required hardenability from the surface to the core [1]. The carburization process is applied to low carbon steels used in gears, ball bearings, railway wheels applications that create a hard and wear-resistant surface and to maintain their ductility. Carburized steels commonly used in these applications include AISI 1018, 4320, 5120, 8620 and 9310; their international grades are 20MnCr5, 16MnCr5, ZIF-7B, 20MoCr4 and V2525 [2].

16MnCr5 and 20MnCr5 steels are frequently used in manufacturing industrial and automobile components (bolts, gears, internal combustion engine parts and valve bodies) and also used in railway vehicle, machine tools, steel rolling equipment and mining machine transmission shaft were investigated [3]. 20MnCr5 and 16MnCr5 show different properties due to different composition amounts. Compositions of the 20MnCr5 and 16MnCr5 steels are given in Table 1. The carbon percentages in the steels affect their hardening. The increase in manganese content provides an increase in strength and hardness. The increase in chromium content increases the depth of hardenability and refines the grain structure. Phosphorus, silicon and sulphur contents of steels are the same, so it has no effect on hardening and strength [4]. Toughness, high fatigue strength and hardness properties are desired in these steels, which are mostly preferred in automotive components. In order to achieve these features, hot forging process and after hot forging process carburization and tempering process applied to the steels are generally used in the industry. However, after these processes, various and undesired anomalies occur in the structure of the materials such as residual stresses, grain growth and distortion. Heat treatment is applied to reduce or eliminate them.

In this study, normalizing is applied and its effect on the parts is examined. Normalization process reduces the internal stresses formed in the production processes of steel. It also improves microstructural homogeneity and response to subsequent heat treatment and increases stability by imparting a thermal memory for other lower temperature processes [5]. In literature; there are several separate studies on these steels [6-8], but no studies which both examined together. The aim of this study is to resolve this lack of literature.

2. Experimental Procedure

The compositions of the materials examined in the study are given in Table 1.

Table 1. Composition of the steels [9]

	%C	%Si	%Mn	%P (max)	%S (max)	%Cr
16MnCr5	0,14-0,19	≤0,40	1,0-1,3	0,035	0,035	0,80-1,10
20MnCr5	0,17-0,22	≤0,41	1,10-1,40	0,03	0,035	1,0-1,30

Normalizing, carburizing and tempering heat treatments applied on the forged 20MnCr5 and 16MnCr5 steels and were examined. The materials were normalized at 960 °C for 30 minutes in the furnace atmosphere containing 0.15

%C. Then materials were cooled in air. In the cementation process, the materials were held in the furnace for 300 minutes and until the temperature reached 935 °C in a carbon atmosphere at 0.4 %C. After the temperature was reached at 935 °C, the carbon atmosphere was increased to 1 %C and samples held for 10 minutes in the furnace. Then, Atmosphere was reduced to 0.67 %C and held for 30 minutes at 850 °C. After the process was completed, materials are quenched was carried out by placed it in the 70 °C oil bath. After the cementation process, tempering was applied to the materials at 140 °C for 120 minutes. The atmosphere, time, temperature and cooling information of the processes applied to the steels are given in Table 2.

Table 2. Parameters of heat treatment processes

Process	Atmosphere (%C)	Temperature (°C)	Time (min.)	Cooling
Normalizing	0,15	960	30	Air cooling
Carburizing	0,4	935	300	Oil quenching (T_{oil}=70°C)
	1	850	10	
	0,67	850	30	
Tempering	-	140	120	Air cooling

After the processes, 8 different samples were examined; hot forged and untreated parts, normalized parts, after normalizing, carburized and tempered parts and without normalizing, carburized and tempered parts. Microstructure, hardness and fatigue strength of the samples were investigated. Metallographic steps were applied for samples microstructure analysis. 2% Nital was used as etching reagent. Fatigue strength testing conditions; fatigue frequency is 120 cycles per minute (2 Hz) and the shape change range (stroke) of the up and down rod arms during the test is 30 mm. The parts were applied bending stress of 400 MPa. The fatigue test for each bar was continued until the bar broke, life comparison was made under the same test conditions. Fatigue life is defined by the number of cycles until the bar breaks under dynamic loads.

3. Results and Discussion

Microstructures of examined samples 16MnCr5 are given in Figure 1 and 20MnCr5 in Figure 2. In the microstructure images of hot forged steels, besides the ferrite phase, there is also a finely dispersed pearlite structure. After normalization heat treatment, microstructures that are ferrite and fine-grained pearlite were obtained with the effect of air cooling in both steels. After normalization, the structure is observed to be dispersed homogeneously. Microstructures of 16MnCr5 and 20MnCr5 resulted similarly to each other after normalizing. The steels have a ferritic-pearlitic structure, and the areas that are carbon diffused turns into a martensite structure is formed after the carburization process. This indicates that the cementation process has been carried out correctly. The microstructure of steel that is correctly applied to heat treatment and tempering process consists mainly of tempered martensite [10]. Tempered martensite was formed in the samples after tempering. However; the structure, amount and properties of martensite change from surface to core. 20MnCr5 has phases with more homogeneous distribution after heat treatments. The reason for this, it is the difference of alloying elements in its content [9].

Hardness values of the tested 20MnCr5 and 16MnCr5 steels are given in Table 3. It was observed that, after normalizing, the core hardness values of the samples which are applied to cementation and tempering processes were higher than the non-normalized samples. No change in surface hardness has been observed**.** Although the normalization process reduces the hardness values of the untreated part, it enabled the subsequent processes to increase the hardness value.

Table 3. Hardness values of the samples

Sample	Code	16MnCr5		20MnCr5	
		Core (HV1)	Surface (HRC)	Core (HV1)	Surface (HRC)
Untreated	S1	295	17	305	19
Normalized	S2	171	4,5	189	9
Without Normalizing, Carburized and Tempered	S3	313	63-64	401	63-64
After Normalizing, Carburized and Tempered	S4	378	63-64	467	63-64

Results of the fatigue test are given in Table 4. It is one of the most important factors affecting the fatigue strength of the microstructure of materials. The microstructure is one of the most important factors affecting the fatigue strength of materials. The fatigue strength of the materials increases with the microstructure becoming more homogeneous. In heat treatments made after normalization, it is seen that martensite plates do not change much in both samples. This explains the higher fatigue strength. Normalizing treatment before hardening is mainly for homogenization and refinement of microstructure and softening the steel. Homogenization and microstructure refinement improve mechanical properties and prevent distortion or cracking of parts with complicated shapes during hardening while softening reduces machining costs [11].

In Figure 3, the fracture cross-sections after the fatigue test of materials are given. The brittle fracture occurred in all rods after fatigue test. Cracks formed as a result of hot forging, which caused the fatigue life to decrease, were removed by heat treatment. Umashankaran et al. [6], in their study, examined the suitability of a crankshaft made of 20MnCr5 by applying the same processes. It was observed that the hardness and fatigue resistance of the structure increased with the heat treatments applied in the study. The results of this study are compatible with the literature.

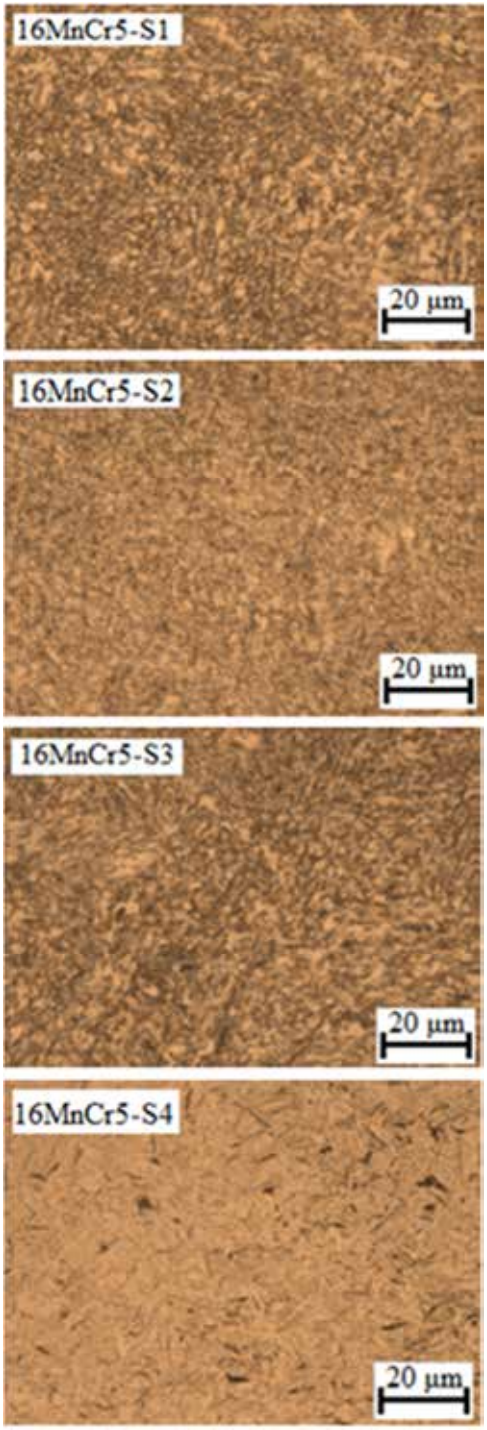

Figure 1. Microstructures of 16MnCr5 examined samples

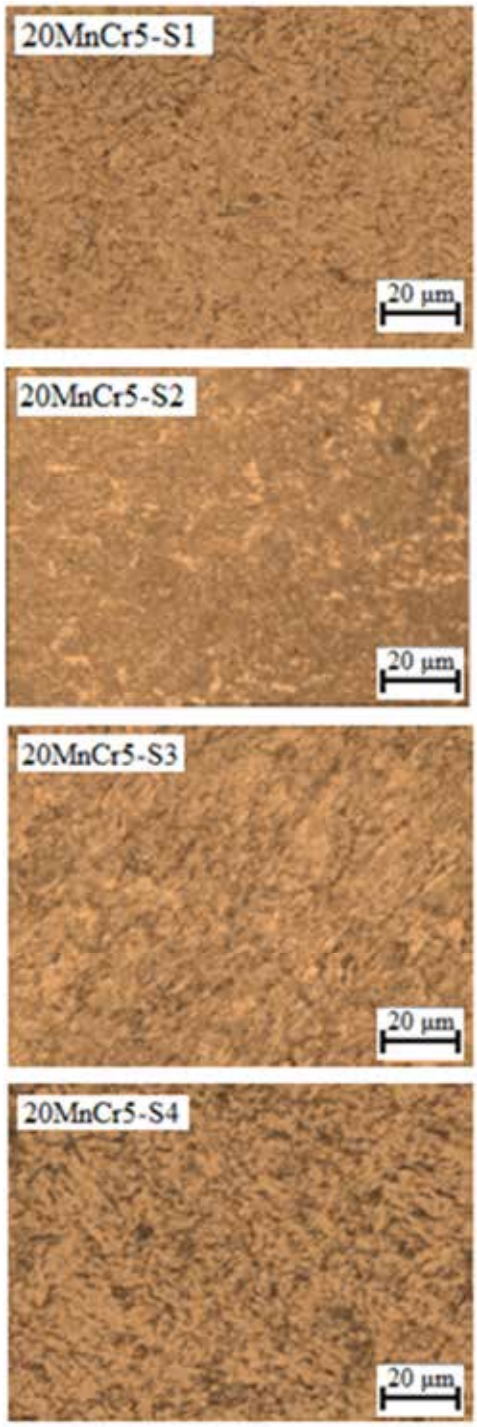

Figure 2. Microstructures of 20MnCr5 examined samples

Table 4. Results of the fatigue test

Code of samples	Number of cycles
16MnCr5-S1	51.320
16MnCr5-S2	20.856
16MnCr5-S3	297.360
16MnCr5-S4	356.465
20MnCr5-S1	58.250
20MnCr5-S2	25.560
20MnCr5-S3	315.450
20MnCr5-S4	386.640

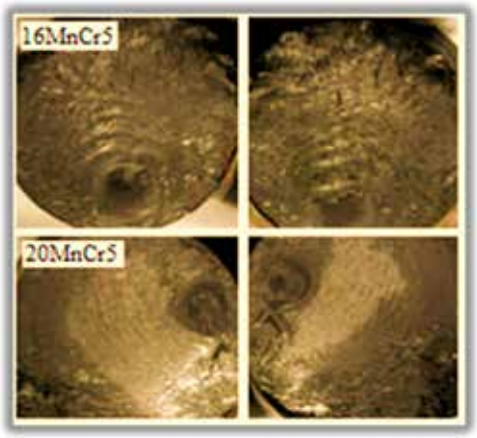

Figure 3. Image of the samples broken in fatigue test

4. Conclusion

The present study focused on the effects of the normalization heat treatment before cementation and tempering heat treatment on the microstructures, hardness and fatigue strength of 16MnCr5 and 20MnCr5.

- After the normalization process was applied to the untreated samples, a more homogeneous distribution of fine-pearlite structure was obtained. Homogenization of the structure reduced the hardness values. However, it has created a more compatible microstructure for the subsequent processes. After carburization, martensite was formed to decrease from the surface to the center. Tempered martensite was formed in the samples after tempering and the structure, amount and properties of martensite change from surface to core.
- Core hardness has been increased in the samples that after normalization applied carburizing and tempering. No change in surface hardness has been observed**.**
- The brittle fracture occurred in all parts after fatigue test. The parts were broken at very low lifetimes. However, the fatigue life of the normalized before the heat treatment is longer than the heat-treated samples without normalization. According to the number of cycles in which the parts are broken, the parts that have been heat-treated by normalizing can be resisted up to approximately 6 times the number of cycles of the untreated part, while the non-normalized parts have resisted up to 5 times the number of cycles.

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