EFFECT OF PRE-QUENCHING AND PRE-NORMALIZATION ON MICROSTRUCTURES AND MECHANICAL PROPERTIES OF 40Cr STEEL AFTER ZERO-TIME-HOLDING QUENCHING

A. Li*

School of Materials Science & Engineering. Henan Polytechnic University, Jiaozuo 454000, China

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Abstract:

Pre-quenching and pre-normalization are selected as pre-treatment processes. Microstructures, the tensile strength and hardness of zero-time-holding quenched 40Cr steel with different pre-treatment are investigated. The results show that the zero-time-holding 40Cr steel quenched by pre-quenching is fine martensite and exhibits higher tensile strength and hardness than that with pre-normalization. The mechanical properties of the zero-time-holding 40Cr steel quenched by pre-quenching are better than that with pre-normalization. The effect of pre-treatment on the mechanical properties of zero-time-holding quenched 40Cr steel becomes prominent when the zero-time-holding quenching temperature decreases. The mechanical properties of zero-time-holding 40Cr steel quenched at 860-890°C can be improved with austenite inverse transformation.

1 Introduction

Zero-time-holding quenching of structural steel means that the samples are quenched immediately when their surface temperature reaches the quenching temperature. Compared with the conventional quenching process, zero-time-holding quenching reduces the time of the microstructure transformation of transparent heat resistant workpeace [1-5]. Zero-time-holding quenching can not only decrease 20-30% the energy consumption and increase the labor productivity, but can also reduce or eliminate the oxidization, de-carbonization and other defects of the part in the process of holding time. Thus, zero-time-holding quenching can raise the quality of the products [6-9].

40Cr steel is widely used in manufacturing of shafts and bolts which always have high strength, good plasticity and good low-temperature impact toughness. The conventional quenching process is considered to be oil cooling after holding the steel at 860°C. Therefore, the importance of our previous work indicating the effect of the original microstructure on mechanical properties of zero-time-holding quenched steels is obvious. It is necessary to investigate the effect of heredity in the microstructure on the microstructure and property of 40Cr steel by zero-time-holding quenching in order to promote the development of zero-time-holding quenching to optimize heat treatment process parameters of the steel and then to improve mechanical properties of 40Cr steel. Quenching and normalization are selected as the pre-treatment respectively and the mechanical properties of 40Cr steel with original martensite and sorbite

* Corresponding author.
E-mail address: anmingli2001@sina.com

microstructures are tested. The influence of pre-treatment on the microstructure and mechanical properties of zero-time-holding quenched 40Cr steel is investigated in detail.

2 Experimental investigation

2.1 Experimental material

The chemical composition of experimental 40Cr steel: C content is 0.41 mass%, Si content is 0.21 mass%, Mn content is 0.64 mass%, Cr content is 0.88 mass%, Ni content is 0.20 mass%, S content is 0.021 mass%, P content is 0.027 mass%, and Fe content is the balance.

2.2 Sample preparation

The tensile sample is a short sample with the dimension of d_0 = 10 mm, L_0 = 5d_0. The dimension of hardness testing samples is 20 mm × 20 mm. The samples for tensile and hardness measurement are shown in Fig. 1

2.3 Heat treatment process

All samples are heated in the same box-type electric furnace. Firstly, the samples are pre-normalized by holding for 20 min at 880°C and subsequently air cooled or conventionally pre-quenched by holding 20 min at 880°C and subsequently oil cooled, respectively. Secondly, the samples after pre-treatment were zero-time-holding quenched and subsequently tempered at different temperatures for 40 min. Comprehensive heat treatment processes are shown in Table 1.

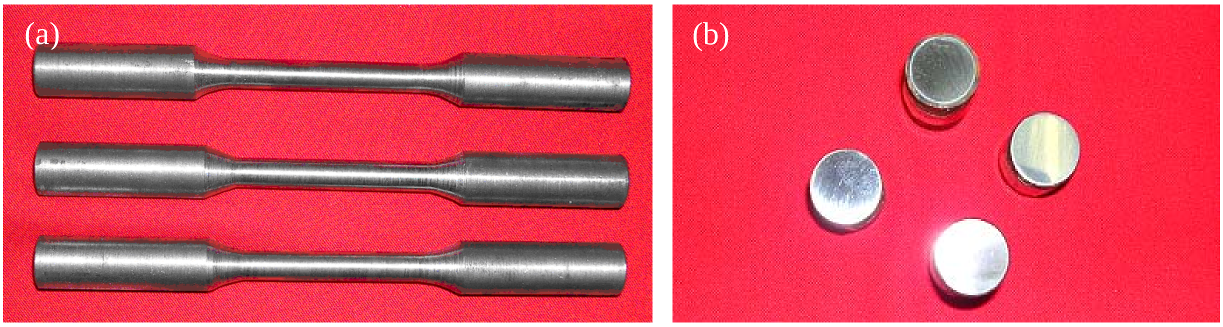

Figure 1. The samples for tensile and hardness measurement (a) Tensile sample (b) Hardness sample.

Table 1. Heat treatment parameters and mechanical properties of 40Cr steel

Code	Quenching temperature (°C)	Tempering temperature (°C)	Pre-normalization		Pre-quenching	
			Hardness (HRC)	Tensile Strength (MPa)	Hardness (HRC)	Tensile Strength (MPa)
A1	860	500	34.0	1138	35.6	1241
A2	890	500	35.8	1182	38.3	1318
A3	920	500	37.3	1223	34.8	1232
A4	860	550	33.0	1019	34.2	1216
A5	890	550	34.8	1047	35.5	1245
A6	920	550	36.5	1129	32.0	1165
A7	860	600	27.7	973	32.4	1188
A8	890	600	29.6	1028	34.9	1217
A9	920	600	31.0	1086	30.1	1130

3 Results and discussion

3.1 Austenitizing temperature and martensite content

Fig. 2 shows the optics micrograph of pre-normalized 40Cr steel. It can be seen that the martensite content of the pre-normalized samples is different after quenching at different temperatures. Some ferrite exist in the zero-time-holding samples quenched at 860°C (Fig.2 a), therefore the strength and hardness of 40Cr steel are lower. The content of ferrite decreases with an increase in the quenching temperature, but the content of martensite increases. The whole structure of martensite can be obtained when the quenching temperature exceeds 900 °C (Fig.2 b).

Few ferrite particles exist in the samples of 40Cr steel pre-quenched by zero-time-holding quenching at 860°C. The content of ferrite particles in the samples pre-quenched by zero-time-holding quenching at 860°C is lower than that in the pre-normalized 40Cr steel. The whole martensite structure which exists mostly in lath martensites can be obtained when 40Cr steel is zero-time-holding quenched in the range 890-920°C (Fig. 3). The microstructure of 40Cr steel zero-time-holding samples quenched at 920 °C is coarser than that at 890 °C.

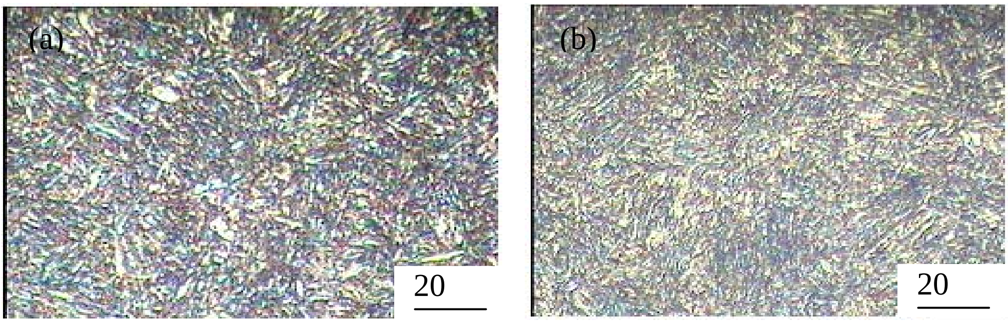

Figure 2. Optics micrograph of pre-normalized 40Cr steel quenched by zero-holding at different temperatures (a) 860°C (b) 890°C.

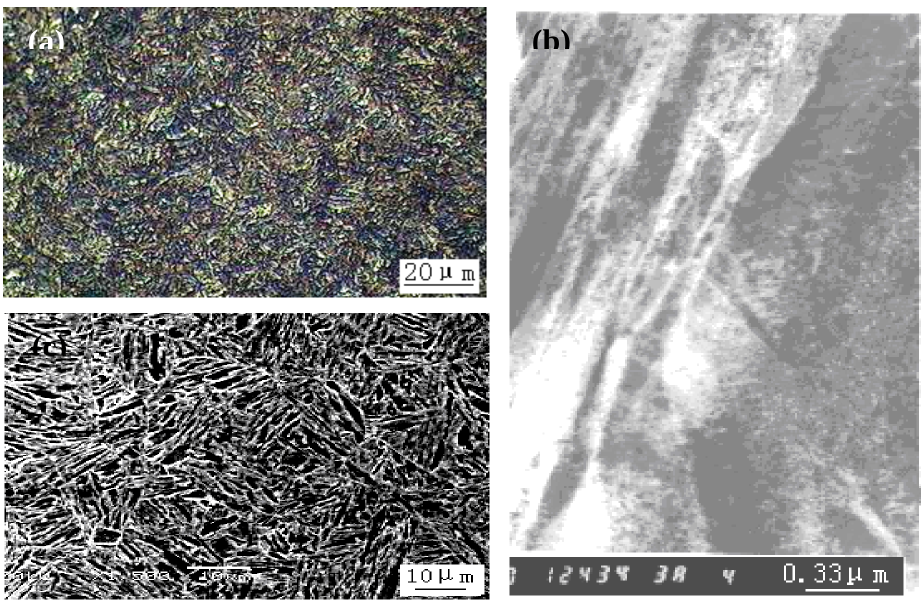

Figure 3. Optics micrograph, SEM and TEM of pre-quenched 40Cr steel quenched by zero-holding at 890 °C (a) Optics micrograph (b) TEM (c) SEM.

3.2 The effect of a pre-treatment process on a phase transformation after quenching

Differential thermal analysis is carried out on a SDTQ600 type differential scanning calorimeter (DSC). Fig. 4 shows the DSC curves of pre-treated 40Cr steel. Ac_1 and Ac_3 of pre-normalized 40Cr steel is 757.45°C and 804.96°C, respectively. And for pre-quenched 40Cr steel, Ac_1 and Ac_3 is 754.85°C and 802.68°C, respectively. The results show that the austenite transformation temperature of the pre-quenched 40Cr steel is lower than that of the pre-normalized 40Cr steel. 40Cr steel with pre-normalization is sorbite, and a pre-quenched sample is martensite.

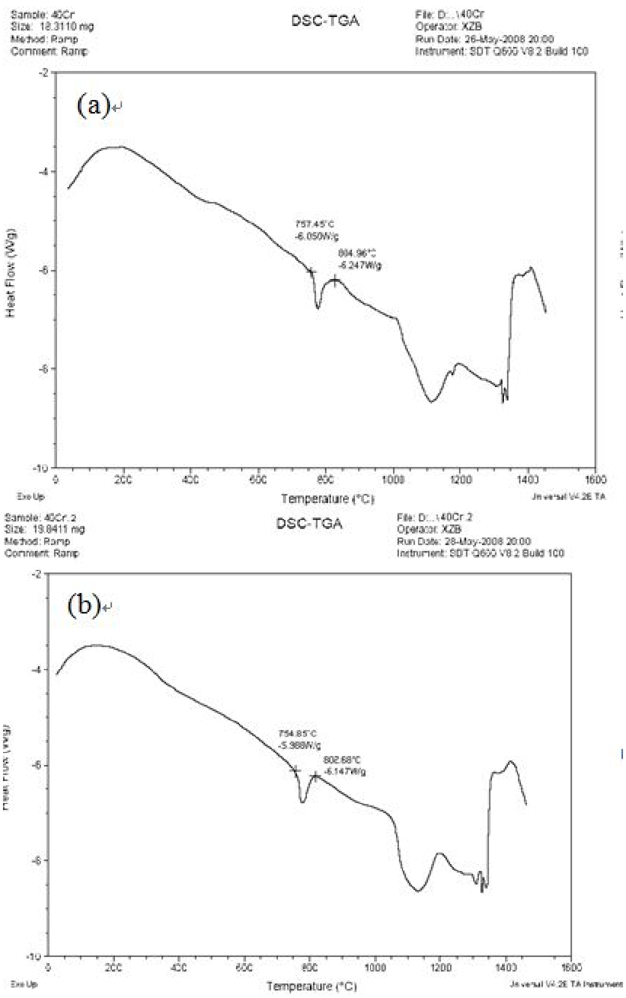

Figure 4. DSC curves of 40Cr steel with various pre-treatments (a) Pre-normalized sample (b) Pre-quenched sample.

The volume free energy of the martensite is higher than that of sorbite because the martensite is a metastable phase and contains lots of dislocations. In the austenite inverse phase transformation, the phase transition drive force is large and then the phase transformation is low.

3.3 The effect of the pre-treatment process on a phase transformation after quenching

Fig. 5 shows the optical micrograph of pre-treated 40Cr steel quenched by zero-time-holding at 890°C. As it can been seen from the figure, the grain size of the pre-quenched 40Cr steel by zero-time-holding quenching at 890°C is 11 grade, and the grain size of the pre-normalized sample by zero-time-holding quenching at 890°C is 10 grade.

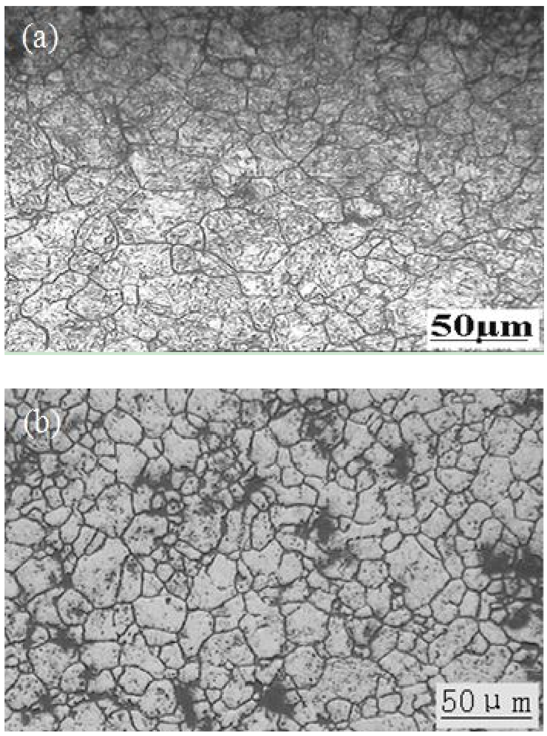

Figure 5. Optics micrograph of 40Cr steel quenched by zero-time-holding at 890 °C with various pre-treatments (a) Pre-normalized sample (b) Pre-quenched sample.

New phase nucleation energy of solid transition □F can be obtained by following equation:

$$\Delta F = \frac{4n\gamma^3}{27(\Delta f_v + E_s)^2} \qquad (1)$$

n is a shape factor; E_s is strain energy of every atom in the grain; Δf_v is the difference of unit volume free energy between new and old phases; γ is the interfacial energy.

By increasing Δf_v (negative value), nucleation energy ΔF is decreased. The nucleation energy of austenite in martensite matrix is low. The smaller nucleation energy is, the greater nucleation rate is and the finer austenite grains are. Moreover, the difference of free energy between martensite and austenite is defined by the ratio saying that, the larger phase transformation driving force is, the smaller degree necessary for of supercooling is.

Considering nucleation, many fine spheroid austenite grain forms in the austenite transformation process of the pre-quenched sample are formed due to quick heating of zero-time-holding quenching. It is possible that acicular austenite nucleates are formed in the martensite boundary, which makes steel microstructure even further refined [10]. Therefore, the austenite inverse transformation can improve the mechanical properties of zero-time-holding quenched 40Cr steel.

3.4 Effect of a pre-treatment process on tensile strength and hardness of the quenched steel

Fig. 6 and Fig. 7 show tensile strength and hardness of the pre-treated 40Cr steel with different quenching temperatures. The tensile strength and hardness of pre-quenched 40Cr steel samples by zero-time-holding quenching at 860-890°C is higher than those of the pre-normalized samples. The tensile strength and hardness of the pre-quenched 40Cr steels by zero-time-holding quenching at 920°C are similar to those of pre-normalized samples.

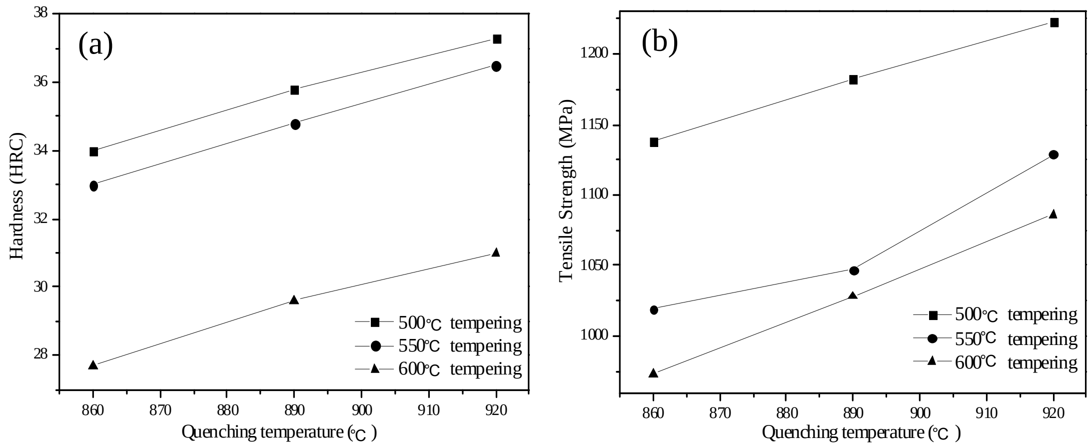

Figure 6. Tensile strength and hardness of the pre-normalized 40Cr steel with different zero-holding-quenching temperatures (a) Hardness (b) Tensile strength.

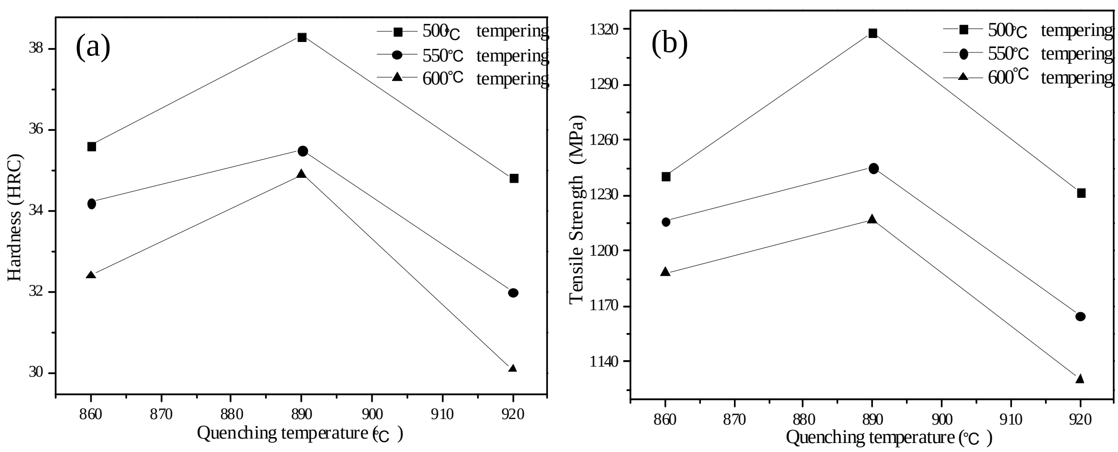

Figure 7. Tensile strength and hardness of the pre-quenched 40Cr steel with different quenching temperature (a) Hardness (b) Tensile strength.

The effect of pre-quenching on tensile strength and hardness of the pre-quenched 40Cr steel samples is reduced by increasing the zero-time-holding quenching temperature, which is ascribed to the fact that the martensite of pre-quenched 40Cr steel becomes coarse with an increase in zero-time-holding quenching temperature. In addition, the austenite inverse transformation can improve the mechanical properties of 40Cr steel by zero-time-holding quenching at 860-890°C.

4 Conclusions

(1) The martensite phase of pre-quenched 40Cr steel is obtained in the zero-time-holding quenching temperature range of 890-92°C. The microstructure is refined when the quenching temperature is low.

(2) Pre-normalized 40Cr steel by zero-time-holding quenching at 860°C yields ferrite and martensite. Not only does the content of martensite particles increase with an increase in the zero-time-holding quenching temperature but the tensile strength and hardness of the samples as well.

The whole martensite structure can be obtained when the zero-time-holding quenching temperature exceeds 890°C.

(3) The effect of original microstructure on the mechanical properties of 40Cr steel is prominent when the zero-time-hold quenching temperature is low, but the effect is reduced by increasing the quenching temperature.

(4) The austenite inverse transformation can improve the mechanical properties of 40Cr steel by zero-time-holding quenching at 860-890°C.

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