THE INFLUENCE OF SUB-TEMPERATURE QUENCHING TEMPERATURE ON THE MICROSTRUCTURE AND PROPERTIES OF 60Si2Mn STEEL

A.M. Li* – M.J. Hu

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

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Abstract:

The influence of sub-temperature quenching temperature on the tensile strength, hardness and toughness of 60Si2Mn steel has been studied, and the ferrite content, austenite grain size and martensite morphology of the microstructure of this steel after sub-temperature quenching analyzed. The results show that duplex microstructure of martensite and ferrite has been obtained by sub-temperature quenching of 60Si2Mn steel. The ferrite content decreases when the quenching temperature increases. The strength and hardness of 60Si2Mn steel increase, however, its toughness decreases within the range of 770~800°C. The maximum strength and hardness can be obtained by quenching at 800°C, but the strength and hardness decrease above 800°C. The small amount of strip ferrite is distributed among martensite lamellar to improve steel toughness. The entire martensite structure can be obtained by quenching at 810°C.

1 Introduction

60Si2Mn steel is traditionally used for making springs of automobiles, tractors, railway vehicles and other high elastic stress components. In recent years, it has been used instead of Cr12 steels [1] for manufacturing small cold moulds. With the expansion of 60Si2Mn steel application field, problems with conventionally completed quenching process arose, referring to the difficulty of obtaining desirable high tenacity [2]. Consequently, it would cause mould fracture, structural failure and eventually collapse of blades. Improving the toughness of 60Si2Mn steel through the quenching process is an effective way of assuring a longer/better service life of cold mould [3].

Sub-temperature quenching is an incomplete quenched process, in which materials are quenched in two-phase region. Compared with the traditional quenching process, the microstructure of lath martensite and ferrite banding can be obtained when the steel undergoes sub-temperature quenching, which is beneficial to steel toughness but only under the premise of not reducing or slightly lowering its strength and hardness so as to be widely applied in the production [4]. Certainly, research into the influence of sub-temperature quenching temperature on the microstructure and mechanical properties of

* Corresponding author. Tel.: 0391 3980631
E-mail address: anmingli2001@sina.com.cn

60Si2Mn steel is of practical significance for the quality of cold mould made from this steel. Hence this paper deals with microstructure and mechanical properties of 60Si2Mn steel quenched under different sub-hardening temperatures.

2 Experimental procedure

2.1 Experimental material

The composition of experimental 60Si2Mn steel is (mass fraction, %): 0.59% C, 1.75% Si, 0.75% Mn, 0.32% Cr, 0.30% Ni, 0.0035% S, 0.032% P, and the balance is Fe, according to the standard of America ASTM 9260.

2.2 Sample preparation

The tensile sample is a short sample with the dimension of d_0=10 mm, L_0=5d_0, where d_0 and L_0 indicate the diameter and effective length of the tensile sample, respectively. The dimension of hardness samples is Ø16 mm × 20 mm. The dimension of an impact V-shaped specimen gap is 10 mm × 10 mm × 55 mm.

2.3 Heat treatment process

All samples were heated in the same box-type electric furnace. Holding quenching time of 20 min was followed by oil cooling. Holding time for tempering was 40 min. The sample number and heat treatment process are shown in Table 1.

3 Experimental results

Three tensile samples and three hardness samples intercepted from Ø16 mm × 2000 mm bar have been processed respectively at each temperature point. The average property value is regarded as the experimental result. The average sample values of tensile strength and hardness are shown in Table 1.

Table 1. Heat treatment parameters and mechanical properties of 60Si2Mn steel

Code	Quenching temperature (°C)	Tempering temperature (°C)	Hardness HRC	Ultimate Tensile strength (MPa)	Elongation (%)
1	770	400	31.0	1034	16.1
2	770	430	30.1	1013	16.3
3	770	460	27.8	971	16.5
4	780	400	38.0	1206	15.5
5	780	430	36.9	1173	15.8
6	780	460	33.1	1120	16.0
7	790	400	43.3	1389	14.8
8	790	430	41.6	1312	15.1
9	790	460	40.2	1245	15.3
10	800	400	46.5	1526	13.3
11	800	430	44.4	1436	14.1
12	800	460	41.8	1335	14.2
13	810	400	43.5	1397	12.3
14	810	430	40.2	1320	12.9
15	810	460	36.4	1207	13.4

4 Results and discussion

4.1 Quenching temperature and the ferrite content

Within the temperature range of 770~810°C, with increasing quenching temperature, the content of ferrite in the quenching structure decreases gradually, but the content of martensite increases, and consequently the distribution of ferrite morphology also undergoes transformations. A large amount of ferrite exists in the sample quenched at the lower temperature, and a part of it has an independent existence when the block has shaped (Fig. 1a). Martensite and ferrite dual-phase structure can be obtained by quenching the sample at 800°C, in which/where ferrite distributes between the martensite plates (Fig. 1b, Fig. 3). The whole martensite structure can be obtained by quenching the sample at 810°C (Fig. 1c).

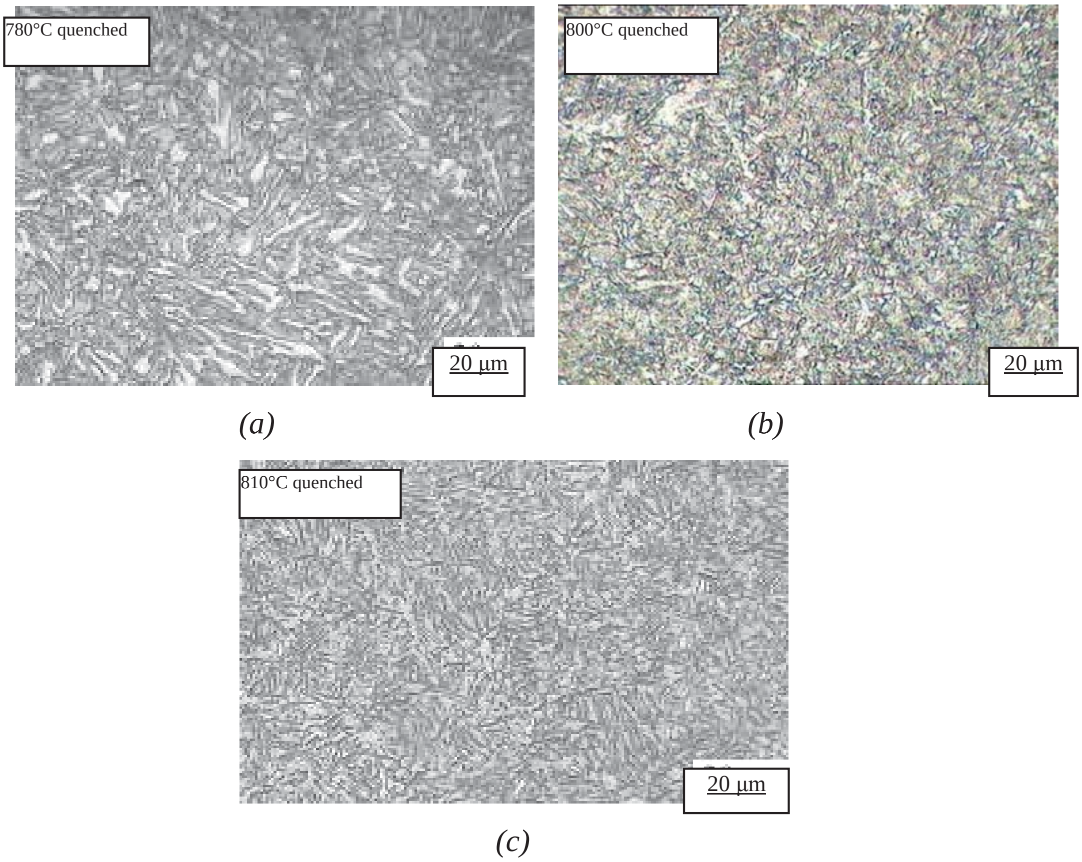


Figure 1. The quenched microstructure of 60Si2Mn steel (a) 780°C quenched (b) 800°C (c) 810°C

4.2 Grain size

Metallographic analysis shows that grain size of 60Si2Mn steel samples with sub-temperature quenched at 780°C is fine (see Fig. 2). The austenite structure has grown in size mainly through the grain boundary migration, and has been split by ferrite that exists in the sub-temperature quenched microstructure and that impedes inhibiting austenite grain boundary migration.

At the same time, as the lower quenching temperature is not beneficial to atomic diffusion, grain boundary migration is slow and the austenite grain growth is consequently hindered [5].

4.3 Martensite morphology

Fig. 2 shows the microstructure of 60Si2Mn steel, and Fig. 3 shows TEM image of the sample quenched at 800°C. The sub-temperature quenched microstructure is mainly fine martensite, with a small amount of ferrite distributed between the lath martensite lamellar.

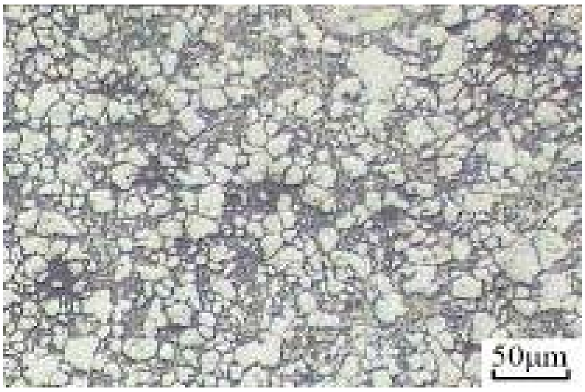


Figure 2. The grain size of 60Si2Mn steel quenched at 780°C

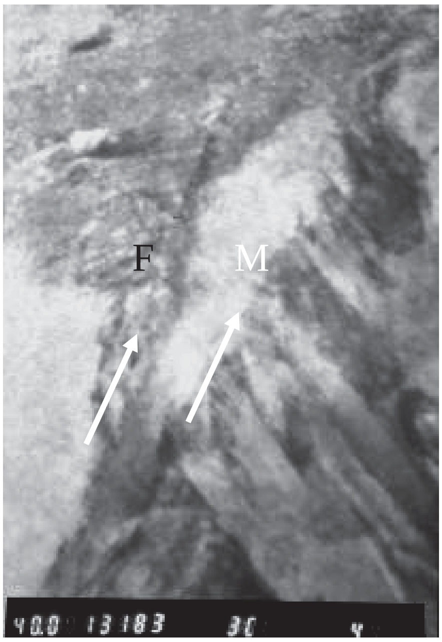


Figure 3. The SEM image of 60Si2Mn steel quenched at 800°C

4.4 Quenching temperature and the mechanical properties

With an increase of sub-temperature quenching temperature within the range of 770~810°C, which is shown in Fig. 4, the values of strength and hardness first increase and then decrease. The specimen quenched at 800°C has the best strength and hardness. The elongation of the sample decreases monotonically with an increase of quenching temperature.

Metallographic analysis shows that a small number of ferrite blocks exist in the sample when quenching temperature is reduced. Obviously, a ferrite block experienced a significant reduction in hardness and strength. Therefore, samples are of lower hardness and strength. A very small amount of lath martensite and ferrite duplex structure is distributed by ferrite between lath martensite when quenched at 800°C. The mechanical property of duplex structure is superior to a single martensite [6]. On the one hand, a small amount of ferrite decreases the strength and hardness of the steel. But compared with complete quenching, high carbon content martensite can be obtained by sub-temperature quenching while the hardness of martensite, on the other hand, can be increased by raising the carbon content, which is partly offset by decreasing strength and hardness caused by the presence of ferrite [7]. Moreover, both the grain size of austenite and martensite structure after sub-temperature quenching are fine. This is why specimen quenched at 800°C has higher strength and hardness.

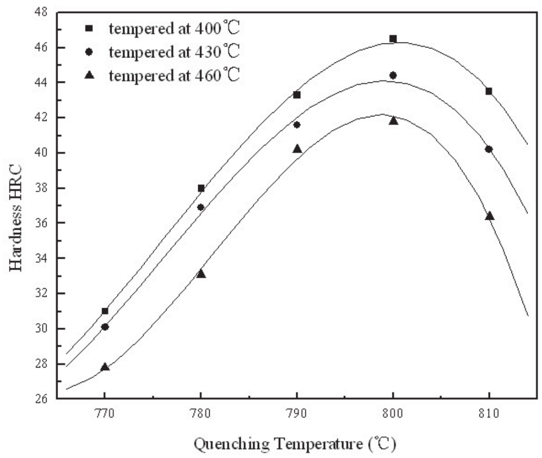
With increasing quenching temperature, strength and hardness first increase and then decrease whereas elongation increases. The experimental test shows that the impact toughness value of 60Si2Mn steel completely quenched at 870°C and then tempered at 460°C is about 24.4 J/cm^2, but the value is 29.3 J/cm^2 when the samples are tempered at 450°C after sub-temperature quenching at 800°C. The duplex structure obtained by sub-temperature quenching improves the toughness of 60Si2Mn steel.

5 Conclusion

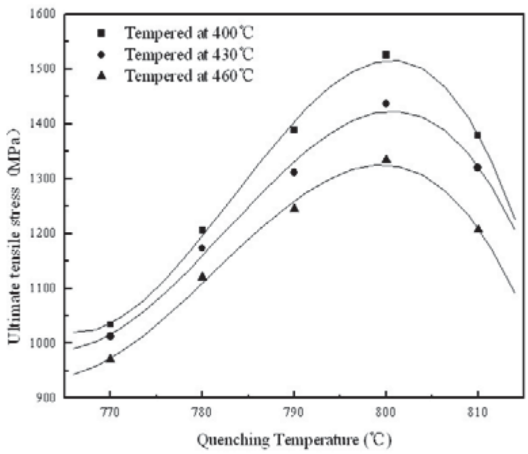
(1) Within the temperature range of 770-810°C, when the quenching temperature increaseas, the ferrite content in 60Si2Mn steel gradually decreases, and the distribution form is correspondingly changed.

(2) The structure of 60Si2Mn steel sub-temperature consists of lath martensite and ferrite, which improves steel toughness.

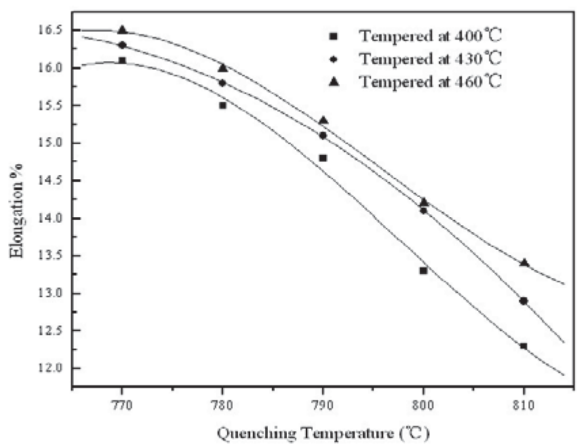
(3) When the quenching temperature is below 800°C, the strength and hardness of 60Si2Mn steel increase. When the temperature is higher than 800°C, the strength and hardness decrease. Within the experimental temperature range, specimens quenched at 800°C have the best strength and hardness.



(a) the curves of hardness



(b) the curves of tensile strength



(c) the curves of elongation percentage

Figure 4. Mechanical properties of 60Si2Mn steel's quenched at 770°C *-810*°C

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