MODIFYING THE MICROSTRUCTURE AND PROPERTY OF 30CrMnSi STEEL BY SUBCRITICAL AUSTENITE REVERSE TRANSFORMATION QUENCHING

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ARTICLE INFO

***Article history*:**
Received: 23.12.2013.
Received in revised form: 15.01.2014.
Accepted: 15.01.2014.
Keywords:
Austenite Inverse Phase Transformation
Subcritical Quenching
Tensile Strength
Hardness
Microstructure

Abstract:

Subcritical austenite reverse transformation quenching was used to improve the mechanical properties of 30CrMnSi steel, and the microstructure and mechanical properties of the samples were analyzed by subcritical austenite reverse transformation quenching. Experimental results show that subcritical reverse transformation quenching can refine the austenite grains of the 30CrMnSi steel. Lath-shaped martensite can be obtained after quenching. Ferrite is exited in the martensite lath when quenching temperature is low. When quenching temperature is higher than 840℃, ferrite disappears and only lath-shaped martensite can be observed. The subcritical austenite reverse transformation quenching at 840℃ can effectively improve the strength and hardness, which is higher than that of the sample by conventional quenching at 870 ℃.

1 Introduction

The haulage link rings of coal winning machine prepared by die forging the 30CrMnSi steel always endure a high tensile stress with abrasive wear and impact load. So it requires a high strength, good plasticity and impact toughness. The conventional quenching process of 30CrMnSi steel is holding at 870℃ by oil cooling. Tempered sorbite can be obtained after conventional quenching and subsequent tempering. During the practical process, brittle fracture sometimes appears in the conventional heating-treated 30CrMnSi steel product due to the poor ductility. It is an effective method for prolonging the service life of 30CrMnSi steel link ring by modifying the quenching technology for improving its strength and toughness [1-3].

The subcritical quenching is a heat treatment process by which the sample is heated to Ac1 ~ Ac3 and subsequently cooled without holding time, which contributes to the formation of martensites and a small quantity of ferrites. The existence of ferrites remarkably improves the toughness of the steel without the decrement of strength and hardness. The austenite reverse transformation is one of effective methods for refining the microstructure of structural steel [4-8]. Herein, the subcritical austenite reverse transformation quenching was used to modify the microstructure and mechanical properties. The microstructures and

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mechanical properties of 30CrMnSi before and after quenching are investigated in detail.

2 Experimental investigation

2.1 Experimental Material

The chemical composition of experimental 30CrMnSi steel (quality percentage, %): 0.29C, 1.21Si, 0.94Mn, 0.93Cr, 0.010S, 0.0127P, and the allowance was Fe.

All samples were heated in SGM2853H box-type electric furnace. First the samples were pre-quenched, respectively, heated at 870 ℃ for 20 min by oil cooling. The martensite structure could be obtained. The final heat treatment process was sub-temperature quenching and tempering. Holding time for quenching was 30 min. Holding time for tempering was 40 min. The heat treatment process of samples was shown in Table 1.

Three tensile samples and three hardness samples were processed, respectively at each temperature point. The average value of the property tested was regarded as the experimental result. Rockwell Hardness (HRC) was measured with HBRVU-187.5 Brinell, Rockwell and Vickers optical hardness tester. The dimensions of hardness samples were Φ20mm × 20mm. The tensile test was processed with WE-600B hydraulic universal testing machine. The tensile sample was the length sample with a dimension of d_0=10 mm, $L_0 = 10d_0$. The impact test was conducted with JB-300B semi-automatic impact testing machine. The impact samples were 10mm×10mm×55 mm with v-shaped notch.

2.2 Experimental results

The average values of tensile strength and hardness of the samples were shown in Table 1.

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

Code	Quenching temperature (℃)	Tempering temperature(℃)	Hardness (HRC)	Tensile Strength (MPa)	Elongation (%)
A1	800	400	32.9	1032	11.2
A2	810	400	36.2	1128	10.5
A3	820	400	39.7	1253	10.4
A4	830	400	41.8	1322	9.7
A5	840	400	43.2	1360	9.3
A6	850	400	42.6	1343	9.0
A7	860	400	41.6	1320	9.0
A8	800	450	31.3	984	11.9
A9	810	450	34.1	1072	11.3
A10	820	450	36.7	1153	11.0
A11	830	450	39.5	1246	10.6
A12	840	450	41.6	1294	10.3
A13	850	450	40.8	1272	10.1
A14	860	450	40.2	1251	10.0

3. Analysis and discussion

3.1 Mechanical properties of the sample quenched at different temperatures

Fig. 1 presents strength and hardness of 30CrMnSi steel with different quenching temperatures. It is noted that the values of the strength and hardness of 30CrMnSi steel is increased by increasing quenching temperature. In the experimental range of temperatures, the strength and hardness of the sample is greatest when quenching temperature is 840 °C, and it is higher than that of the sample (1125 MPa, 42.7 HRC) after conventional heating treatment (quenching at 870 °C and tempering at 400 °C). For the samples tempered at 400 and 450 °C, the elongation is decreased by increasing quenching temperature. So subcritical austenite reverse transformation quenching is beneficial to the improvement of the overall mechanical steel properties.

Experimental testing shows that the impact toughness of 30CrMnSi steel completely quenched at 870 °C and then tempered at 420 °C is about 34.4 J/cm^2, which is obviously lower than subcritical austenite inverse transformation quenching of 30CrMnSi steel quenched at 830 °C and then tempered at 420 °C which reaches about 43.7 J/cm^2. The subcritical austenite inverse transformation quenching improves the toughness of 30CrMnSi steel, which is favorable to prevent brittle fracture of link ring.

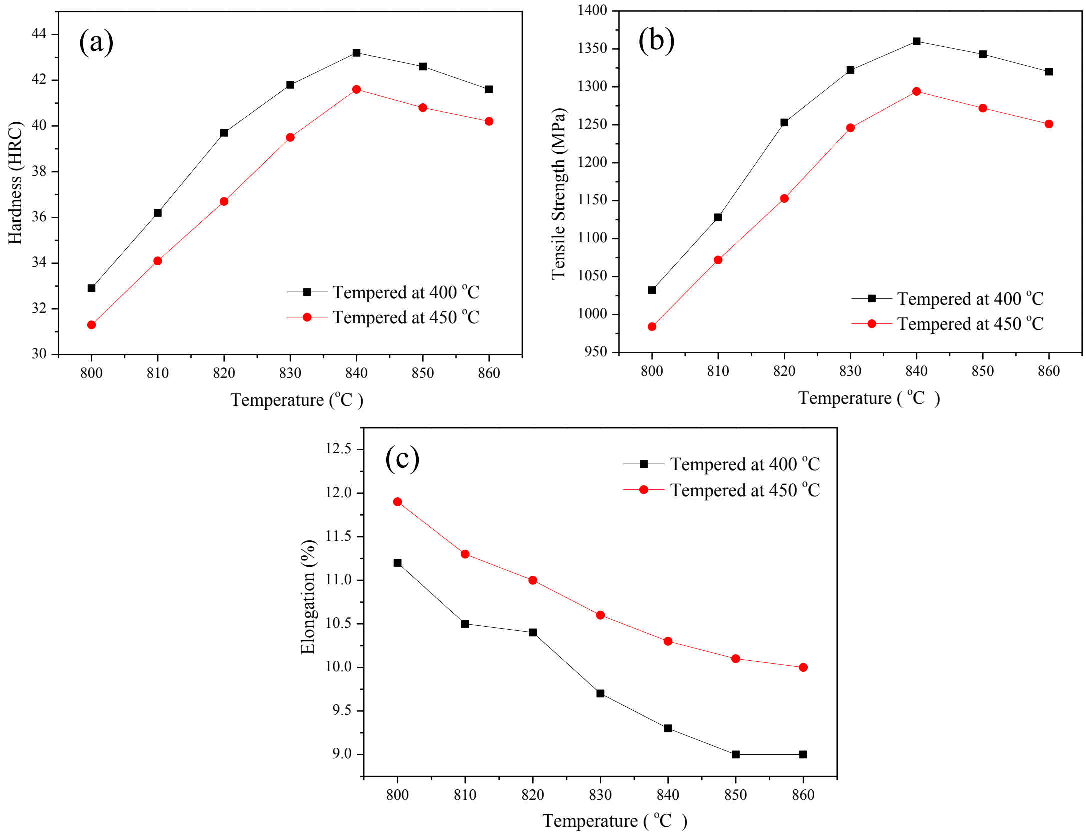

Figure 1. Tensile strength, hardness and Elongation of 30CrMnSi steel by quenched at different temperatures:(a) Hardness (b) Tensile strength (c)Elongation.

3.2 The microstructure of the sample quenched at different temperatures

Fig. 2 shows the optical micrographs of 30CrMnSi steel after quenching at different temperatures. It can be seen from Fig. 2 (a) that the martensites with a small quantity of ferrites can be obtained when the sample is treated by subcritical reverse transformation quenched at 800°C. The amount of martensites increases and the amount of ferrites decreases by increasing quenching temperature. When the quenching temperature is 840 °C, only martensites can be observed (Fig. 2 b). The martensites in the sample quenched at 860℃ are coarser than that at 840℃ (Fig.2 c), which is the reason that the strength and hardness are higher compared with the sample quenched at 840℃. The mechanical properties of 30CrMnSi obtained by the subcritical reverse transformation quenching are determined not only by the morphology of martensite, but also by the amounts and distribution of ferrite.

Transmission Electron Microscopy (TEM) analysis shows that the fine lath-shaped martensite is obtained in the 30CrMnSi steel when the subcritical reverse transformation quenching temperature is 840 ℃ (Fig. 3 a), which may be ascribed to the refinement of austenitic grain and the formation of the acicular austenite formed in the martensite boundaries between the process of reverse transformation [7]. From Fig. (b), it can be seen that film-like ferrites are distributed between the martensite lath when quenching temperature is 820 ℃, which is beneficial to the increment of elongation but on the other hand, it degrades the tensile strength [9]. Obviously the composite microstructure of lath-shaped martensite and banded ferrite contributes to the improvement of toughness.

3.3 The grain size by austenite reverses transformation quenching

Fig. 4 shows the optical micrographs of 30CrMnSi steel after quenching. The austenite reverse transformation quenching at 800-840℃ refines the 30CrMnSi steel. The results show that the grain size of the sample by conventional quenching at 870℃ is 9 grade (Fig.4-a), and the sample by the austenite reverse transformation quenching at 840℃ is 10 grade (Fig.4-b). The main reason that the mechanical properties of 30CrMnSi steel are improved by austenite reverse transformation quenching is the significant refinement of the grain.

New phase nucleation energy of solid transition ΔF can be obtained by the following equation:

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

n is 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.

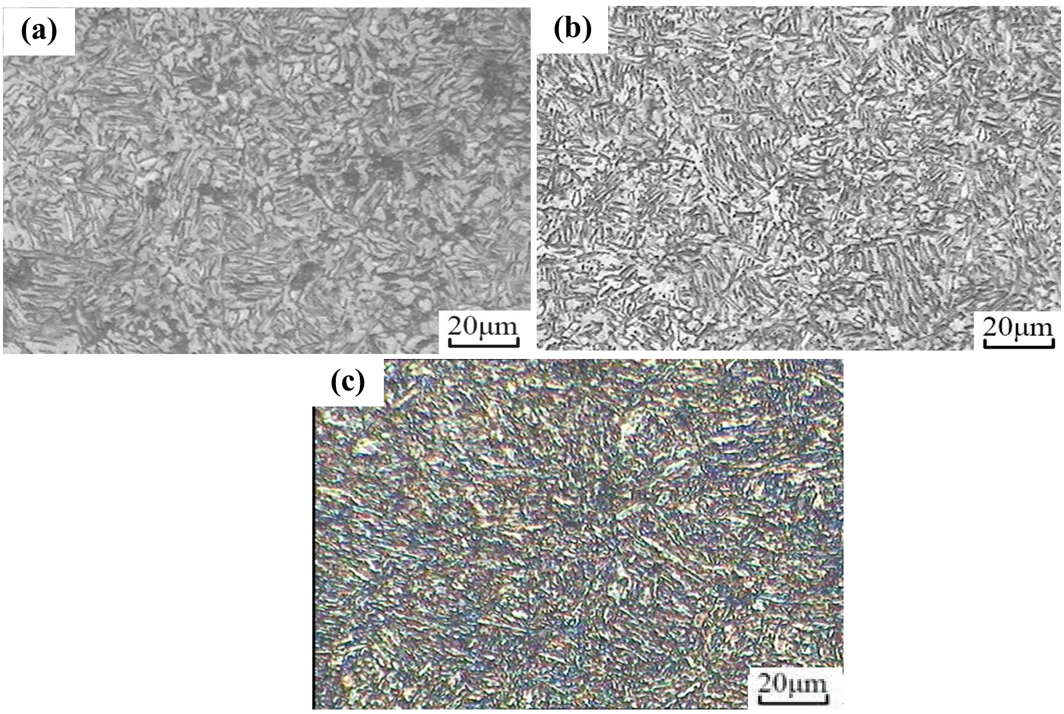

Figure 2. Optical micrographs of 30CrMnSi steel after quenching at different temperatures: (a) 800 ℃, (b) 840 ℃, (c) 860 ℃.

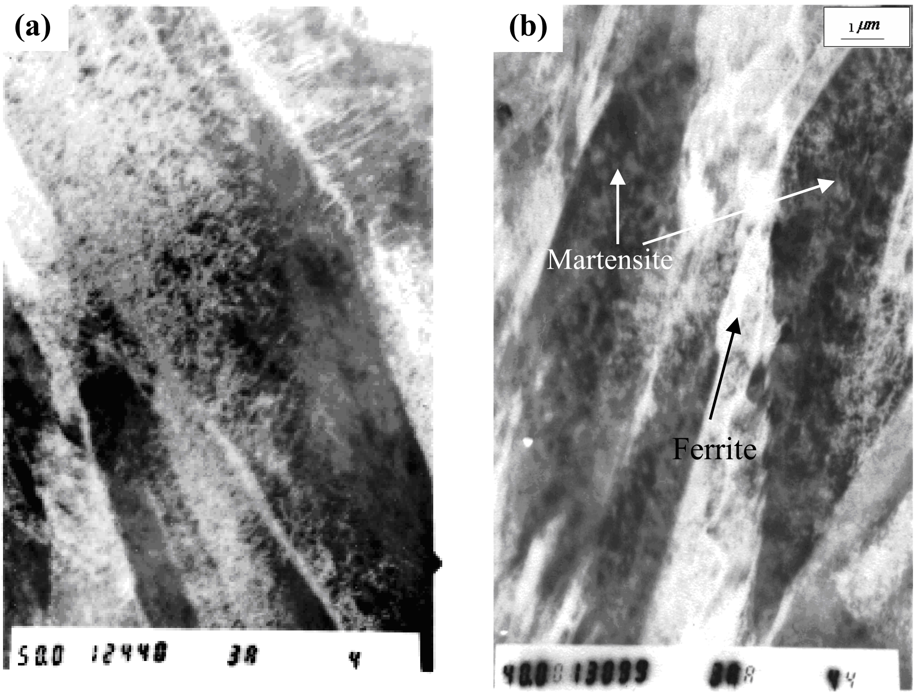

Figure 3. TEM of 30CrMnSi after quenching at different temperatures: (a) 840 ℃, (b) 820 ℃.

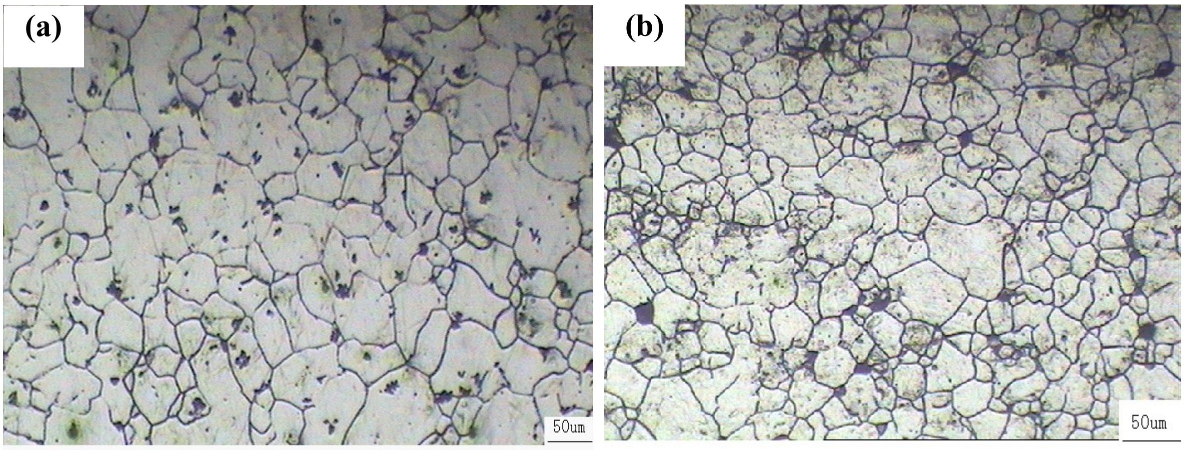

Figure 4. Optical micrographs of 30CrMnSi steel after quenching: (a) Conventional quenching at 870℃, (b) Subcritical austenite reverse transformation quenching at 840℃.

By increasing Δf_v (negative value), nucleation energy ΔF can be decreased. The nucleation energy of austenite in martensite matrix is low. The smaller nucleation energy is, the greater nucleation rate is, the finer austenite grains are. The difference of free energy between martensite and austenite is large. The phase transformation driving force is large. The necessary degree of super-cooling is small. From the perspective of nucleation energy and with reference to the quenched sample, the higher nucleation rate of the spheroidal austenite in the process of the austenite reverse transformation is, the finer the original grain is. Moreover, the acicular austenite might be formed in the boundary of the lath martensite[7], which can further refine the grain. In addition, because the subcritical quenching temperature is low, there is fine carbide in the sample, which can not only hinder the growth of austenite grain but also act as the core of the non-spontaneous nucleation. Therefore, the austenite reverse transformation subcritical quenching can effectively refine the grain size.

4 Conclusions

(1) The subcritical austenite reverse transformation quenching can effectively refine the microstructure of the 30CrMnSi steel.
(2) Fine lath-shaped martensite can be obtained by subcritical austenite reverse transformation subcritical quenching.
(3) The martensites with a small amount of ferrites can be obtained when the 30CrMnSi is treated by subcritical reverse transformation quenching at 800~830 ℃. When the quenching temperature is more than 840 ℃, only martensites are observed.
(4) Subcritical austenite reverse transformation quenching has a great influence on the strength and hardness of 30 CrMnSi steel. The maximum strength and hardness of the sample can be achieved when quenched at 840℃.

References

[1] Dong, Y.S., Yang., J.W.: *The Relationship Between Abnormal Mechanical Properties and Microstructure of 30CrMnSi Steel after Intercritical Hardening and Tempering*, Heat Treatment of Metals, 14, (1989), 7, 18-24.

[2] Ma, Y.X., Zhou, Z.N.: *Research on Sub-temperature Quenching Process of 30CrMnSiA Steel*, Hot Working Technology, (2009), 8, 151-153.

[3] Chen, J.R., Li., J.X.: *Subcritical quenching of 30CrMnSi2MoVA Steel*, Physics Examination and Testing, (1994), 1, 6-9.

[4] Han, J.M., Cui, S.H., Li, W.J.: *Dual phase heat treatment of low-alloy steel*, J Iron & Stell Res Int, 12, (2005), 5, 47-51.

[5] Dong, J., Vetter, H., Zoch, H.W.: *Shortening the duration of heat treatment in the lower bainitic range*, Transactions of Materials and Heat Treatment, 25, (2004), 5: 555-560.

[6] Chen, G.D.: *Study of Dual- phase Heat Treatment for High Strength Structure Steel*, Heat Treatment of Metals, 25, (2000), 5, 19-22.

[7] An, Y.Z.: *Heat Treatment Technology* [M], Machine Industry Press, Beijing 1984

[8] Li, A.M., Hu, M.J.: *The influence of sub-temperature quenching temperature on the microstructure and properties of 60Si2Mn steel*, Engineering Review, 32, (2012), 3: 181-185.

[9] Cui, K.: *Steel materials and non-ferrous materials* [M], Mechanical industry press, Beijing 1981