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Effect of intercritical quenching on microstructure and tensile properties of steels 15 and 15Mn2Nb

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The microstructure and tensile properties of steels 15 and 15Mn2Nb after quenching from intercritical ($\gamma + \alpha$) temperatures were studied. It was shown that steel 15 has an "island-type" dual-phase structure (ferrite plus martensite) after intercritical quenching, while the steel 15Mn2Nb has the "lamellar" structure with alternatively arranged ferrite and martensite needles. Such a lamellar dual-phase structure obviously has improved strength and ductility and is suggested as one of the effective methods in developing high strength dual-phase steels.

1. Introduction

Quenching from the intercritical range ($\gamma + \alpha$) of temperature has been recognized as a method for improving the mechanical properties of HSLA steels [1–4]. This is essentially due to the dual-phase structure developed in which the soft ferrite provides good ductility and the hard martensite plays the role of a load-carrying element, forming a special kind of composite material. Nevertheless, intercritical quenching generally can not give HSLA steels tensile strength higher than 60 to 70 kg mm^{-2} and thus the design of high strength dual-phase steels will be of theoretical and practical importance. The aim of the present paper is to clarify the possibility of increasing the properties of dual-phase steels by suitable alloying and heat treatment.

2. Material and methods

Chemical composition of the steels used was as follows:

Steel	C	Mn	Si	Nb	S	P (%)
15	0.17	0.38	0.56	–	0.020	0.010
15Mn2Nb	0.15	1.95	0.25	0.09	0.030	0.030

Melts of 40 kg weight were forged into strips of millimetre thickness, prequenched from 930° C in order to obtain the lath-martensitic structure and then intercritically quenched from 740, 770, 800 and 840° C after heating for 15 min. The quenching medium selected was 5% NaCl water solution. All strips were finally tempered at 200° C for 1 h and then ground to 2 mm in thickness.

Tensile tests were carried out with specimens 2 mm x 30 mm x 130 mm and a strain rate 4 x 10^{-4} sec^{-1}. Microstructures were examined optically and with a carbon replica on the electron microscope DX4-10. The volume fraction of martensite was determined by automatic counting techniques (Epiquant). Fractographs and line distribution of the carbon content were taken by using the scanning electron microscope S-550.

TABLE I Volume fraction of martensite (V_M) in per cent and its carbon content (in parenthensis) after intercritical quenching at various temperatures*

Steel	Quenching temperature (° C)			
	740	770	800	840
15	35 (0.65)	43 (0.48)	52 (0.34)	84 (0.24)
15Mn2Nb	38	46	55	86

*The critical temperatures of these steels are: steel 15 – Ac_1 = 720° C, Ac_3 = 863° C; steel 15Mn2Nb – Ac_1 = 715° C, Ac_3 = 860° C.

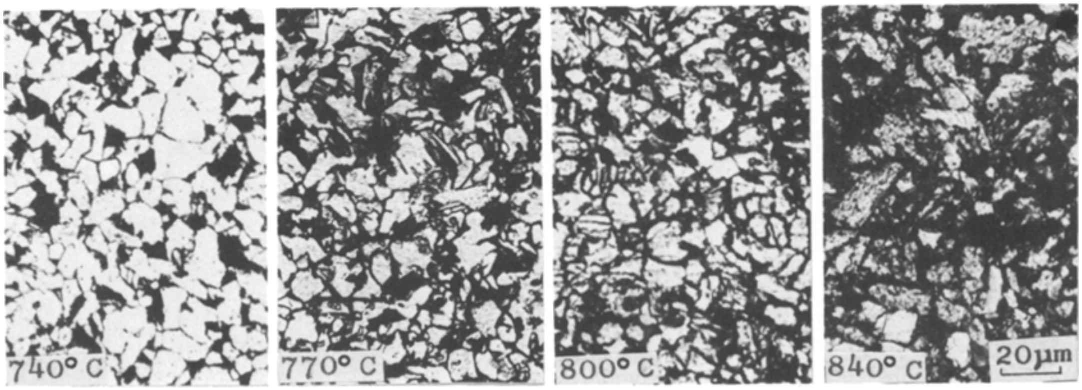

Figure 1 Optical micrographs of steel 15 after 930° C quenching and then quenched from various intercritical temperatures.

3. Results and discussion

3.1. Effect of quenching temperature on microstructure

The microstructure of steel 15 quenched from various temperatures is shown in Fig. 1. It may be seen that both ferrite and martensite grains are equiaxed in form and randomly distributed with each other. The volume fraction of martensite (austensite) increases and the carbon content in it decreases with increasing quenching temperature, as shown in Table I. Such microstructures are typical in dual-phase steels [1] and may be called the "island-type" dual-phase structure.

The microstructure of steel 15Mn2Nb is quite different from steel 15. Fig. 2 shows that the grain size is much smaller and most of the ferrite phase is distributed as needles lying alternatively with martensite of the same orientation, forming nodules as in lamellar pearlite of an $Fe-Fe_3C$ mixture. This kind of structure may be called a "lamellar" dual-phase structure and the mechanism of its formation is not quite clear. One of the possible reasons would be the retardation of ferrite recrystallization during heating at intercritical temperatures by niobium which produces non-soluble NbC particles. The needle-like grains of ferrite and martensite are developed by inheriting from 930° C the prequenched structure of low carbon, lath martensite. The electron micrographs taken by the replica method (Fig. 3) indicate that the martensite grains of island type dual-phase structure in steel 15 are made up by martensite laths mixed with some plates. But in steel 15Mn2Nb, needles of the two phases are alternatively arranged and parallel to each other in orientation, just like the nodules in pearlite.

The intensity of the carbon distribution obtained by wave-length dispersive spectrum analysis is shown in Fig. 4. It may be seen that in steel 15Mn2Nb (Fig. 4b) the carbon content rises up and drops down periodically in accordance with the lamellar arrangement of the ferrite and marten-

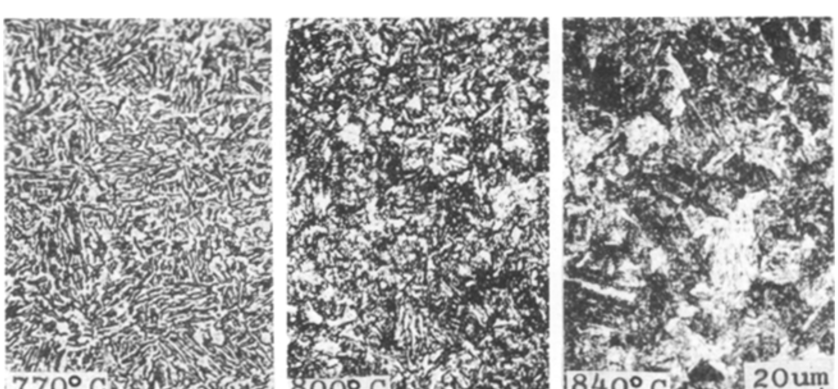

Figure 2 Optical micrographs of steel 15Mn2Nb after 930° C prequenching and then quenched from various intercritical temperatures.

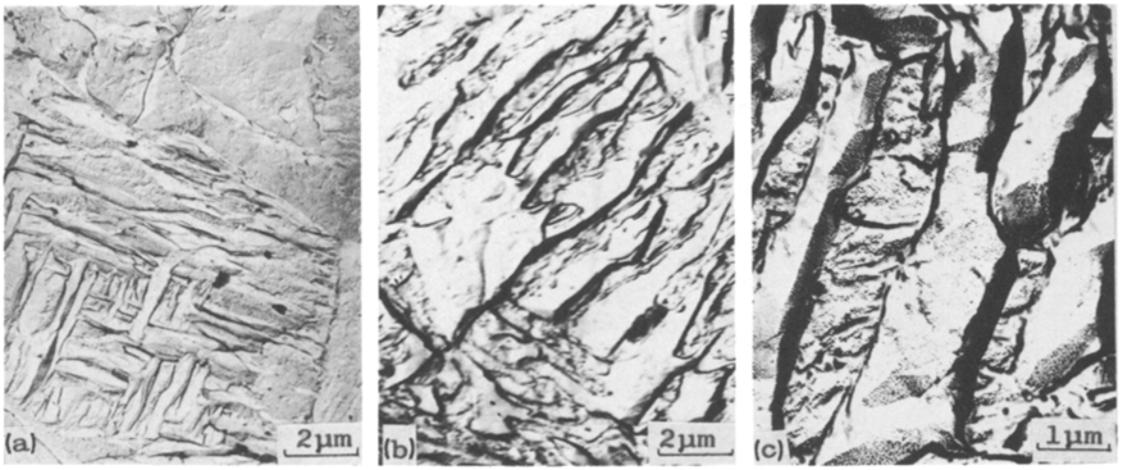

Figure 3 Electron micrographs obtained after 930° C prequenching and 770° C quenching: (a) steel 15; (b) steel 15Mn2Nb.

site phases. The width of the needles of these two phases is of the order of 0.3 to 0.5 μm. Such a lamellar dual-phase structure has been observed previously [4] in a laboratory steel with 0.065% C and 2% Si also after prequenching from the γ-region and intercritical quenching from the $\gamma + \alpha$ region.

3.2. Effect of intercritical quenching temperature on tensile properties

The stress–strain curves of the steels after intercritical quenching from various temperatures are shown in Fig. 5. It can be seen from Fig. 5a that the normalized steel 15 has good ductility but the strength level is too low, while the 930° C quenched and 200° C tempered condition gives, on the contrary, a high strength with poor ductility. The dual-phase states can give this steel appreciable increase in strength without obvious expense in ductility. In comparison with steel 15, the steel 15Mn2Nb due to the favourable effect of manganese in strengthening the ferrite phase and niobium in refining the microstructure and developing the lamellar dual-phase structure gives significantly improved mechanical properties, as shown in Fig. 5b.

Tensile properties of these steels after intercritical quenching are shown in Fig. 6. Here, one can find a well-defined straight line relationship of both the yield and ultimate strength values with respect to the volume fraction of martensite. Although the strength (microhardness) of the martensite phase will be decreased with its increasing volume fraction due to decreased carbon content by increasing the quenching temperature, but the strength of the ferrite phase will be increased with V_M, as shown in [3]. Therefore, with increasing V_M the decreased strength of

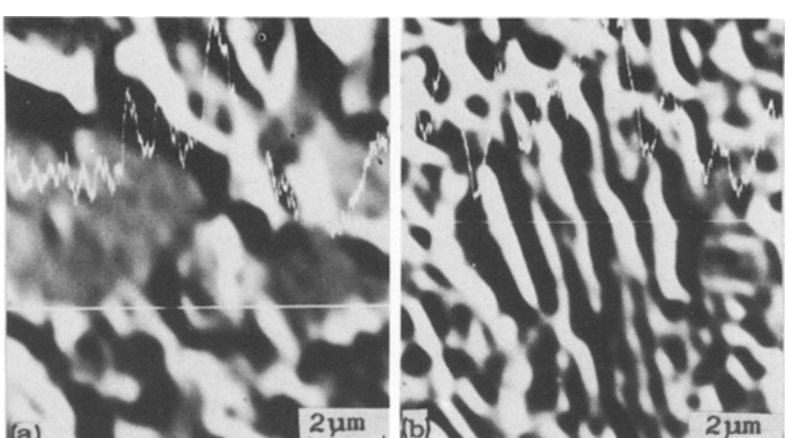

Figure 4 Wave-length dispersive spectra of carbon content: (a) 770° C quenched steel 15; (b) 770° C quenched steel 15Mn2Nb. The white areas are martensite and the dark areas ferrite.

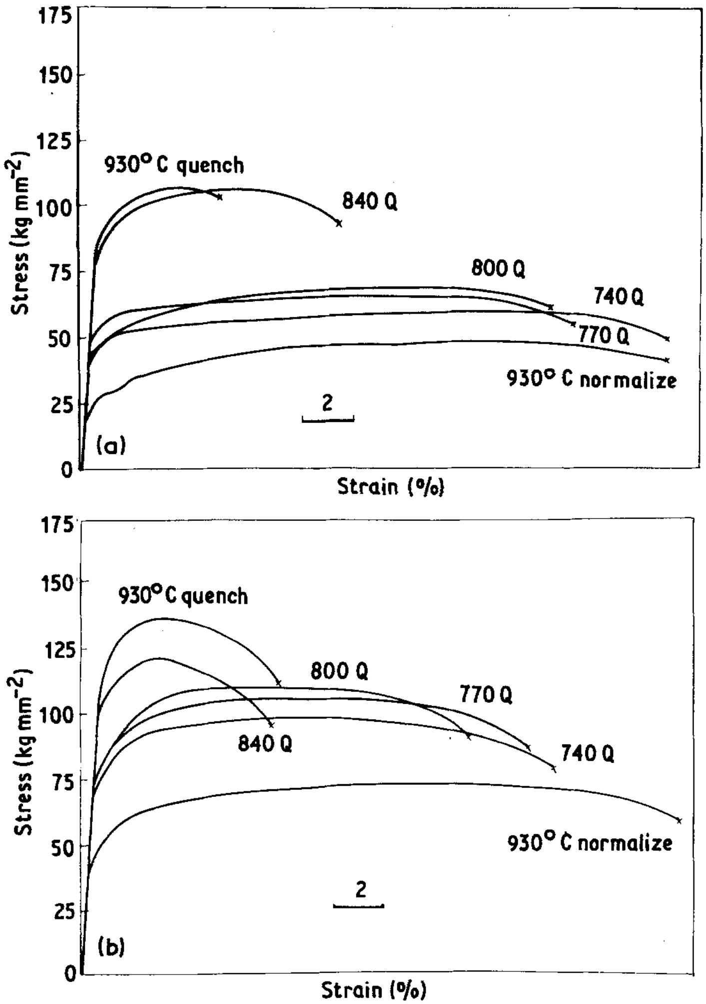

Figure 5 Stress–strain curves of the steels after intercritical quenching from various temperatures and 200° C tempering: (a) steel 15 and (b) steel 15Mn2Nb.

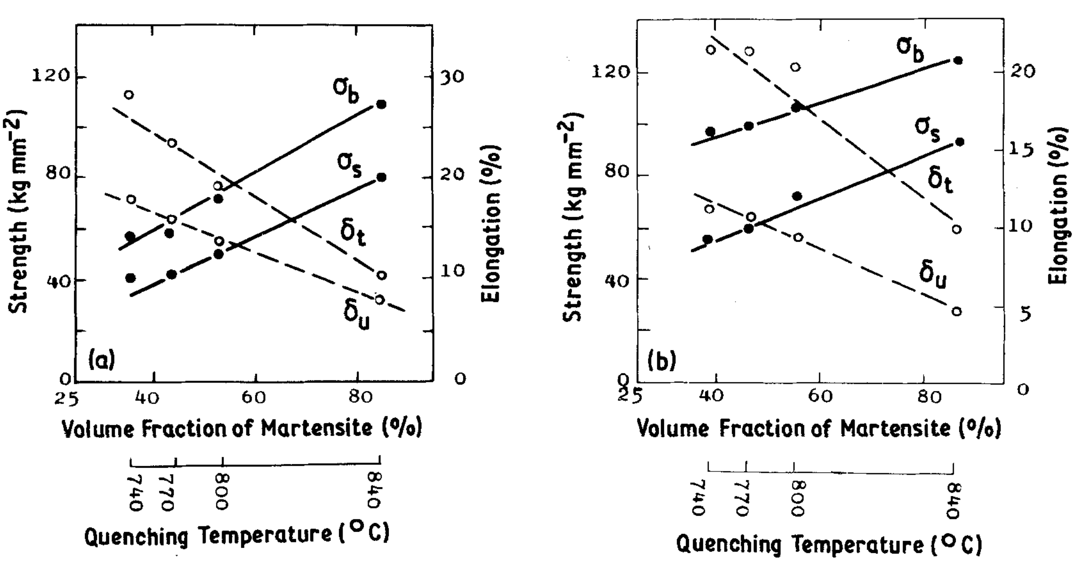

Figure 6 Tensile properties of the steels against volume fraction of martensite and quenching temperature: (a) steel 15 and (b) steel 15Mn2Nb. (σ_b is the ultimate tensile strength; σ_s is the 0.2% proof strength; δ_u is the uniform elongation and δ_t is the total elongation).

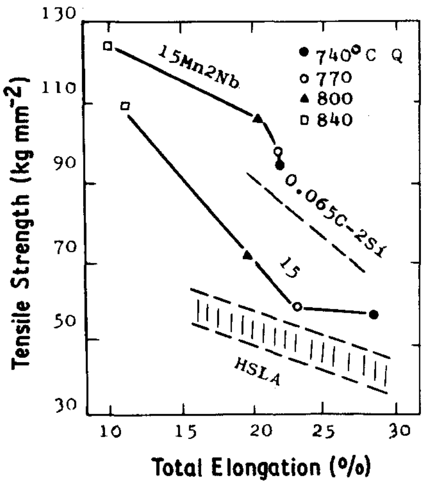

Figure 7 Strength–ductility relationship of steels.

martensite will be compensated for by the increased strength of ferrite and as a result a straight line relationship between the strength of the steel and V_M is achieved.

3.3. On the development of lamellar dual-phase structures as a method of improving the mechanical properties of low carbon steels

The comprehensive diagram showing the combination of strength and ductility of several steels is given in Fig. 7. It is clear that the dual-phase steel 15Mn2Nb has the best mechanical properties in comparison with other steels. For example, after 930° C prequench and 770° C intercritical quenching followed by 200° C tempering, this steel can give the yield strength 60 kg mm^{-2}, ultimate tensile strength 100 kg mm^{-2}, uniform elongation 11% and total elongation 22%. Such a steel can be used directly for the demands of high strength components and can also be utilized as an intermediate state for further processing with an appropriate degree of cold deformation.

4. Summary

It was shown in this paper that the addition of suitable alloying elements as manganese and niobium and the application of intercritical quenching can appreciably improve the mechanical properties of a low carbon steel by developing a special, lamellar dual-phase structure. Although the mechanism of the formation of such microstructures is not fully understood, the retardation of recrystallization processes of ferrite during heating in the intercritical range of temperature will be of primary importance. Therefore, similar studies on other steels and the investigation on the kinetics of austenitization in the intercritical range of temperature should be considered in developing dual-phase steels.

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