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INFLUENCE OF NIOBIUM AS SOLUTE ELEMENT ON HIGH TEMPERATURE MECHANICAL BEHAVIOUR OF LOW CARBON STEEL

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ABSTRACT

The morphological changes during the tempering of low carbon Fe-Nb steel are described and related to the corresponding changes in the high temperature mechanical property. Compositional variation of microalloy caused resultant modification of the mechanical properties of the low carbon steel under investigation. The importance of solid solution, dispersion hardening and particularly grain refinement within the tempering temperature range ($650^0C - 750^0C$) is highlighted. The importance of carbide forming niobium in modifying the tempering behaviour is discussed. At 750^0C tempering and water quench, enhanced matrix hardening occurs irrespective of niobium compositional difference.

KEYWORDS : Low carbon steel, tempering, mechanical properties, precipitation, microstructure.

1. INTRODUCTION

Tempering of steel provides a means of controlling the mechanical properties of steels and hence their use in engineering applications. Its importance can be highlighted when changes in mechanical properties are related to microstructural changes. Nutting (1983) provided adequate review on the tempering of carbon and alloy steels.

In pure iron, the $\delta \rightarrow \alpha$ reaction is extremely rapid but as is well known, the addition of alloying elements both in interstitial and substitutional solid solution retards the rate of transformation. Carbon has a large effect because of its much larger solubility in austenite than in ferrite. Hence during the $\delta \rightarrow \alpha$ transformation, carbon is precipitated as carbide and the rate controlling process in Fe-C alloys will be the diffusion of carbon in austenite (Honeycombe, 1981). Carbon acts principally by solid solution strengthening in non-stabilized steels but mainly by precipitation strengthening when Nb, Ti or V is present (Pickering, 1958). The formation of MX precipitates in austenitic stainless steels occurs when strong carbides/nitrides formers (Ti, Nb, V, Ta) are added to the alloy (Le Bon and de Saint Martin, 1975). MX precipitates usually form on dislocations within the matrix, on stacking-faults, on twin and grain boundaries. Stabilizers such as Nb or Ti have long been known to reduce the stability of carbon in austenite (Sourmail, 2001). In fact, NbC precipitation in low carbon steels provides an effective way to increase the mechanical properties. It should be noted that detailed quantitative characterization of this phase is still scanty. This has informed the present study's investigation of the influence of compositional variation of Nb on the mechanical properties of high purity Fe-Nb alloy.

2. EXPERIMENTAL TECHNIQUES

2.1 Materials

The samples of high purity Fe-Nb alloys were provided by AERE, Harwell, United Kingdom in plate form and cold rolled state with Nb compositions of 0.2 and 0.5wt%.

2.2 Heat Treatment

The samples were solution treated at 1050^0C for 30minutes and subsequently quenched in air, oil and water. They were then tempered at temperature range $600 - 750^0C$ in steps of 50^0C for one hour.

2.3 Hardness Measurement

Monsanto tensiometer with Brinell Indentor attachment was employed in the determination of hardness. The stainless steel indentor has a radius of 5mm. A force of 0.75KN was applied for 30seconds and then removed. This operation was repeated several times in order to obtain statistically balanced data for all the samples. The indentation diameter was determined with the aid of an optical microscope.

2.4 Impact Test

The Charpy V-notch testing machine was employed in carrying out this test. Each of the samples was notched by the machine, making a V-notch of 45^0 at the center of the samples. The V-notched samples were mounted on the impact machine having its pointer touching the notch. The hammer arm was then released from a preset height of about 35cm to fracture the sample. The calibrated gauge on the machine indicates the energy required for fracture.

2.5 Characterization of the alloys

The microstructure of the alloys was examined using optical microscopy and scanning electron microscopy (SEM). The samples for SEM observations were slightly etched with an etchant consisting of 5g $FeCl_3$ + 10ml HCl dissolved in 50ml H_2O.

3. EXPERIMENTAL RESULTS AND DISCUSSION

(Mechanical Behaviour of the Alloys)

Figures 1 and 2 show the plot of the hardness values against the tempering temperature for 0.2Wt%Nb and 0.5Wt%Nb alloys respectively quenched at various media. Generally, the hardness decreases as the tempering temperature decreases - with the hardness values higher in alloy with 0.5Wt%Nb. The fracture toughness is also found to increase as Nb content increases and also decreases as the tempering temperature increases (Figure 3).

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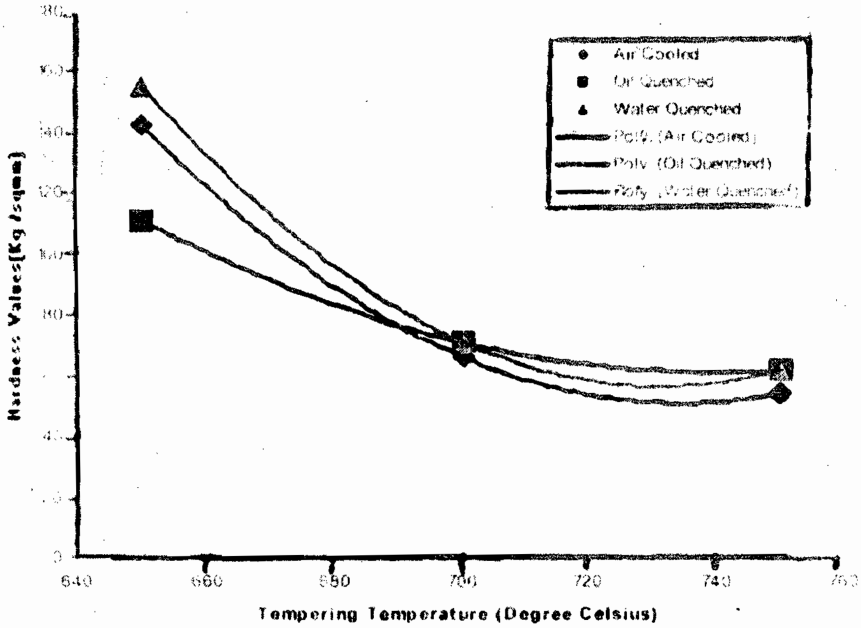


Figure 1: Hardness values against Tempering Temperature for Alloy A (0.2wt%Nb)

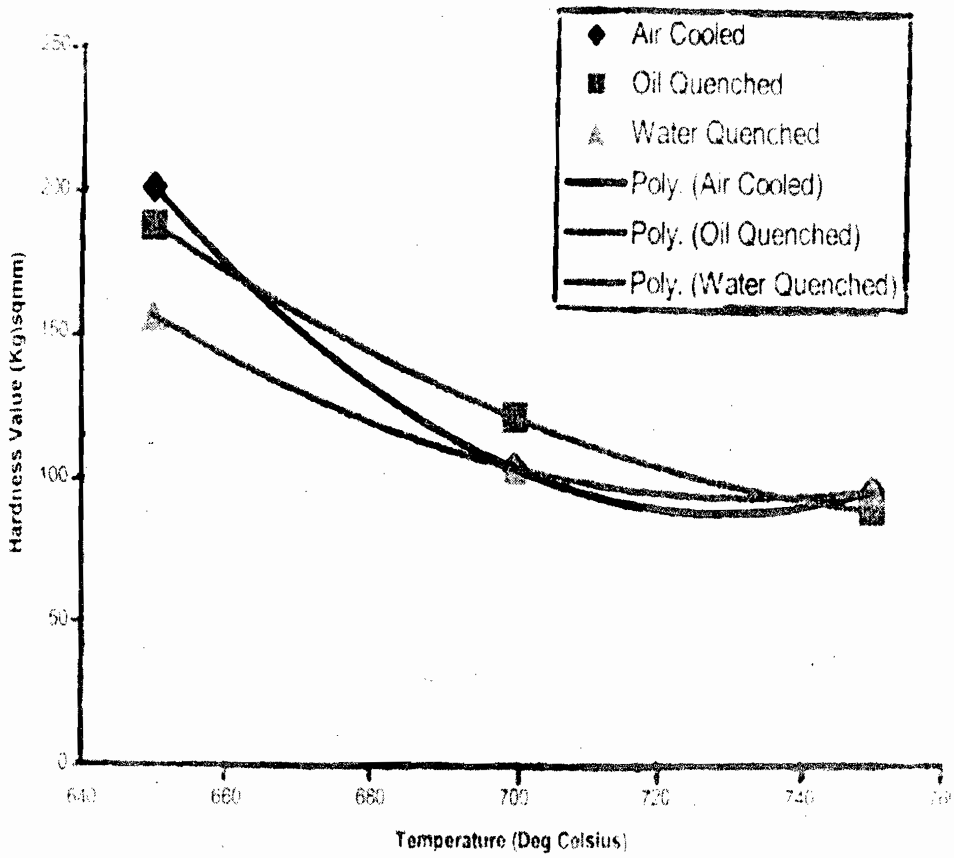


Figure 2: Hardness values against Tempering Temperature for Alloy B(0.5wt%Nb)

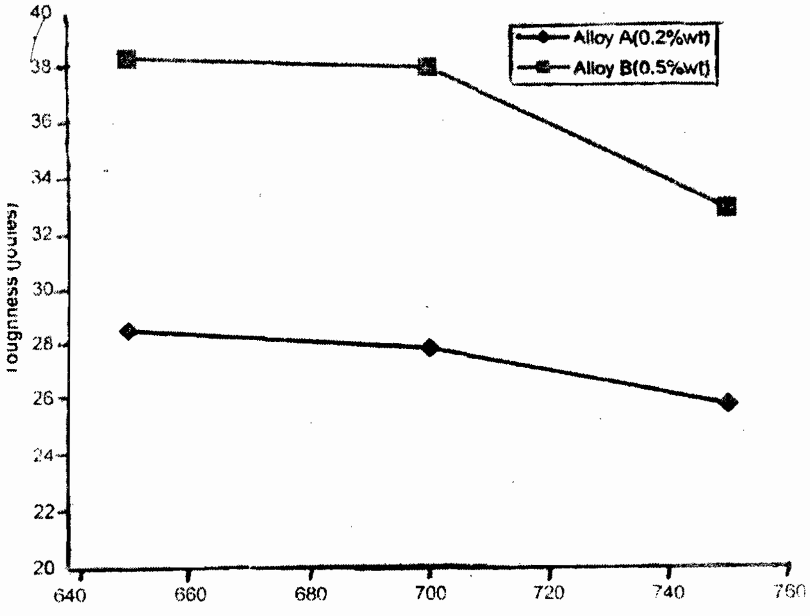


Figure 3: Toughness Against Tempering Temperature

As shown in the SEM of Plate 1, whitish precipitates of NbC could be seen in water quenched samples at 750°C. As reported by Sourmail (2001), dislocations are preferential nucleation sites for this phase. The NbC has a NaCl fcc (face centred cubic) structure with lattice parameter of 4.47Å (Sourmail, 2001). It should also be noted that plates of $M_{23}C_6$ could be seen at grain boundaries and around NbC precipitates (Plate 2).

Plate 1: SEM showing the whitish precipitation of NbC in water quenched sampled at 750°C.

Plate 2: SEM showing plates of $M_{23}C_6$ surrounded by NbC precipitates

This could be explained by the possible nucleation of $M_{23}C_6$ on the Shockley bounding dislocation and growth in the stacking fault presumably helped by an enrichment of the stacking fault in chromium. As reported by Lewis and Hattersley (1965), the precipitation of $M_{23}C_6$ has been the focus of many investigations, motivated by its importance in terms of corrosion resistance. The presence of $M_{23}C_6$ on grain boundaries is often associated with intergranular corrosion (Ramaswamy and West, 1970; Beckitt and Clarck, 1967). Furthermore, a G-phase forms predominantly on grain boundaries in Nb-stabilized steels depending on the silicon content. It has an FCC structure with a lattice parameter of 11.2Å corresponding to a content of 116 atoms per unit (Powell et al, 1984; Kikuchi et al, 1986; Andren et al, 1980). This phase could not be easily observed in our present alloy. Carbides generally provide barriers to dislocation motion in order to enhance hardening. The Ashby – Orowan relationship can be used to assess the influence of carbides on hardness of martensitic steels (Irvine, 1970; Little and Henderson, 1958; Little et al, 1977):

$$\sigma_f = \sigma_o + \left[\frac{k}{s}\right] \log \left[\frac{d}{b}\right]$$

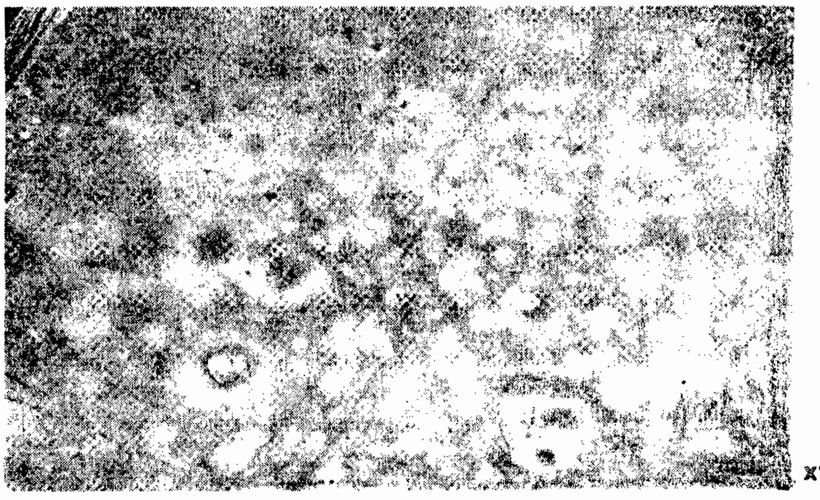
Where

σ_f	=	Fracture stress
σ_o	=	Yield stress
s	=	Interparticle spacing
d	=	Particle diameter
b	=	Burger's rector
k	=	constant

From the above relation, the larger the grains and the smaller the interparticle spacing, the higher the fracture stress. Though carbides provide barriers to dislocation motion to encourage hardening it should be noted that when niobium atoms are added, the niobium carbide particles' hinderance to dislocation cannot arrest the decrease in hardness due to the loss of the interstitial solute hence softening becomes predominant. It is known that the mechanical properties of tempered martensite structures depend upon the carbon content of the steel, the amount of retained austenite and the nature of the alloying elements. The presence of large amounts of retained austenite decreases the hardness of tempered martensite. The martensitic lath structure could easily be observed in samples air cooled at 750^{0}C (Plate 3).

x150

Plate 3: SEM showing the martensitic lath structure in samples quenched in air at 750^{0}c



x150

P... SEM showing the disc shape primary niobium carbides formed during solution treatment

However, the lower the carbon content, the greater is the ductility and toughness. But niobium which is a carbide former reduces the solubility of carbon in the austenite, hence reducing the carbon content of the matrix. It can then be suggested that softening of the matrix can be achieved easily when niobium is one of the alloying elements in low carbon steels. Its addition increases the tempering resistance and the refinement of the prior austenite grain size. Primary niobium carbides formed during solution treatments appear as disc shape in SEM (Plate 4). However, the secondary niobium carbides formed after tempering due to recrystallisation effect are located on the lath, and austenite lath packet boundaries junctions.

4. CONCLUSION

- The mechanical behaviour of low carbon Fe-Nb steels has been examined.
- As niobium contents increased, the fracture toughness was found to increase.
- However, the hardness values decreased as the tempering temperature increased. This is probably due to the inability of the niobium carbide particle to sufficiently arrest the dislocation motion.
- The presence of the metastable phase $M_{23}C_6$ was also reported.
- It has been established that NbC precipitation in low carbon steels provides an effective way to enhance the mechanical properties of these alloys.

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