

The Study of Microstructure and Mechanical Properties of Two High Strength Steels

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Abstract. The microstructure and mechanical properties of two high strength steels with different carbon content were studied by means of metallographic microscope, scanning electron microscope, transmission electron microscope and mechanical testing machine. The results showed that the microstructure of the 0.2C (wt.%) steel and 0.4C (wt.%) steel was tempered sorbite, a large number of granular carbides dispersed on the ferritic matrix. The carbides contained Fe_3C and M_6C ($\text{Fe}_3\text{Mo}_3\text{C}$) phase. Compared with 0.2C steel, the content of the carbides of 0.4C steel was larger, while the particle size was smaller. The tensile and yield strength of 0.4C steel were higher, but the elongation was lower and the toughness was worse. In addition, the hardness values of the two materials were basically the same.

1. Introduction

With the increase of oil and gas exploitation depth, the terrain conditions become increasingly severe, which requires higher strength on the oil casing. Meanwhile, the use of high strength pipeline steel has also gradually highlighted its necessity and importance, due to the increase of oil and gas transmission pressure. High strength steel is playing an increasingly important role in oil and gas exploitation and transportation. From the earliest three carbon steel grades to the successful promotion and application of X65 and X80 and now the successful development of X100 and X120, the research on higher strength grades has never stopped and the development and application of high strength steel have always been one of the key directions in the field of oil and gas development and transportation [1]. This article selects two kinds of self-developed high strength steel as the research object. Through the analysis of scanning electron microscope, transmission electron microscopy and tests of tensile strength and hardness, the characterization of structure and mechanical properties of the two steels under different carbon content was compared.

2. Materials and Experiments

The carbon content of the two materials prepared in this experiment are 0.2% (wt.%) and 0.4% (wt.%) (0.2C steel and 0.4C steel for short). The specific chemical composition is shown as table 1. It was melted in a vacuum induction melting furnace and then cast into ingots. After forging, the ingots were kept in the air furnace at 1150 °C for 2.5 hours for homogenizing treatment. Then, they were hot rolled into 25 mm thick plates and quickly cooled in water. The rolling process was started at 1080 °C and finished at 820 °C. Finally, the samples were tempered at 600 °C for 1 h.



Table 1. The chemical composition of the experimental steels (wt.%)

Samples	C	Si	Mn	Cr	Ni	Ti	Mo
0.2C	0.2	0.2	1	1.2	0.02	0.02	1.2
0.4C	0.4	0.2	1	1.2	0.05	0.05	1.5

The samples were eroded by 4% nital (volume fraction) for 20 - 80 seconds after grinding and polishing. The erosion time of SEM samples is slightly longer than that of metallographic samples. OLYMPUS BX53M metallographic microscope and Quanta 200F scanning electron microscope were used for the observation. The microstructure was also analyzed by JEOL JEM-2100 transmission electron microscopy. The samples were first mechanically polished below 80 microns and punched into 3 mm wafer by Gatan 659. The specimens were then further thinned by Gatan 691. cs with ions reduction at 3° incidence angle and 5 KeV energy.

The tensile testing was conducted with Cortest® machine at room temperature. According to GB/T 228.1-2010 standard, samples were prepared with an intermediate standard distance of 25.4 mm and a diameter of 3.8 mm. In addition, three groups of parallel samples were selected for each material. The tensile fracture was observed by Quanta 200F scanning electron microscope. In addition, the hardness was measured by DHV-1000Z micro Vickers tester. 3*3 points were evenly selected on each sample.

3. Results

3.1. Microstructure

Fig. 1 shows the metallographic diagram of the two steels. Fig. 1(a) shows that the microstructure of 0.2C steel is tempered sorbite, which is a tempered structure of martensite. It is a mixture of ferrite and granular carbide, a composite structure with carbide (including cementite) pellets distributed in the ferrite matrix [2]. Fig. 1(b) shows that the 0.4C steel is also tempered sorbite. No discernible difference of metallographic structure of the two steels was observed.

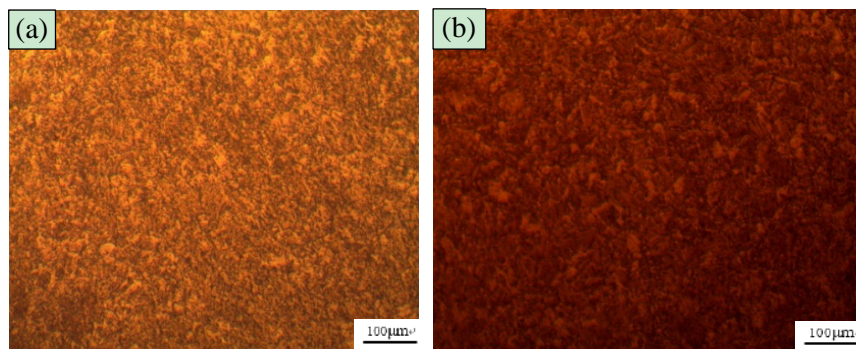
**Figure 1.** Metallographic diagram of the two steels. (a) 0.2C steel, (b) 0.4C steel.

Fig. 2 shows the SEM examination of the two steels. Fig. 2(a) shows that large numbers of carbides are dispersed in 0.2C steel and no grain boundaries can be clearly distinguished. Fig. 2(b) shows details of the carbides in Fig. 2(a) at higher magnifications. It can be seen that the sizes of the granular carbides are below 1 µm. Fig. 2(c) shows the large amounts of fine carbides uniformly distribute in 0.4C steel. The enlarged view shown as Fig. 2(d) reveals the particle sizes of carbides are below 0.5 µm. The comparing of Fig. 2(a) and Fig. 2(c) shows that the carbide content of 0.4C steel is higher than that of 0.2C steel. In addition, the particle sizes of the carbides in 0.4C steel are smaller from the analyzation of Fig. 2(b) and Fig. 2 (d). It can be attributed to the higher content of the alloying elements like Mo and Ti, which could inhibit the growth of carbides and lead to the smaller of precipitates [3]. In addition, the larger amounts of carbides itself can also prevent the growth of carbides.

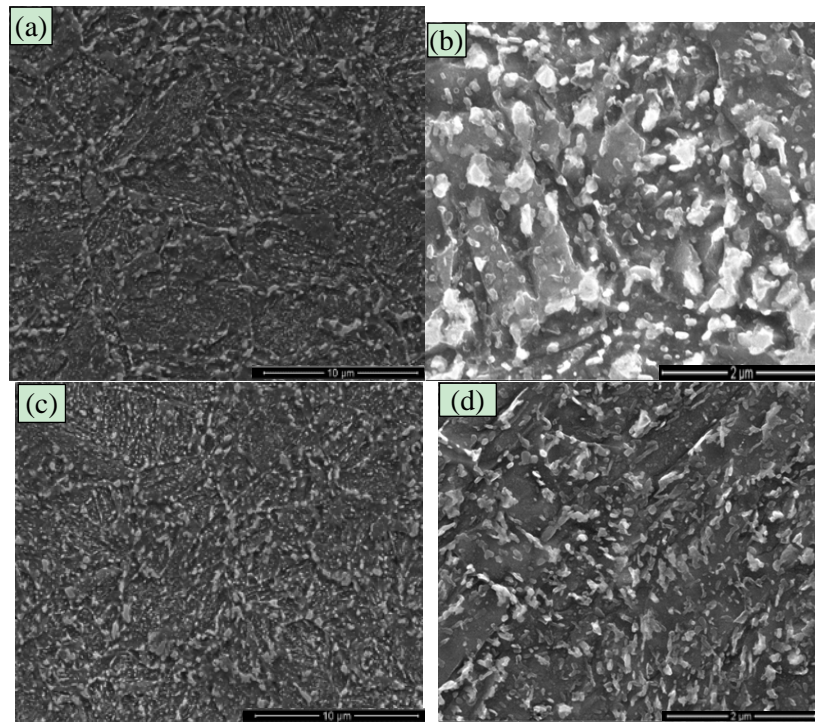


Figure 2. SEM images of the two steels. (a) 0.2C steel, (b) was higher magnification of (a), (c) 0.4C steel, (d) was higher magnification of (c).

Fig. 3 shows the TEM images of the two steels. Fig. 3(a) shows that the average equiaxed grain size of the 0.2C steel was about 0.4 µm. The submicron carbide precipitation is mostly distributed along the grain boundary. Fig. 3(b) shows that the TEM morphological feature of 0.4C steel is similar to 0.2C steel. Fig. 3(c) reveals that intensive granular carbides about 100 nm in size precipitate in 0.4C steel. Fig. 3(d) shows details of carbides marked in Fig. 3(c) at higher magnification. Through the analysis of selected area electron diffraction, the carbides are identified as $\text{Fe}_3\text{Mo}_3\text{C}$ phase, which is an M_6C structure. It indicates that the carbides contain M_6C phase apart from the Fe_3C .

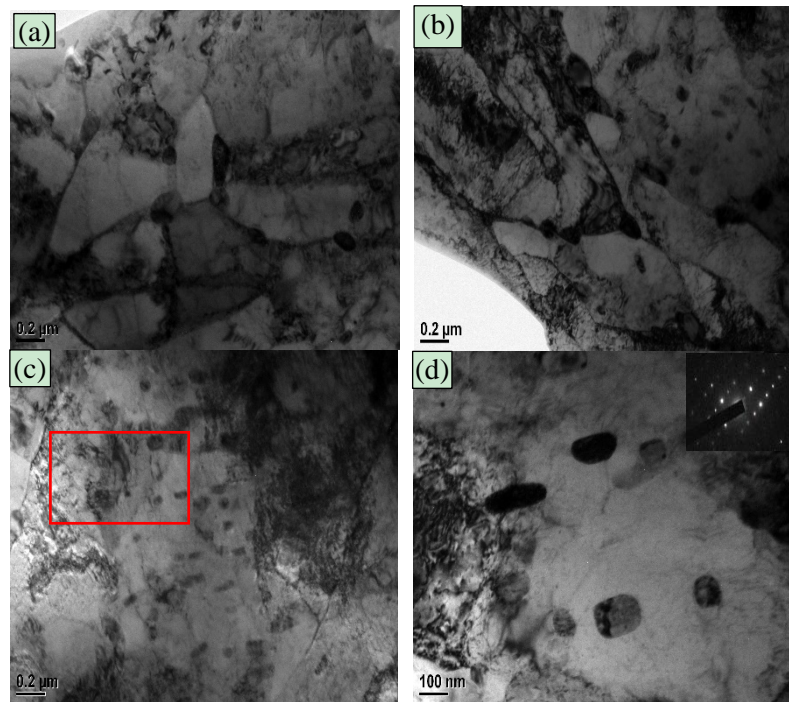


Figure 3. TEM images of the two steels. (a) 0.2C steel, (b) and (c) 0.4C steel, (d) was higher magnification of (c) and the corresponding selected area electron diffraction.

3.2. Tensile Property

Fig. 4 shows the stress-strain curves of the two steels. Fig. 4(a) shows that an obvious yield stage exists in the tensile curve of the three parallel samples of 0.2C steel. Fig. 4(b) shows that no obvious yield platform forms in 0.4C steel. Table 2 shows the tensile properties of the two steels gathering from the curves. The 0.2C steel showed a rupture strength of ~ 800 MPa, yield strength of ~ 740 MPa and an elongation and a shrinkage of ~ 25% and 65%. In comparison, the 0.4C steel showed higher strength, ruptured at ~ 1150 MPa with yield strength of ~ 1060 MPa but a decrease elongation to ~ 18% and shrinkage to ~ 63%. The result shows that the tensile and yield strength of 0.4C steel are higher. While, the elongation and shrinkage are worse. This is because of the strengthening effect of more carbides precipitation in 0.4C steel.

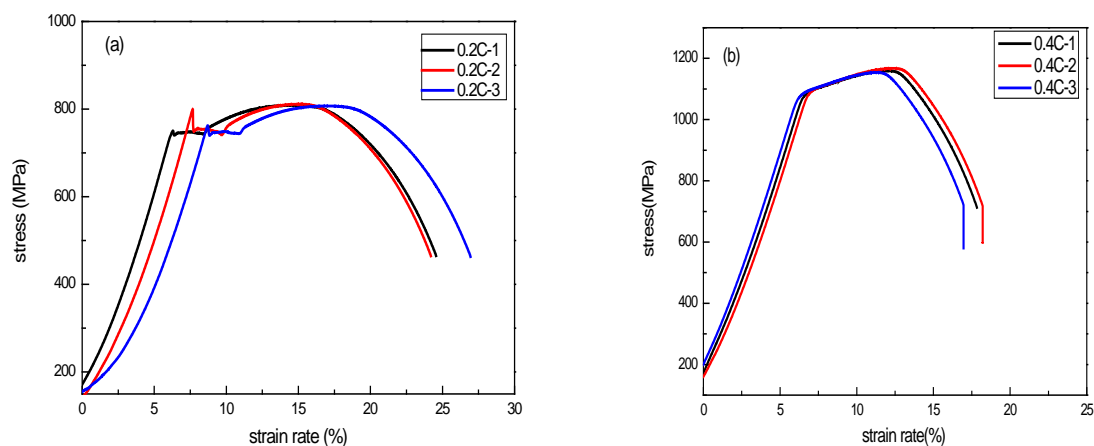


Figure 4. Tensile curves of the two steels. (a) 0.2C steel, (b) 0.4C steel.

Table 2. Tensile properties of the two steels

Average	0.2C	0.4C
Tensile Strength (MPa)	810	1160
Yield Strength (MPa)	749	1069
Elongation (%)	25.2%	18%
Shrinkage (%)	65.5%	63.4%

3.3. Fracture Analysis

Fig. 5 shows the fracture morphology of the two steels. Fig. 5(a) shows that necking occurs in 0.2C steel. It is seen that several cracks extend along the edge to the centre and a 45° shear plane appears. Fig. 5(b) shows that large number of deep dimples exist in the fibre region with no parabolic shear dimples, which indicates the good toughness of 0.2C steel. Fig. 5(c) shows that a deep penetrating crack appears in 0.4C steel and no obvious boundaries differentiate fibre zone and shear zone. Fig. 5(d) shows that the dimples of 0.4C steel are small and shallow and some sections have shown the tendency of approaching quasi-cleavage, which indicates that the toughness of 0.4C steel is low and brittleness is large. It can be concluded that the toughness of 0.4C steel is worse compared with 0.2C steel, which is consistent with the tensile elongation result before.

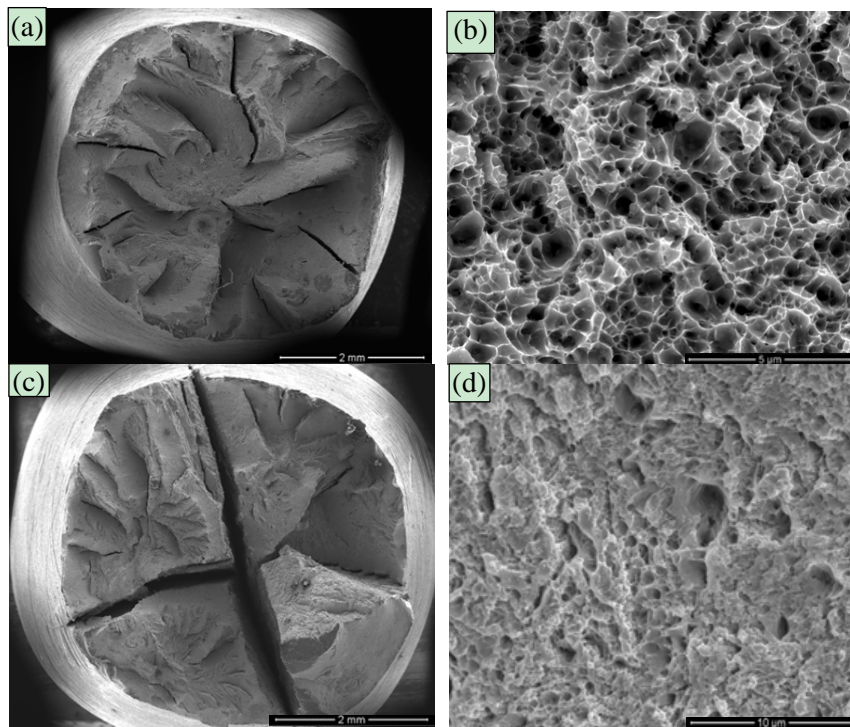

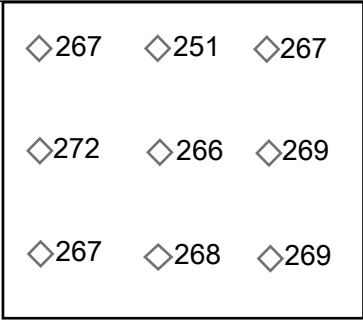


Figure 5. Fracture diagrams of the two steels. (a) 0.2C steel, (b) was higher magnification of (a); (c) 0.4C steel, (d) was higher magnification of (c).

3.4. Hardness

Fig. 6 and Fig. 7 show the Micro Vickers hardness of the two steels. Fig. 6 shows that the hardness values of the 9 points in 0.2C steel at different positions are little difference, which indicates the uniform distribution of the microstructure. The average hardness value was 268. Fig. 7 shows that the hardness values of 0.4C steel range from 251 - 272 with a relatively uniform microstructure. The average value was 266. Different from the tensile properties, the hardness difference between the two steels was little. It verifies that the microstructure of the two steels is similar, which is consistent with the microstructure analysis before.

	
Figure 6. Micro Vickers hardness at different locations of 0.2C steel.	Figure 7. Micro Vickers hardness at different locations of 0.4C steel.

4. Conclusions

(1) The microstructure of the 0.2C and 0.4C steels were all tempered sorbate, which was a composite structure with carbide (including cementite) pellets distributed in the ferrite matrix.

(2) The carbides contain $\text{Fe}_3\text{Mo}_3\text{C}$ phase, which is a M_6C structure. Compared to 0.2C steel, the carbide content of 0.4C steel was larger and the size was smaller.

(3) The tensile and yield strength of 0.4C steel were higher but the toughness was worse. While, the hardness values of the two steels were basically the same.

5. References

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