Development of Micro-alloyed Axle Steel Used on Heavy-haul Train

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INTRODUCTION

Improving the material of axles is not only used to enhance the reliability of the use of heavy haul railway wagon axle, but also effective means to raise railway transportation capacity. This article describes a micro-alloying axle steel which will be used on large axle load railway wagons, designed to provide a reference of material improvements for the world heavy haul railway wagon axles, adapt to future development of heavy haul world trends of improving vehicle axle load, and increasing single vehicle load. The relationship of the interaction of the different ingredients micro-alloying elements of vanadium on the microstructure and properties of the carbon axle steel were investigated in this study. The method of improving strength and toughness of the axle steel was achieved. The shape and position of the V-C and V-N were observed, and the relationship between the precipitates and dislocation were also studied through SEM and TEM. Finally, the micro-alloying axle steel was tried to produce, and the related performance was tested.
Application of the new micro-alloyed steel mentioned above on heavy axle load freight car in the future and improvement of reliability level of the axles made of the steel are expected. The innovation of the study are vanadium micro-alloying based on medium-carbon axle steel and the fine composite performance with strength in well coordination with toughness which meeting the heavy axle load freight car's demands of axle steel. The results will guide the research and development of railway rolling stock medium-carbon axle steel, providing technical theoretical basis for the upgrading of the railway vehicle equipment level [1-3].

EXPERIMENTAL PROCEDURE

Experimental materials

The chemical composition of the sample are shown in Table 1, number 1 is vanadium micro-alloyed axle steel, and number 2 is common axle steel specimen. Both of the heat treatment processes are two normalizing and one tempering. Cutting specimens along the longitudinal of the forging, then processed into standard tensile test and impact test specimens.

Table 1 chemical composition of the specimens

Number	C	Si	Mn	P	S	N	V
1	0.52	0.27	0.77	0.009	0.006	0.0083	≤0.20
2	0.52	0.27	0.76	0.013	0.005	0.0045	/

Note: contents of Cr, Ni and Al are less than 0.30 percent.

Mechanical property test

Based on tensile testing method for metal materials in GB/T 228-2002 and charpy pendulum impact testing method for metallic materials in GB/T 229-2007, we use the WAW-Y500 servo universal testing machine to do tensile test, WSP030 type impact testing machine to do room temperature impact test.

Microstructure observation

Taking the metallographic sample to do grinding and polishing and using nitric whose concentration is 4percent to erode. Then observe the Metallographic organization of the specimen under Neophot21 optical microscope and Philip Quanta 400 scanning electron microscope.

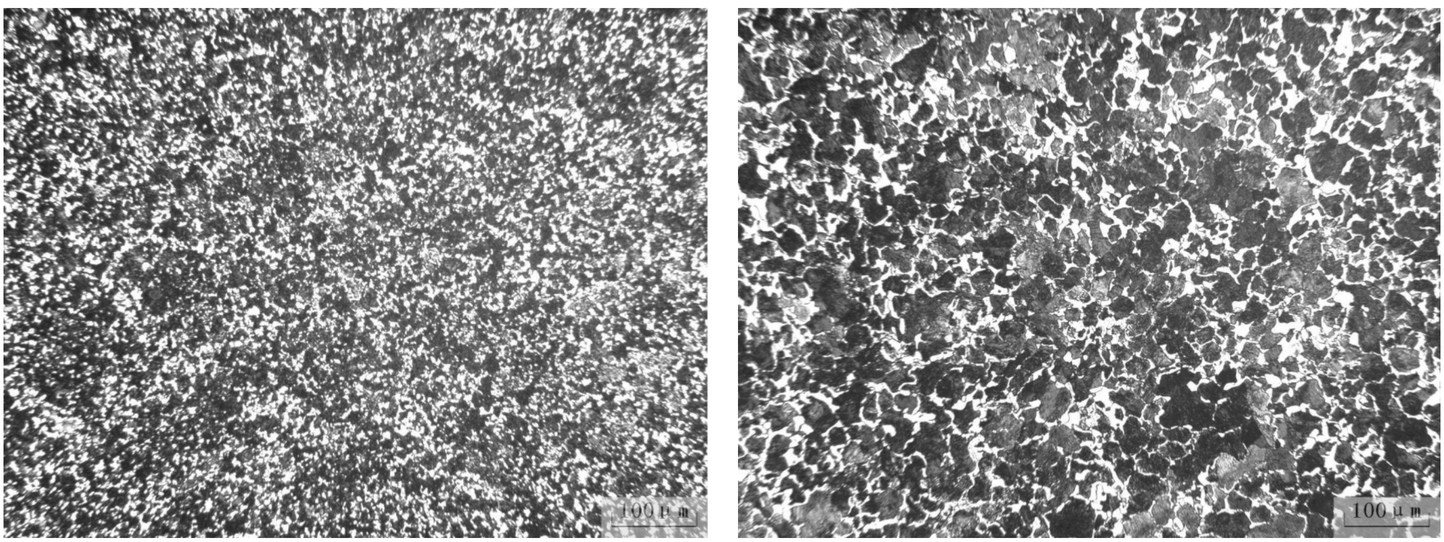
Observation and analysis of precipitates

Taking the slice with thick of 0.5mm and grinding until 30-50 μm. After using the double jet thinning apparatus to reduce the thickness of the grinded slice to perforation, then make it into thin film sample to observe under H-800 transmission electron microscope. Through the low temperature electrolysis and filtering, the precipitation phase can be separated and collected from steel [4-6], then adopting Philip APD-10 X-ray to do diffraction analysis.

RESULTS AND DISCUSSION

Observation and analysis of microstructure

Figure 1 shows the optical microstructure. The organization is composed of ferrite and pearlite. In the figure you can see clearly that grain refinement effect is very obvious. Based on formula of Hall-Petch [7]: $\sigma_s=\sigma_0+k_y d^{-1/2}$. The contribution of grain refinement on the yield strength has a proportional relationship to the grain size $d^{-1/2}$. Namely the finer is the grain, the more significant is the strengthening effect. From the measured mechanical properties, as table 2 shows, compared to ordinal axle steel of No.2, with the addition of micro-alloy element vanadium, the grain size of sample steel No.1 is nearly two times higher. And the yield strength is 20% higher. This shows that fine grain strengthening effect is very significant, also it is the main way of strengthening and toughening.



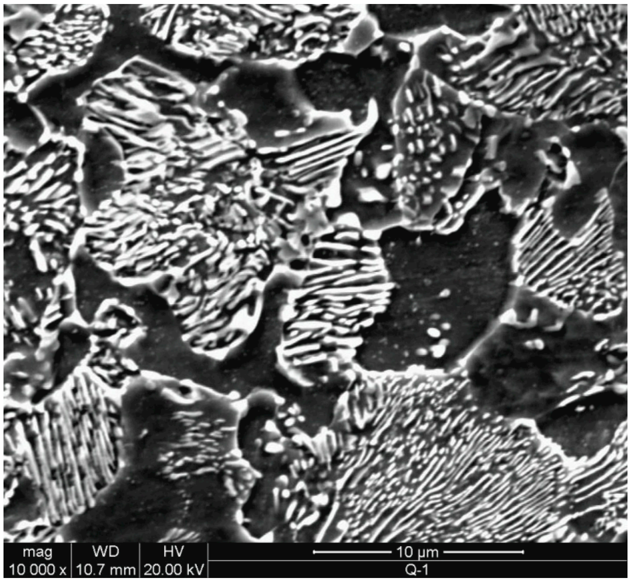
a. The sample of No.1 b. The sample of No.2

Figure 1. optical microstructure

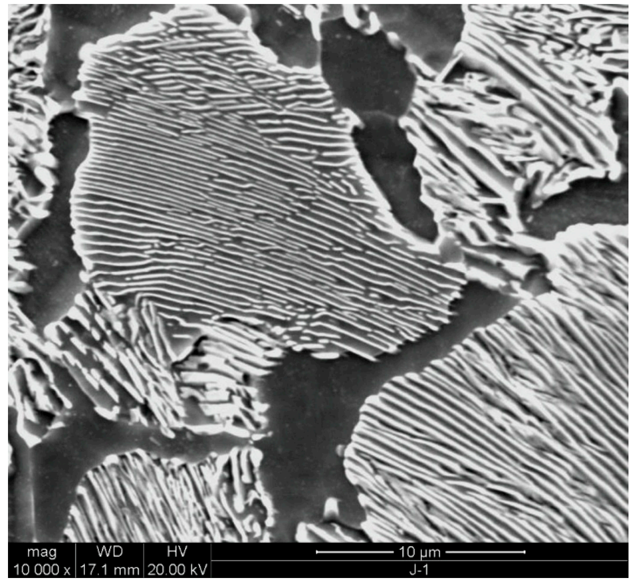
Table 2 Mechanical properties of the specimens

Number	Tensile strength (MPa)	The yield point (MPa)	Section shrinkage (%)	Elongation (%)	Impact value Akv_2/J		Grain size
					The lowest	Average	
1	720	425	52.5	26.5	61	63.0	8.5
2	670	350	48.5	25.0	39	42.8	6.5

Using the scanning electron microscope in further high magnification to observe the microstructure, we discover the cementite in lamellar pearlite of the No.1 sample with addition of micro-alloy V has broken. Meanwhile there has dispersed phase around it. However the cementite in No.2 sample with no addition of V is relatively integrated, as showed in figure 2.



a. No.1 sample

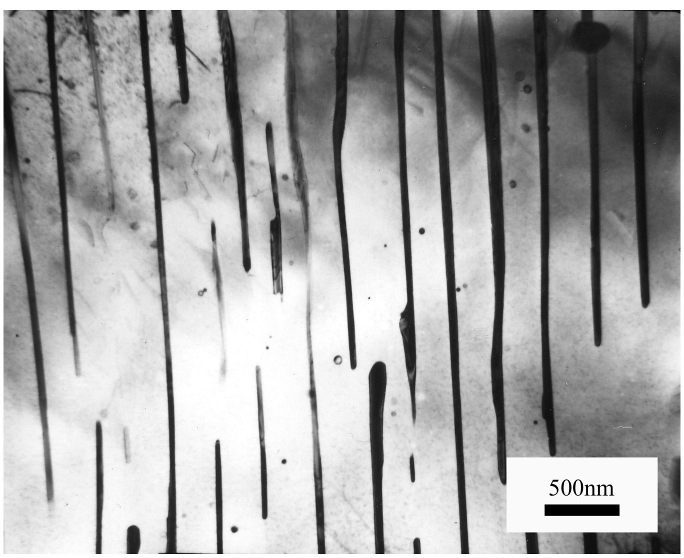


b. No.2 sample

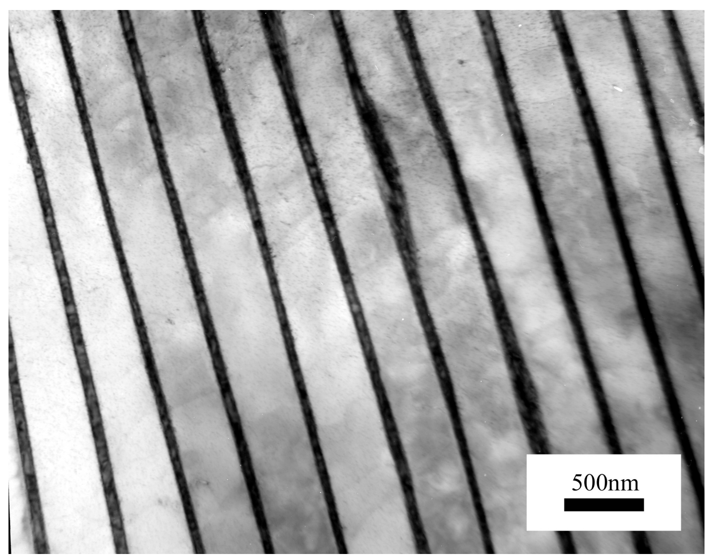
Figure 2.observation under scanning electron microscope 10000×

Observation and analysis of the precipitates

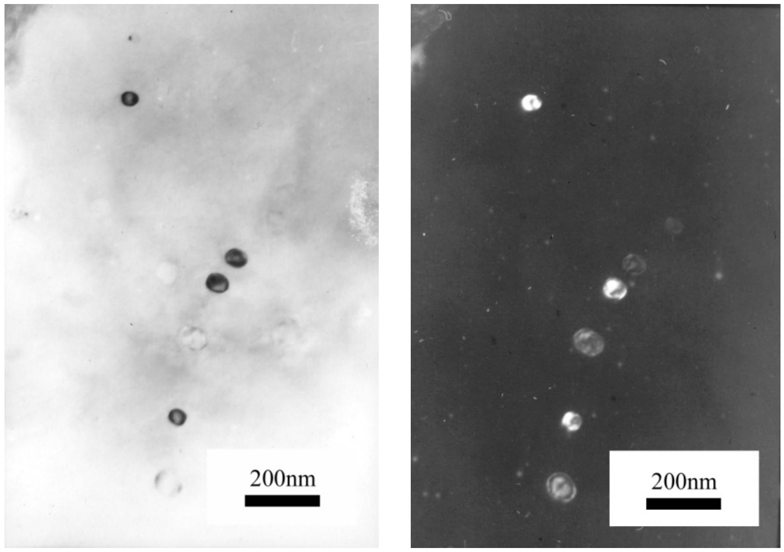
By observing and analyzing the thin crystalline sample of No.1 axle sample with addition of micro-alloy element V, we discover that the ferrites between the cementite lamellaes in the sample which is added element V appear fine and dispersed precipitated secondary particle, as shown in figure 3(a). Meanwhile from the figure, you can also see the cementite in the vanadium micro-alloyed axle steel sample has broken. As the bright and dark field phase of the precipitates shown in figure 3(c), at higher magnification, the precipitates' size is about ten to one hundred nanometer. From the metallographic photos of the sample that with no addition of micro-alloy element, as shown in figure 3(b), we discover it has no precipitate, also the cementite is integrated.



a. the precipitate in ferrite between cementite lamellae of No.1sample 20000×



b. integrated cementite lamellae of No.2 sample 20000×



c. bright and dark field phase of the precipitates of No.1 sample 50000×

Figure 3. observation under transmission electron microscope

Under the condition that heat treatment process is almost the same, the tested steel's microstructure with addition of micro-alloy element is different from that with no addition of micro-alloy element. And reflecting in the performance, as shown in table 2, the match of strengthening effect and toughness are different. The tensile strength of vanadium micro-alloyed axle steel increases 7%, while the value of impact toughness nearly 50% .The main ways for strengthening the vanadium micro-alloyed axle steel include grain refinement and precipitation strengthening. The grain refinement is the main method, because it can not only improve the strength, but also the toughness. Precipitated phase in ferrite of the pearlite take a role as precipitation strengthening. Meanwhile the appearance of the broken cementite lamellae also improves the toughness of the tested steel.

On the condition that: Co target, pipe flow 35mA and pipe pressure 35KV, start-stop angle 20~115°, The scan rate 50 and step 0.02°, we do X-ray diffraction analysis to confirm the precipitate phase. As shown in figure 4.

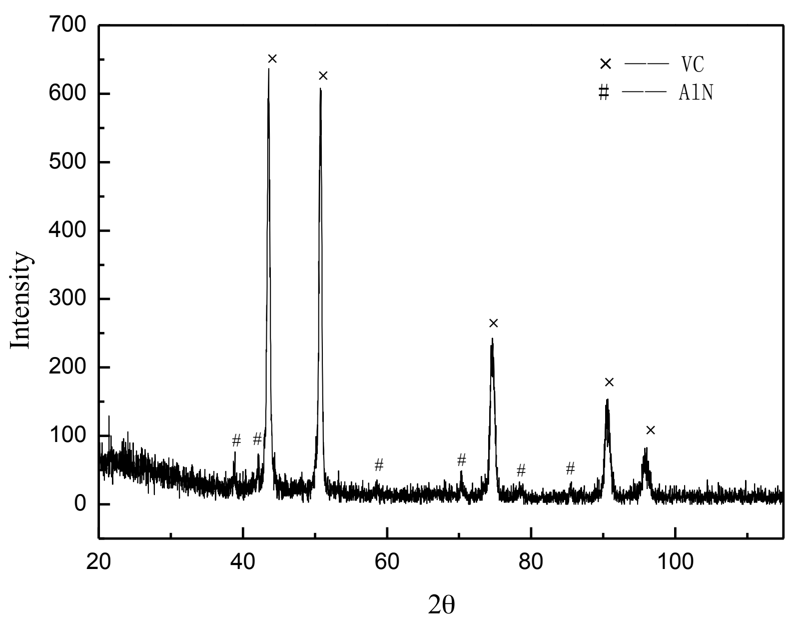


Figure 4. Result of X-ray diffraction test for No.1 sample

Analysis of the phase structure shows that the main precipitates of the vanadium micro-alloyed axle steel are VC and AlN.

Through precipitation from the ferrite, V can increase the strength of the steel. For the normalized steel, carbon nitride formed in the rolling process and after rolling [8]. And during the normalizing process, precipitated phase can prevent the austenite grain's growth at normalizing temperature. The grain size of the ferrite can finally be refined [9]. Grain refining strengthening and precipitation strengthening can be fully played through micro-alloying of vanadium. Then the strength and toughness of the steel can match better.

CONCLUSIONS

(1) Adding appropriate amount of vanadium to the axle steel can refine the grain. The strengthening effect is very obvious, and it is the main method of strengthening and toughening.
(2) Scanning and transmission analysis of samples show that second phase particles, whose size from tens to hundred nm, precipitate on ferrite between cementite lamellae of the vanadium micro-alloyed axle steel. Meanwhile the cementite lamellae break, to a certain extent this also improves the strength and toughness of the steel.
(3) The x-ray diffraction analysis shows that the precipitates of vanadium micro-alloyed axle steel include VN and AlN. The precipitation of micro-alloy element vanadium increases the strength of the steel. And through fining ferrite grain, it gives full play to the function grain refinement strengthening and precipitation strengthening. The strength and toughness can match well.
(4) Through comparative and analysis of the relevant tested properties of micro-alloyed steel, we can expect that if this axle steel material was used in railway freight car with heavy shaft, it will satisfy the steel need for the railway freight car with heavy shaft, and be more beneficial to the safety and reliability of the axle.

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