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Materials

Effects of sulfur addition methods and Ca-Si treatment on the microstructure and properties of 30MnVS

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Abstract: The effects of sulfur addition methods and Ca-Si treatment on the microstructure and properties of free-cutting non-quenched and tempered steel 30MnVS were investigated by using optical microscopy, SEM and tensile test methods. The results show that sulfur addition methods influence the morphology of sulfides and the properties of 30MnVS slightly. Ca-Si treatment is beneficial for the formation of complex sulfides which normally have oxide cores, therefore, improving the distribution of sulfides in the tested steel and enhancing its toughness. The two methods, pyrite addition during LF process and S wire feeding during VD process, slightly influence the morphology and distribution of sulfides and the properties of 30MnVS; Ca addition not only promotes the nucleation of sulfides on the cores of calcium aluminate inclusions, but also creates modification effect on MnS, reducing the relative plasticity and hot deformability of sulfides during hot rolling process, thereby reducing the length/width value of sulfides and improving their distribution, and significantly enhancing its mechanical properties, in particular, the impact toughness increased by 30%.

Key words: free-cutting steel; sulfur addition; modification; sulfide; mechanical properties; microstructure

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1. Introduction

The auto industry has been developed fast in recent years. In 2006, the total sales volume of various vehicles in the auto industry was 7.216 million, while the ratio of our national vehicle sales volume to global total sales volume was up to 11.1% from 8.7% in 2005, which exceeded Japan. The Chinese auto industry is thus listed as No.2 auto industry in the world and becomes the backbone industry, which influences our national economy greatly.

As the performance of modern autos has been improved continuously, requirements for materials used for autos are also improved gradually. The engine crank shaft and connecting rod are the key parts for auto power transfer, and they endure long time impact loading, therefore, materials for them should have good impact toughness. Moreover, the machinability requirement is also very high, since the shape of crank shafts is very complicated and the processing cost is very high. However, the problem of morphology control of sulfides, which is a key factor influencing the impact toughness and machinability of free-cutting non-quenched and tempered steel, has not been resolved. Presently, most of sulfides in free-cutting steels made in China are of strip type, and they greatly influence the mechanical properties and machinability [1-5] of rolled steel products. Modification treatment for sulfides has been done by using elements such as RE, Ca and Ti to reduce the hot deformation of sulfides, and certain effect was achieved [6-14]. However, there are few research reports concerning the morphology control of sulfides in free-cutting steels during industrial production.

This work was to study the effects of sulfur addition methods and Ca-Si treatment on the properties of 30MnVS through readjusting the production process and explore a large-scale production process by re-

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ducing the length/width value of sulfides in free cutting steel.

2. Experimental material and method

The chemical composition of the tested steel 30MnVS is shown in Table 1.

The production process of 30MnVS is: 100-t EAF+LF+VD→R12 m 5-strand continuous casting machine (320 mm×300 mm）→17-stand high rigidity continuous rolling mill. The LF capacity was 100 t, Ar blowing from a single hole in eccentric position, and precipitation deoxidation by Al wire feeding and slag diffusion deoxidation were used. The LF treating time was 50-60 min. Before VD, the slag basicity was reduced and the Ar blowing intensity and flow were controlled. The VD treating time was >10 min. Before VD treating finished, the Ar blowing intensity was reduced. During the CCM process, casting strands between the ladle and tundish, and those between the tundish and mould were protected. The mould EMS parameters were controlled within a reasonable range, and the overheating and casting speed were also controlled.

To make test comparison, 30MnVS was produced using different S addition processes and Ca-Si treatments. The detailed parameters are shown in Table 2.

Table 1. Chemical composition of 30MnVS wt%

C	Si	Mn	S	Cr	Ni	V
0.30-0.33	0.50-0.70	1.40-1.60	0.05-0.09	≤0.20	≤0.17	0.08-0.14

Table 2. Technical parameters of production experiment

Heat No.	LF	VD	Ca-Si wire feeding / m
	Pyrite / kg	S wire feeding / m	
E10702705SX	40	—	60
E10703178XX	—	430	60
E10703179XX	—	450	250

The microstructure was inspected and analyzed by metallographic microscope and SEM. The tensile property test was done on a CMT-4503 electronic omnipotent test machine according to China National Standard GB/T 228-2002 with a tensile speed of 1 mm/min. The impact test was done on a ZBC 2302-1 impact test machine according to China National Standard GB/T 229-1994.

3. Experimental results and analysis

3.1. Chemical composition and microstructures

The chemical composition of 30MnVS made by different processes is shown in Table 3. From Table 3 it can be seen that the S content can be controlled within a standard range by pyrite addition during LF process or by S wire feeding during VD process. Ca modification treatment is a kind of normal method for inclusion modification, and has important influence on the morphology of sulfides. Since Ca is very active, it is very difficult to get high yield by adding alloys. Therefore, to investigate the effect of Ca modification treatment, the Ca-Si addition was increased from 60 to 250 m per heat during production, and the slag composition was also adjusted to reduce Ca loss. From Table 3 it can be seen that different Ca-Si treatments result in a great difference of Ca content. When the 250-m Ca-Si wire is added during VD process, the Ca content reaches 27 ppm, much higher than 5 ppm resulted from the original process, while there is little influence on the contents of other alloying elements.

Table 3. Chemical composition of 30MnVS made by different processes wt%

Heat No.	C	Si	Mn	S	V	Ca
E10702705SX	0.32	0.60	1.56	0.065	0.11	0.0004
E10703178XX	0.31	0.58	1.53	0.063	0.12	0.0005
E10703179XX	0.30	0.60	1.52	0.067	0.13	0.0027

The microstructures for the longitudinal section of free-cutting steel made by different processes are shown in Fig. 1. Compared Fig. 1(a) with (b), it can be seen that there is no obvious difference in sulfide morphology for free cutting steels made by these two kinds of processes, and most of the sulfides are distributed in strip type, which shows that the S addition method has no a great influence on sulfide morphology. From Fig. 1(c), it can be seen that, in comparison with the steel without Ca addition treatment, long strip sulfides in the steel with Ca addition treatment are obviously reduced, the length/width value of sulfides is also reduced, and the distribution of sulfides is very uniform.

Fig. 2 shows the SEM morphology of sulfides in free-cutting steel after Ca addition treatment. From Fig. 2(a) it can be seen that, after Ca addition treatment, the morphology of sulfides in free-cutting steel is intermittent, which should result from long strip sulfide fracture during the rolling process. Fig. 2(b) shows the microstructure of a single sulfide inclusion. It can be seen from Fig. 2(b) that it contains a dark core. Scanning analysis is done along the white line in Fig. 2(b) as a spectrum line, and the results are shown in Fig. 2(c). It can be seen that the dark core in the sulfide is a calcium aluminate complex inclusion. Unlike Al element, Ca not only exists in the core, but also in the external sulfide, which shows that Ca addition treatment can not only promote the nucleation of sulfides on calcium aluminate complex inclusions, but also combine with MnS to form MnS-CaS complex sulfide [15-16]. During hot rolling deformation process, the calcium aluminate core in the centre of the sulfide inhibits the deformation of the sulfide, and the relative plasticity of CaS contained in the sulfide is much smaller than MnS. The increase of CaS content in the sulfide will reduce the hot deformability of sulfide inclusions. As hot-rolling deformation increases, the long strip sulfides are gradually broken into short rod sulfides, and thus reduce their length/width value.

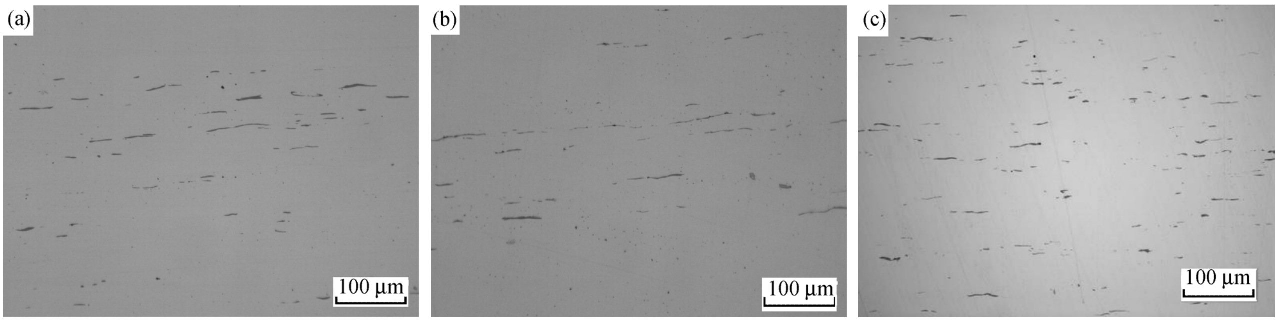
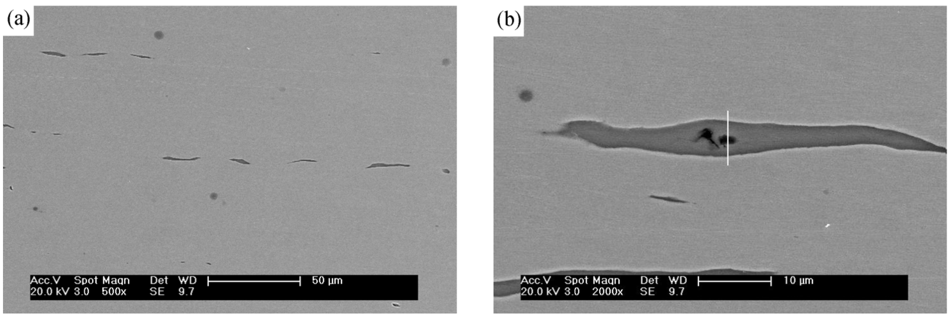


Fig. 1. Morphology and distribution of sulfide in as-rolled 30MnVS: (a) pyrite addition during LF process; (b) S wire feeding during VD process; (c) Ca addition treatment.



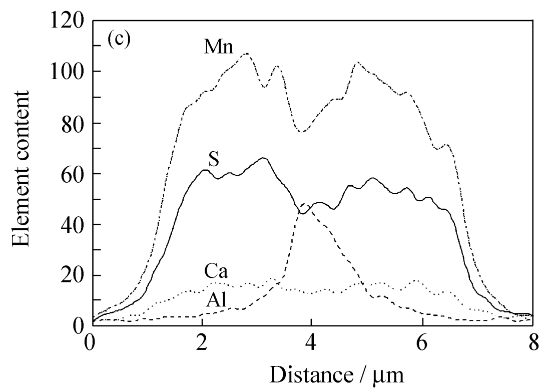


Fig. 2. SEM morphology of sulfides in 30MnVS and spectrum analysis results: (a) Ca addition treatment; (b) spectrum line scanning path; (c) changes of all elements.

3.2. Mechanical properties

Similar to the metallographic structure, the sulfur addition methods slightly influenced the strength, plasticity, impact toughness and other mechanical properties as shown in Table 4. While Ca treatment significantly improves the morphology and distribution of sulfides in free-cutting steel, the mechanical properties have also been significantly improved, especially for the impact toughness, which increases from 61 to 81 J.

Table 4. Mechanical properties of as-rolled 30MnVS steel (ϕ50 mm)

Heat No.	Yield strength / MPa	Tensile strength / MPa	Area reduction / %	Impact toughness / J
E10702705SX	680	952.5	17.5	59.5
E10703178XX	705	970.0	17.0	61.0
E10703179XX	710	977.5	17.5	81.0

4. Conclusions

(1) The two methods, pyrite addition during LF process and S wire feeding during VD process, slightly influence the morphology and distribution of sulfides and the properties of 30MnVS.

(2) Ca addition treatment can significantly improve the morphology and distribution of sulfides in 30MnVS free-cutting steel, and significantly enhance its mechanical properties, in particular, the impact toughness increased by 30%.

(3) Ca addition not only promotes the nucleation of sulfides on the cores of calcium aluminate inclusions, but also creates modification effect on MnS, reducing the relative plasticity and hot deformability of sulfides during hot rolling process, thereby reducing the length/width value of sulfides and improving their distribution.

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