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Study on the Grinding Machinability of 9Mn2V under Different Heat Treatment Processes

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Abstract. The relationship between heat treatment processes and grinding performance of cold die steel 9Mn2V had been built in this paper. Serious meshy segregation of carbide, excessive amounts of retained austenite, coarse and inhomogeneous distribution of material structure were significant causes of grinding burn and grinding crack. In order to improve the abrasion-resistance and mechanical properties of workpiece material, cryogenic and tempering treatment were added. Disappear of meshy segregation of carbide, network carbide was within second grade, retained austenite content was within 4%, martensite became much more fine and homogeneous, all of these advantages could be obtained by adopting cryogenic and tempering treatment in twice. The grinding experiment results indicated that workpiece material 9Mn2V which using this process could provide superior grinding performance.

Introduction

9Mn2V belongs to low alloy cold die steel, it has better comprehensive mechanical properties than carbon tool steel. It has a series of advantages, such as favorable hardenability and little quenching distortion, etc. The hardness would be much more than 62HRC, it also has high wear resistance and preferable toughness, these reasons made it as a good choice to manufacture the thread gauge.

The heat treatment of 9Mn2V usually includes spheroidizing annealing, quenching, tempering, cryogenic treatment and aging [1]. As a kind of hyper-eutectoid steel, isothermal spheroidizing annealing is commonly used as advance heat treatment of 9Mn2V. It could relieve the residual stress of raw material after forging, improve the machinability of 9Mn2V and provide good microscopic structure for next heat treatment. The quenching temperature is usually between 780 to 820℃, this temperature is too low or too high would bring many defects, for example, hardness decreases and quenching distortion. With good toughness and abrasion resistance, low temperature annealing at 150 to 250℃ is always used in industry.

Cryogenic treatment of die steel for achieving improvement in abrasion resistance and dimensional stability has become the topic of current research interest [2-6]. Crygenic treatment would decrease the amount of retained austenite, improve the abrasion resistance of die steel by more homogenized distribution of carbides [2, 3]. Shallow or deep cryogenic treatment would improve the mechanical properties of steel [4], change the state of residual stress [5]. By applying these treatments, smaller and much more uniform martensite laths could be acquired and distributed in the microstructure [6].

The present work deals with investigation of the grinding machinability of 9Mn2V under different heat treatment. The material properties were also studied before grinding experiments, such as microstructure, carbides morphology, amount of residual martensite, hardness, abrasion resistance etc. These trials would help finding out the appropriate heat treatment for this material to avoid grinding burn which happened often during grinding of thread gauge.

Experimental Procedures

Workpiece material. The normal composition (in wt.%) of 9Mn2V detected before heat treatment are shown in Table 1. Mass fraction of Mn is more than 1.7%, the presence of this element would improve the hardenability of steel and strengthen the material matrix. The content of V is little, but the role of it can't be ignored. It could refine the crystalline structure and improve the toughness of steel.
Experimental set-up and measurements. The experiments included heat treatment experiments, abrasion tests and plunge surface grinding tests. Heat treatment experiments were carried out on cubic samples with the width of 30mm. Table 2 shows the different heat treatment sequences tested on the samples. All of the samples used in the experiments were treated as spheroidizing annealing before quenching. Surface grinding tests were carried out on KGS1020 precision grinding machine with a vitrified bonded aluminum oxide grinding wheel (3SG80KV) which is produced by Sol-gel technique. Blocks of workpieces measured 30mm(length)×6mm(width)×30mm(height) were supplied for trials. Fixed grinding speed v_s=27 m/s and feed rate v_w=15 m/min with varying grinding depth were used. The grinding depths a_p were 0.005, 0.01, 0.02mm, grinding width b was as same as the width of workpiece. The experiments included single time grinding and reciprocating grinding. Cycle times in reciprocating were 40 and 80. In experiments no coolant was employed for the convenience of measuring grinding temperature using thermal infrared imager, but the measurement hadn't been discussed in this paper. Intermittent dressing was conducted using a single point diamond dresser before every test. The feed rate of dresser and depth of dress were 0.2 mm/rev, 0.01 mm respectively.

Table 1 Chemical composition of heat treatment specimen material 9Mn2V (wt.%)

C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V
0.884	0.192	1.724	0.012	0.004	0.093	0.093	0.069	0.039	0.128

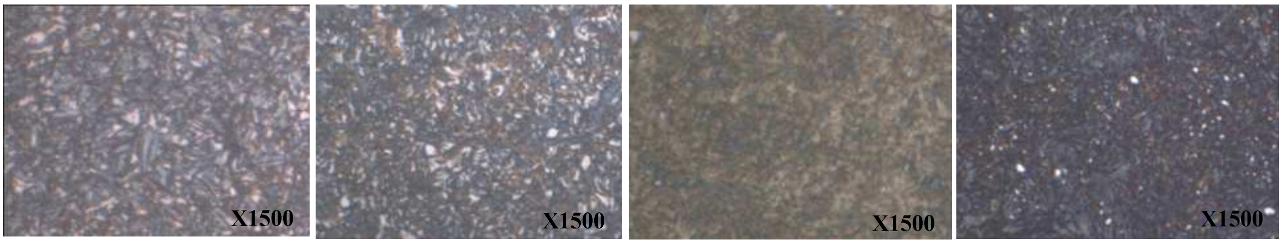
Table 2 Chemical composition of heat treatment specimen material 9Mn2V (wt.%)

Sample	Heat treatment sequences				
1	Quenched at 820℃ for 45 min followed by oil cooling	-	-	-	-
2	Quenched at 820℃ for 45 min followed by oil cooling	Tempered at 175℃ for 2h	-	-	-
3	Quenched at 820℃ for 45 min followed by oil cooling	cryogenic treatment at -70℃ for 7h	Tempered at 175℃ for 2h	-	-
4	Quenched at 820℃ for 45 min followed by oil cooling	cryogenic treatment at -70℃ for 7h	Tempered at 175℃ for 2h	cryogenic treatment at -70℃ for 7h	Tempered at 175℃ for 2h

Grinding forces were measured online in single time grinding with a Kistler9272 piezoelectric dynamometer and Kistler5070 multi-channel charge amplifier. The metallurgical structure and carbide morphology of heat treated samples were analyzed by Olympus BX60M metalloscope. Content of retained austenite was detected by X-350AC X-ray stress analyzer. Ground surface residual stress was measured by Proto LXRD measurement system.

Results and Discussion

Metallurgical structure of heat treated samples. Fig. 1 shows the metallurgical structure of heat treated samples. The microstructure of Sample 1 and 2 is the compound of coarse and acicular martensite, partial residual austenite and carbides. But Sample 3 and 4 has the compound microstructure of slender needle-shaped martensite, small quantity of residual austenite and granular carbides. Comparison of the microstructure from sample 1 to 4, it indicates cryogenic treatment had certain influence on the metallurgical structure, such as grain size of acicular martensite and carbides, content of residual austenite. Cryogenic treatment could make martensite distribute uniformly and get the carbides much more refined, because it promoted the transformation of austenite to martensite and decreased the content of residual austenite [6]. The microstructure obtained by cryogenic treatment has certain impetus to the mechanical properties and dimensional stability of 9Mn2V.



(1) (2) (3) (4)

Fig. 1 Metallurgical structure of samples 1-4 after different heat treatment

From Fig. 1 (1) and (2), it shows that there is a certain amount of granular carbides dispersed in coarse martensite. These carbides have two noticeable features: firstly, the particle sizes of these carbides are bigger than 5μm generally; secondly, in the form of clusters of these particles indicate primary carbides are obtained after conventionally quenched and tempered heat treatment (CQT). In the matrix of martensite, the number of primary carbides have decreased greatly in sample 3 which using shallow cryogenic treatment (-70℃) and tempered treatment (SCT) in one time. At the same time, some tiny and spotted carbide appear as shown in Fig. 1 (3). The particle sizes of these carbides are less than 5μm generally, it shows these secondary carbides had been precipitated out during cryogenic treatment. The number of secondary carbides increased and their distribution was more homogeneously as shown in Fig. 1 (4), these was obtained after cryogenic treatment and tempered treatment in two times.

Content of retained austenite and hardness. The content of retained austenite in sample 1 and 2 are more than 22% as shown in table 3. A great quantity of existence of retained austenite would decrease the abrasion resistance of material [2, 3]. Retained austenite is also instability under low temperature, it would change to brittle martensite easily and cause deformation of workpiece [5, 6]. But the content could decrease to 8% by SCT in one time, also the content would decrease to 4% when using SCT in two times. The detection results indicate the effection of deep cryogenic treatment (DCT) on decreasing the content of retained austenite could obtained by using SCT in two or more times.

Table 3 Content of retained austenite in different samples

1	2	3	4
27%	22%	8%	4%

The macrohardness of different samples is shown in Table 4, it was tested for three times per every sample and the average value was calculated. The content of retained austenite in sample 1 is more than 27%, this makes sample 1 has a low macrohardness value. The change of retained austenite to martensite and precipitation out of secondary carbides would increase the hardness. Sample 4 had been through two times of cryogenic treatment, the lower content of retained austenite and much more numbers of secondary carbides make it has larger macrohardness than sample 3 which just had been cryogenic treated for only once.

Table 4 Macrohardness of different samples (HRC)

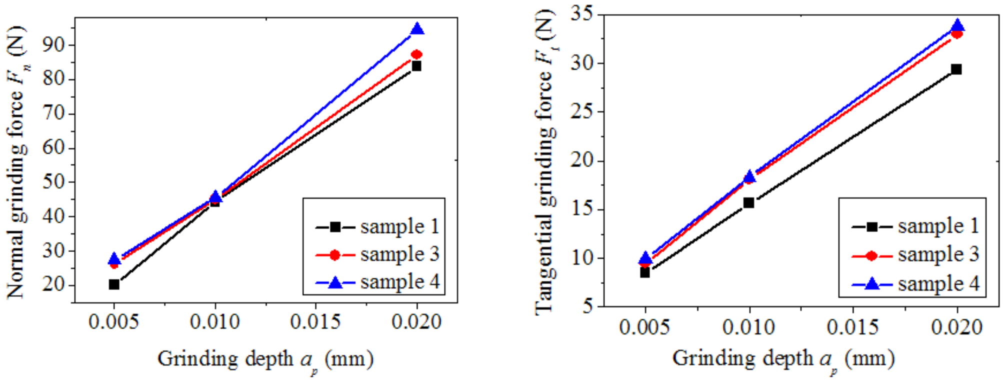
1				2			
test1	test 2	test 3	Ave.	test1	test 2	test 3	Ave.
61.5	61	61.5	61.3	60	60.5	60	60.2
3				4			
test1	test 2	test 3	Ave.	test1	test 2	test 3	Ave.
62	61.5	61.5	61.7	62.5	63	62.5	62.7

Analysis of abrasion resistance. Abrasion resistance of samples was investigated by means of pin-on-disc sliding wear tests. The tests were performed on MM-200 abrasion tester with constant load of 50N under dry conditions. The sliding velocity was 0.41m/s and sliding time was 30 minutes. Wear mass loss of abrasion tests are presented in Table 5 for the four types of samples. It is evident from Table 5 that wear mass loss of SCT samples is significantly lower than conventionally quenched or CQT samples. It means the cryogenic treatment could improve the abrasion resistance of 9Mn2V efficiently. Transformation of retained austenite to martensite, precipitation out of secondary carbides, all of these factors could make positive contributions to abrasion resistance of material [4]. It is also very interesting to note that wear mass loss of sample 4 which had been cryogenic treated for two times is less than sample 3. It indicates the abrasion resistance of 9Mn2V could be further strengthening by increasing the times of cryogenic treatment.

Table 5 Wear mass loss of different samples (g)

1				2			
test1	test 2	test 3	Ave.	test1	test 2	test 3	Ave.
0.0052	0.008	0.0059	0.0064	0.0045	0.0042	0.0054	0.0047
3				4			
test1	test 2	test 3	Ave.	test1	test 2	test 3	Ave.
0.0035	0.0039	0.0038	0.0037	0.0027	0.0029	0.0025	0.0027

Grinding forces. As depicted in Fig. 2, with increasing grinding depth both the normal and tangential grinding forces increase. It is as expected increasing in grinding depth would increase the value of maximum undeformed chip thickness h_{max} and actual area of contact, leading to increased sliding forces [7].



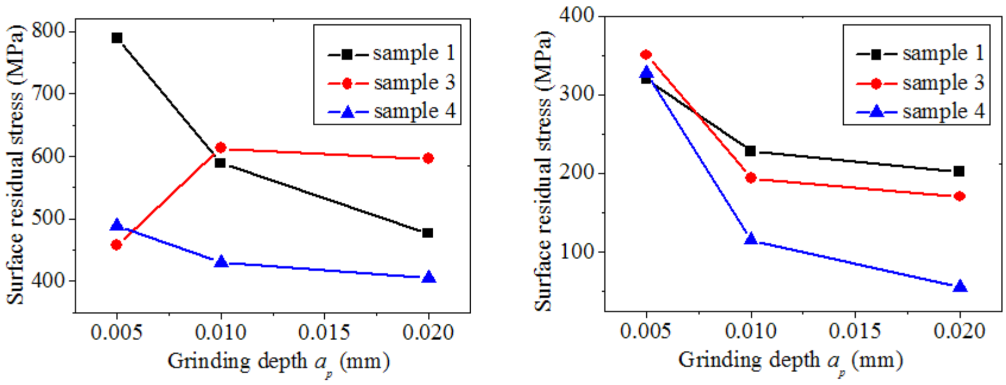
(a) (b)

Fig. 2 Normal and tangential grinding force vs. grinding depth a_p

When compare the normal, tangential forces of samples 3 and 4 with sample 1, values of normal and tangential forces are higher than the sample which had not been cryogenic treated. A number of key factors contribute to these results including: slender needle-shaped martensite which is obtained by quench, cryogenic and temper treatment has high hardness, and it also has better abrasion resistance. Under these conditions, the high hardness plays the major role in the deformation of material and it leads to higher tangential force.

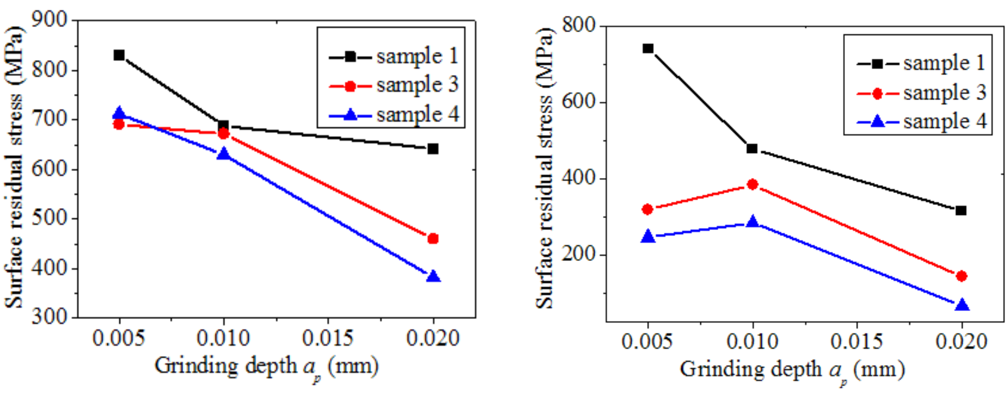
The transformation and quenching stresses are so high after quench treatment, it always follows by cryogenic and tempered treatment. This could eliminate or reduce the quenching stress, improve the toughness of material to avoid brittleness on one side, it also could keep the material in the state of high hardness, strength and excellent abrasion resistance. After tempering in 175℃, surface hardness of 9Mn2V would decrease about 1.0～4.0HRC, impact toughness increases to the maximum value of 48J/cm^2 and this value is only 5.0 J/cm^2 after quenching [1]. It indicates the plasticity of 9Mn2V has been enhanced greatly after tempering. Material removal mechanism is mostly by chip formation when grinding depth is great, plastic removal of workpiece material plays the major role. Enhancement of plasticity and impact toughness of 9Mn2V would strengthen the capacity of resisting deformation, the more grinding forces are needed in material removal [8].

Surface residual stress. Fig. 3 and Fig. 4 show the X-ray measurement results of ground surface residual stress after grinding in different reciprocating cycles. Stress parallel or perpendicular to feeding direction is in a state of tension and the value of stress is much higher in parallel direciton. The cause of residual stress in grinding has three mainly aspects: plastic deformation, thermal cycling of surface layer and microstructure transformation [9]. Thermal cycling of surface layer plays the major role, it has greater effect because of high temperature generated when grinds these alloys, tensile residual stress increases with increasing in grinding temperature.



(a) parellel to feeding direction (b) perpendicular to feeding direction

Fig. 3 Surface residual stress after 40 reciprocating grinding cycles



(a) parellel to feeding direction (b) perpendicular to feeding direction

Fig. 4 Surface residual stress after 80 reciprocating grinding cycles

The value of surface residual stresses are much lower in sample 3 and 4 which had been cryogenic and tempered treated, what is more sample 4 has the lowest value. Microstructure refinement and uniform distribution of tempered martensite in the matrix of sample 4 which had been cryogenic and tempering treated in two times, improvement of carbide segregation would enhance grinding heat conduction, reduced content of residual austenite improves the stability of material microstructure to avoid the transformation of residual austenite under high grinding temperature, all of these favorable factors improve the grinding machinability of 9Mn2V.

Conclusions

Investigation on grinding machinability of 9Mn2V under different heat treatment processes has been performed in this paper. The following conclusions are based on the experiment results:

1. Cryogenic treatment had positive influence on the metallurgical structure, such as grain size of acicular martensite and carbides, content of residual austenite, macrohardness of material and abrasion resistance.
2. Enhancement of plasticity and impact toughness of 9Mn2V which had been treated by cryogenic and tempering would strengthen the capacity of resisting deformation, the more grinding forces were needed in material removal, but it also would give lower surface grinding stresses.
3. Cryogenic and tempering treatment could improve the grinding machinability of 9Mn2V greatly, grindability would be further enhanced if the material could be cryogenic and tempering treated in twice.

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