High Manganese Steel Alloying Process and Its Influence on Microstructure and Properties of the Steel

Zhongliang SHI† *and Mingyuan GU*
State Key Laboratory of Metal Matrix Composite Materials, Shanghai Jiaotong University, Shanghai, 200030, China
Junyou LIU
Dept. of Materials Science & Engineering, Hebei Institute of Mechanical-Electrical, Shijiazhuang, 050054, China
Yansheng YIN
Dept. of Materials Science & Engineering, Dalian University of Technology, Dalian, 116023, China

[Manuscript received December 7, 1993, in revised form May 11, 1994]

The influence of two kinds of alloying processes, adding Nb (or Ti) and N-Mn alloy as well as adding Nb (or Ti) and spraying N_2, on microstructures and properties of a high manganese steel has been studied. It has been found that adding Nb(or Ti), accompanying with N-Mn alloy, is unfavourable to microstructure compactness of the high manganese steel, but adding Nb (or Ti) and spraying N_2 into the melt is good for refining austenitic grain, forming a lot of hard particles and improving microstructure compactness. The mechanical properties of the high manganese steel have relation to the content of elements Nb or Ti. Its fracture mode will turn ductile fracture into brittle cleavage fracture gradually. By X-ray and TEM analysis, it is proved that the austenite can be transformed to deformation-induced α martensite after adding a certain amount of element Nb (or Ti). The microstructure transformation of alloying high manganese steels through deformation is one of methods for strengthening austenite matrix and increasing the work-hardening rate as well as improving antiwear property.

1. Introduction

It is well known that austenitic manganese steels exhibit a marked wear resistance to impact and gouging abrasion. According to a great number of failure analysis on high manganese steel jaw plates the reasons of failure are mainly elastic-plastic deformation heap because the castings are subjected to impact and compression on the occasion of wear, the heap layers are worn because of fatigue and plough. Only is strength of the material raised, the ability of antiwear performance can be improved. One of methods is alloying for high manganese steels. These elements such as Cr, Mo, Ti, V, N were added[1-6]. The dispersed hard particles can be formed and the size of austenite crystal grain gets fine, thus the strength-toughness of high manganese steels can be improved. Little reports have been published on the study of nitrogen alloying process. In the paper, the influence of two kinds of alloying processes, adding Nb (to Ti) and N-Mn alloy and adding Nb (or Ti) and spraying N_2, on microstructure and properties of a high manganese steel has been studied. Its surface layer microstructure transformation after deformation (rolling, compression and impact wear abrasion) has been further investigated by X-ray and transmission electron microscopy (TEM). These studies intend to serve for production and application.

2. Experimental Procedures

The chemical compositions of alloying high manganese steels including different nitrogen treatments are given in Table 1. The No.1 was adding N-Mn alloy into high manganese steel melt, the No.2-8 were spraying N_2, the last was an ordinary high manganese steel.

The raw materials (Mn-Fe, scrap steel, pig iron *etc.*) were melted in 10 kg basic intermediate frequency induction furnace. The melt was heated to 1500°, one process was adding Nb-Fe (or Ti-Fe) and N-Mn alloys into the melt, then deoxygenized with pure aluminum, the another process was adding Nb-Fe (or Ti-Fe) and spraying N_2 into the melt. The N_2

† To whom correspondence should be addressed

Table 1 Chemical compositions of samples (wt-%)

No.	C	Mn	S	N	Si	Nb	Ti	Notes
1	1.060	11.640	0.019	0.052	0.430	-	-	adding N-Mn
2	1.080	11.200	0.015	0.057	0.410	-	-	spraying N_2
3	1.050	11.300	0.014	*	0.430	0.140	-	spraying N_2
4	1.040	11.390	0.014	0.048	0.420	0.240	-	spraying N_2
5	1.140	11.150	0.014	0.051	0.420	0.420	-	spraying N_2
6	1.100	11.210	0.015	0.054	0.420	0.640	-	spraying N_2
7	1.050	11.310	0.014	0.065	0.420	-	0.160	spraying N_2
8	1.150	11.310	0.011	*	0.410	-	0.300	spraying N_2
9	1.050	11.780	0.019	0.029	*	-	-	no alloying treatment

Notes: * shows no chemical analysis

was 99.999% of purity and still twice dehydration with silicagel treatment shown in Fig.1. The as-cast blocks were liquid-quenched after solid solution treatment at 1050°C for 1—2 h, then machined to standard U-type notched impact specimens and standard tensile specimens, impact specimen fractures were observed with scanning electron microscopy (SEM).

In order to research surface layer microstructure changes after deformation, following test methods were used:

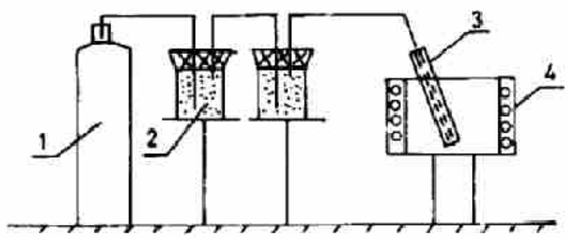

Fig.1 Schematic of melting process. 1-N_2 gas pot, 2 - silicagel, 3-spray gun, 4-furnace

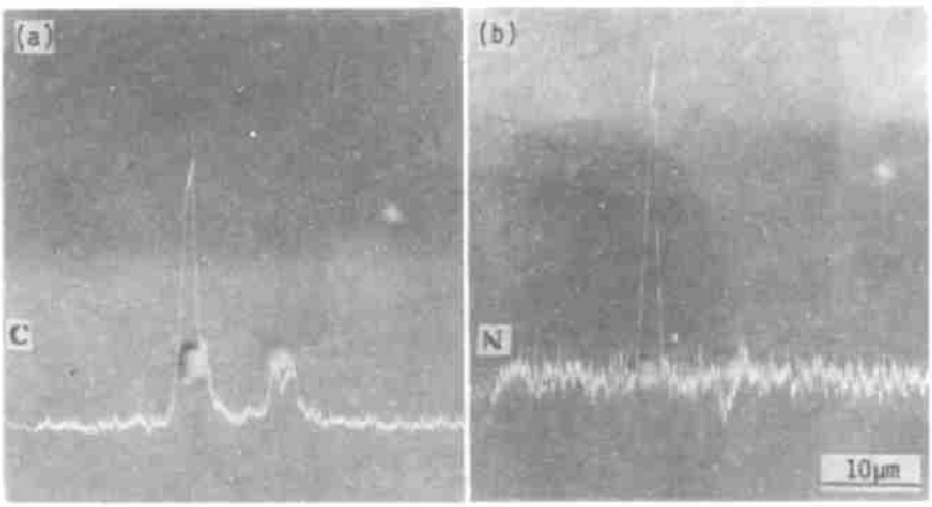

Fig.2 Electron probe analysis on hard particles of sample 7 (not etched)

(1) Impact wear abrasion test: the test was conducted on the type MLD-10 wear test machine. The size of samples was 10×10×30 mm^3, the test parameters were: impact work, 2.0—2.2 J; the dry abrasion time, 30 min; abraser, silica sand; flow rate, 4—5 kg/min; granulation, the size of 4—6 mm, sharp, globular and multiangular mixed. The relative abrasion rate was determined.

(2) Rolling: the general deformation was 40%, the number of rolling was 6—8 times.

(3) Compression: the compression test was done on 0.6 MN universal testing machine, the value of deformation was about 33—40% with load of 0.3 MN.

The surface layer microstructure of samples after deformation was analyzed by X-ray and TEM.

3. Experimental Results

Compared as-cast sample 1 with as-cast samples 2–8, there are a lot of gas contraction cavities in the gate of sample 1, but in the rest samples there are no cavities.

It is found that golden yellow hard particles have been formed when surveying non-etched microstructure of sample 7 after liquid-quenching by SEM. The hard particles have distributed in austenite matrix. They are Ti(CN) and TiC according to electron probe analysis, as shown in Fig.2(a), (b).

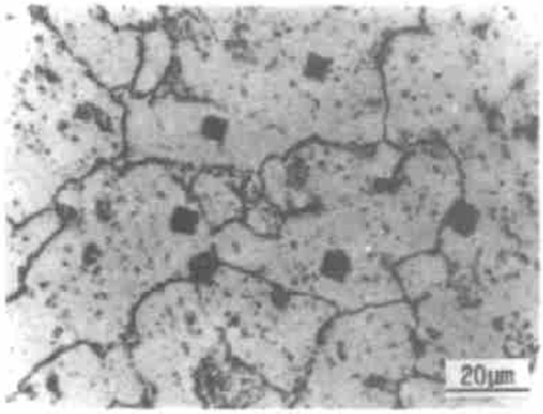

Fig.3 Optical micrograph of sample 4 at ambient temperature

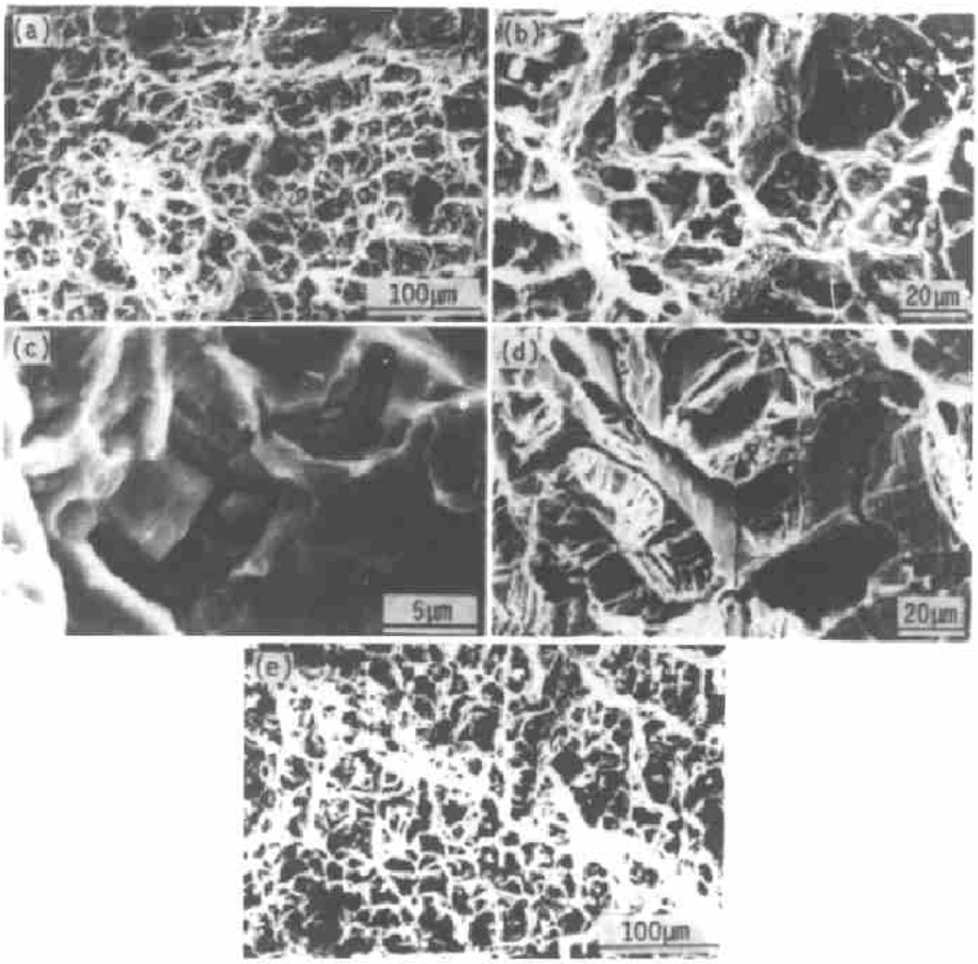

Fig.4 Impact fracture morphologies of high manganese steels containing Nb

Figure 3 is the microstructure of sample 4 at ambient temperature which cooled rapidly from 1050°C to ambient temperature (the square marks were used to fix the field of vision). It shows that a lot of hard particles have been formed and dispersed into the austenite matrix.

Fracture morphologies of impact samples 3-6 and 9 are shown in Fig.4. The fracture behaviour of sample 9 shows a splitting fracture structure, and splitting bands may be along its dendrite, as shown in Fig.4(a), while the impact fracture of sample 3 has a lot of dimples and shows ductile fracture clearly, as shown in Fig.4(b). It illustrates that the proper content of

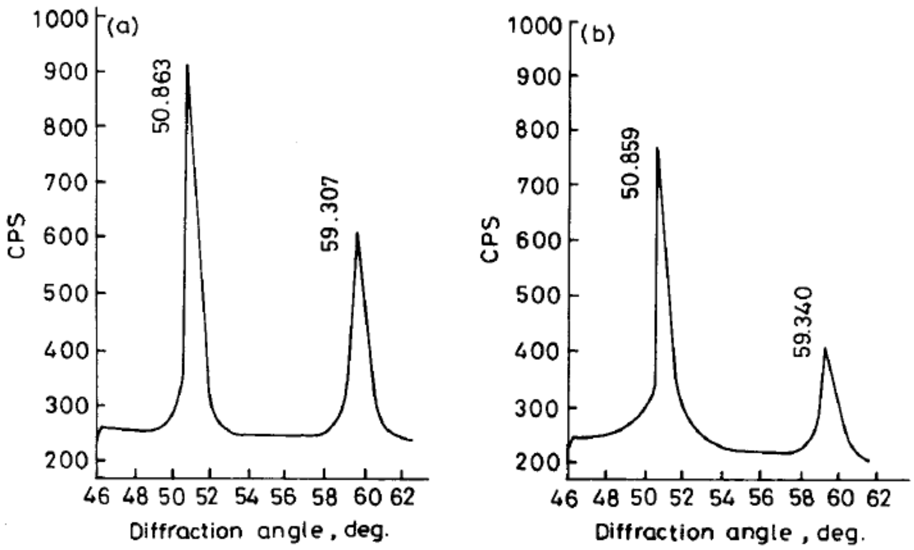

Fig.5 X-ray diffraction spectrogram after compressing samples 2 (Co$K\alpha$)

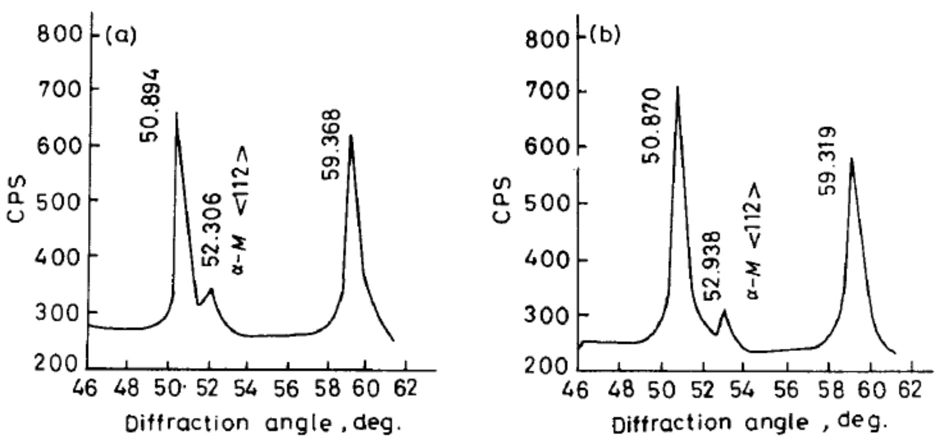

Fig.6 X-ray diffraction spectrogram of sample 4 (Co$K\alpha$)

element Nb could refine austenitic grain. It can be shown that the fracture mode will turn ductile fracture into brittle cleavage fracture gradually, with increasing the content of element Nb, as shown in Fig.4(b)—4(e).

Figures 5 and 6 show the X-ray diffraction results for sample 2 and sample 4. The microstructure of sample 2 can not form deformation induced α martensite, but the sample 4 can form it under the same conditions (rolling, compression and impact wear abrasion). The results have been proved by surveying microstructures of sample 2 and sample 4 with TEM, as shown in Figs.7 and 8. A number of martensite of sample 4 can be formed but only a lot of deformation twins in sample 2 have been formed under above deformation situations. Under the same conditions, a number of induced α martensite can be found in samples 7 and 8 by means of X-ray analysis. So it can be given that high manganese steels containing Nb (or Ti) and spraying N_2 are favourable to deformation induced martensite formation.

The mechanical properties and wear abrasion weight loss ε have been measured, as shown in Table 2. ε is defined as following:

$$\varepsilon = \frac{\text{weight loss of sample 9}}{\text{weight loss of samples } 1-8}$$

The wear abrasion resistance of high manganese steels has been raised by 26—97% according to the results in Table 2.

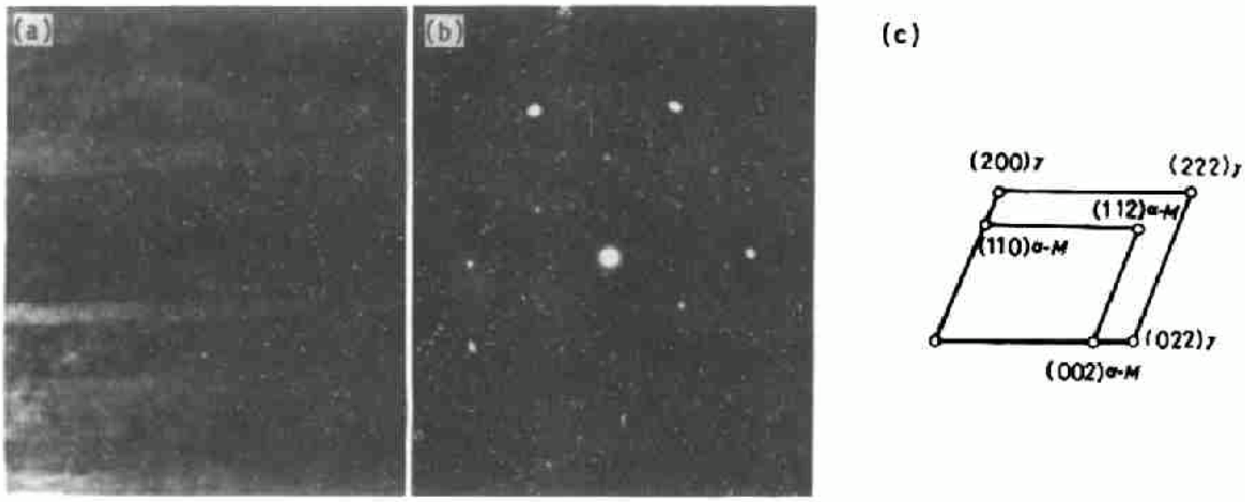

Fig.7 TEM photograph of sample 1 after rolling

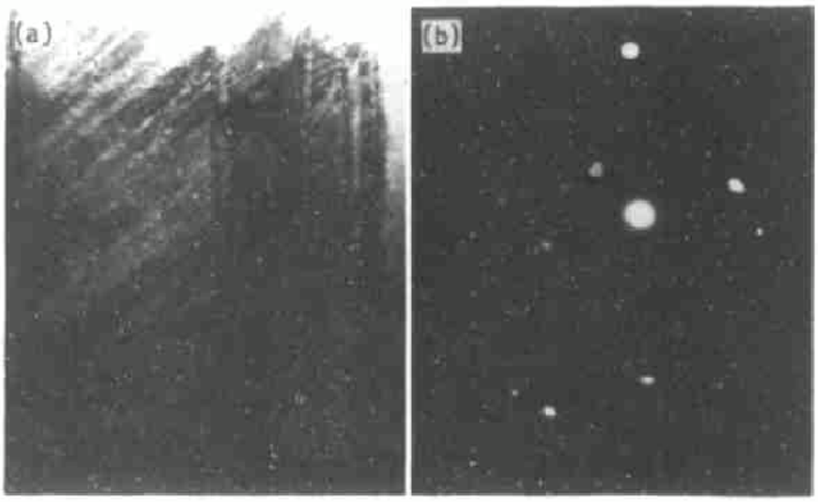

Fig.8 TEM photograph of sample 2 after compression

Table 2 Mechanical properties and abrasion weight loss of samples

No.	α_k(J)	σ_b, MPa	HB	weight loss, mg	ε
1	226.90	649.1	225.00	234.60	1.28
2	174.10	718.1	201.00	228.50	1.33
3	115.20	774.7	209.00	172.0	1.71
4	92.10	769.9	227.00	151.70	1.97
5	76.10	821.1	236.00	175.20	1.71
6	46.70	738.4	239.00	198.40	1.51
7	146.70	835.1	218.00	160.10	1.87
8	117.20	-	229.00	169.30	1.77
9	164.60	669.4	198.00	299.60	1.00

4. Analysis and Discussion

4.1 Influence of two different nitrogen treatments on compactness of samples

Not only in the gate of the as-cast sample 1 but also in its surface layer, there are a lot of gas contraction cavities, and in its surface layer there are densely pinholes. The rest as-cast samples have good compactness. Because the [N] concentration in melt increases when the N-Mn ferroalloy is added into the melt. [N] has a great solubility at high temperatures. The segregation coefficient of [N] in the melt is about 0.65—0.72, [N] is rich in the front of solid-liquid interface during solidification. According to the equation for the interface solute distribution, when [N] is beyond the saturated concentration, the N_2 bubbles will form.

The solubility of [N] is about 0.04% at 1600°C[8], the reaction $2[N]\rightarrow N_2$ is decided by thermodynamics and kinetics factors. Time is needed for [N] to transform to N_2 and for N_2 bubbles nucleations to grow. When the melt pours into sand mold, the surface layer will solidify at transient time because of rapid cooling, the N_2 formed by [N] can not escape and stay in the surface layer of cast sample. Therefore the gas contraction cavities and pinholes are formed. Especially, at the area of final solidification, the joint between the cast sample and gate shows clearly gas contraction cavities and pinholes. But in the samples 2—8 with spraying N_2, there are no gas contraction cavities and pinholes, because N_2 will expand, the bubble diameter will increase at high temperature. According to Stoke equation, the speed of N_2 rising will be rapid. The N_2 bubbles are favourable to absorbing [O], [S] and inclusions of the melt, the flowability of melt will be improved, thus the as-cast samples have good compactness.

4.2 Influence of Nb *(or* Ti*) and* N *on microstructure of the high manganese steel*

When elements Nb, Ti and N exist in the melt of the high manganese steel, the free enthalpy of NbC, TiC, NbN, TiN: $\Delta G<0$, at 1600°C by the thermodynamics calculation. Carbonitride with Nb or Ti may form at first in the initial stage of solidification. Spraying N_2 is good for improving kinetic condition of the formation of carbonitride with Nb of Ti. Figures 2(a) and 2(b) exhibits hard particles which are Ti(CN) and TiC by electron probe analysis. In the paper[7] it is given that Nb(CN), $Nb_2(CN)$ exist in medium manganese steel containing Nb. They are hexagonal crystals, which lattice plane (0001) and austenite lattice plane (111) are close-packed planes, their atom arrangements are similar. Therefore the carbonitrides with Nb or Ti are favourable to γ nucleation and γ grain refinement. Besides, these hard particles have good thermal stability and prevent austenite grain growth during heat treatment (as shown in Fig.3).

Besides a part of carbonitride particles with Nb distribute in austenite, the main part of carbonitride particles locate around austenite boundaries. Thus, the impact toughness α_K decreases with increasing the content of element Nb (as shown in Table 2). Figure 4(c) shows that particles with Nb are blocky, these hard particles are liable to forming crack propagating path. With increasing the content of Nb, the fracture morphology changes, the ductile fracture with a lot of dimples changes gradually into brittle fracture with a lot of cleavage steps. According to the results in Table 2, the proper range of element Nb is about 0.14—0.42%.

4.3 Relation between deformation and microstructure of the high manganese steel

The induced martensite of the high manganese steel can be formed under stress and deformation, but not every composition of high manganese steel can be. For example, it can be formed only in the high manganese steel produced by adding Nb and spraying N_2 under our testing conditions. It is shown that the transformation of deformation induced martensite has close relation to the composition and microstructure of high manganese steels.

As stated above, the surface layer microstructure of the high manganese steel containing Nb and [N] can take the transformation: $\gamma\rightarrow\alpha$-M under above impact wear abrasion, rolling and compression conditions. The work-hardening rate has improved. The effects of Nb (or Ti) have three aspects: (1) Solutioning in austenite, the element Nb (or Ti) improves austenite stability. Because the mismatch values between Nb or Ti and Fe(γ) are 19.7 and 15.3%[8]. It has not a great effect on microstructure because of little solution; (2) A number of dispersed hard particles have formed in the high manganese steel produced by adding Nb (or Ti) and spraying N_2. They are NbC, Nb(CN), TiC, Ti(CN) examined by electron probe analysis and TEM. These hard phases capture a part of carbon solutioned in austenite. Thus, the stability of austenite decreases. It is liable to form deformation induced α-martensite. Besides, the refined austenite grain is favourable to deformation strengthening of austenite; (3) Whether γ turns into α-M or not is dependent on its dislocation structure under deformation[9]. Cottrell atmosphere can be formed because of the affect between Nb, Ti and C, N in austenite. Thus, the tiny area distribution of C, N is not uniform, the fault energy of austenite decreases on deformation. Austenite is prone to transform into deformation induced α martensite. It is good for antiwear abrasion of high manganese steel. The better the wear abrasion resistance, the less the addition of Nb content. The antiwear abrasion of sample 4 is better than that of sample 6 as shown in Table 2. Even though the hardness of this material increases, these hard particles mainly distribute along austenite boundary, they are liable to peeling under impact fatigue, and cracks form around these hard particles. Therefore, adding proper Nb (or Ti) and spraying N_2 into high manganese steel has a great influence on microstructure and properties.

5. Conclusions

(1) Adding N-Mn alloy into high manganese steel is harmful to the microstructure compactness of the steel.

(2) Adding Nb or Ti and spraying N_2 into high manganese steel has following results:

(i) purifying the melt, refining austenitic microstructure and modifying the distribution of hard particles.

(ii) favourable to γ induced transformation under deformation and improving the strength-toughness of high manganese steel.

(3) With increasing the content of element Nb, the impact fracture mode will turn ductile fracture into brittle cleavage fracture gradually. The proper Nb content in high manganese steel is about 0.14—0.42%.

(4) The results of impact abrasive wear tests show that the abrasive resistance of alloying high manganese steels increases by 26—97%.

REFERENCES

[1] Xijie CHEN: *High Manganese Steel*, Beijing, Mechanical Industry Press, 1989, 60. (in Chinese)
[2] Liu Yingjie: *Friction and Wear*, 1983, **(3)**, 5.
[3] N.Jost and I. Schmidt: *Wear*, 1986, **111**, 377.
[4] Anshi Yang: The Proc. Symp. on the *First Antiwear Materials*, 1980.
[5] Y.N.Dastur and W.C.Leslie: *Metall. Trans.*, 1987, 249.
[6] P.H.Adier, G.B.Olson and W.S.Dwen: *Metall. Trans.*, 1986, 1725.
[7] Zhengming HE et al.: The Proc. Symp. on the Second *Antiwear Materials*, 1986.
[8] Longshen LI: *Cast Steel and Melt*, Beijing, Mechanical Industry Press, 1986, 30. (in Chinese)
[9] Zhuyao XU: *Martensite and Martensite Transformation*, Beijing, Science Press, 1980, 52. (in Chinese)