Reverse Austenite and its Effect on Mechanical Properties

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Introduction

The phase transformation of an unequilibrium structure during heating has aroused increasing interests. Some results of investigations on the partial transformation of martensite into austenite in Fe-Ni alloys, low carbon-low alloy steels, 18% Ni maraging steels, etc. have been reported.(1-7) Considering the importance of reverse austenite in maraging stainless steel, the present work devoted to study the rule of formation, the morphology and distribution, the substructure of reverted austenite in a newly developed steel by means of TEM, X-ray diffraction technique, dilatometer and high temperature microscope, etc. The effect of reverse austenite on mechanical properties and the mechanism of the transformation have been also discussed.

Marterial and Experimental Methods

The steel used in this work was a $00Cr_{13}Ni_6MoNb$ maraging stainless steel, which was melted in a 5-ton electric arc furnace and remelted in a vacuum consumable electrode furnace. After homogenization the ingot of 360 mm diameter was forged and rolled to desired sections. The chemical composition (wt%) of the steel was as follows:

C	Mn	S	P	Si	Cr	Ni	Mo	Nb
0.02	0.061	0.004	0.01	0.21	13.89	6.60	1.10	0.39

The specimens were austenitized at 1023k for 1 hour, then aged at different temperature.
Transmission electronmicroscopy and X-ray diffraction provided the tools for microstructural analysis.
Phase transformation temperature was determined in a Formaster-F dilatometer.
A high temperature light microscope (HM-339) was used to observe the surface change during phase transformation.

Results

1. Mechanical Properties and Amount of Reverse Austenite

The yield strength, ultimate tensile strength, elongation and impact toughness (ak) of the specimens aged at 573K-973K for 4 hours and the amount of reverse austenite are shown in Fig.1. It can be seen that the yield and tensile strength reach the peak value at about 723K and then decrease with increasing aging temperature to the lowest value at 893K, beyond that the strengthes anormaly increase again. The ductility and toughness have their peak at 893 K.

Reverse austenite appears after 823K and reaches its maximun at 883K-893K, after that the amount measured at room temperature decreases.

With increasing aging time at 853K from 0.25h to 16 h, the changes of properties and amount of reverse austenite are shown in Fig.2. From Fig.1 and Fig.2 it is interesting to note the correlativity between mechanical properties and amount of reverse austenite.

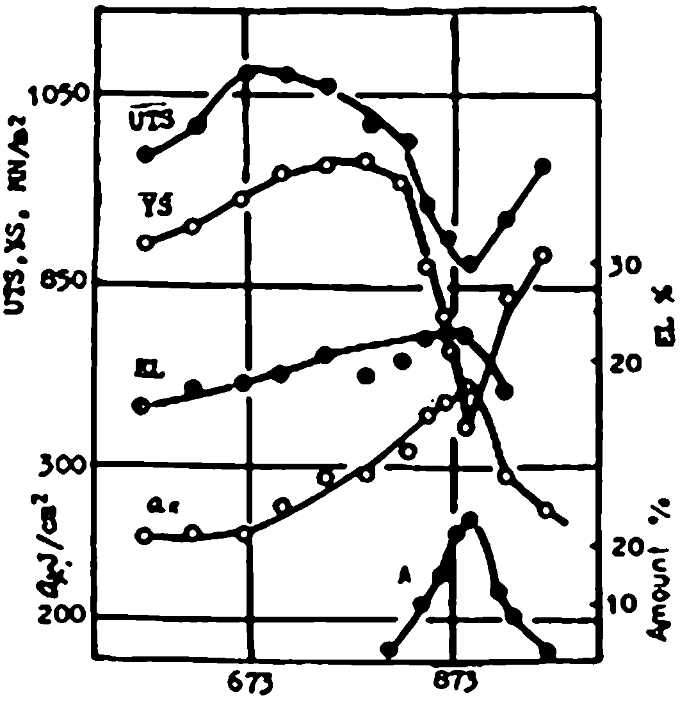

Fig.1 Mechanical properties and amount of reverted austenite vs aging temperature
Aging time: 4h

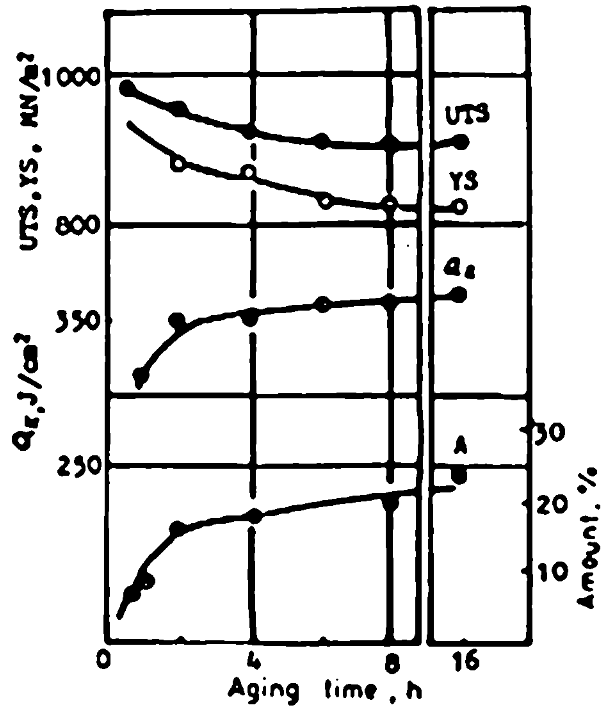

Fig. 2 Mechanical properties and amount of reverte austenite vs aging time
Aging temperature: 853K

2. Phase Transformation Temperature

As and Af temperatures of the steel are 823K and 963K respectively, as heating rate is 5 K/min.. These temperatures increase with increasing heating rate. They are 975K and 1078K at a rate of 6000 K/min.. This variation is very obvious and different from that of Ms temperature, which is almost undependent on cooling rate in the steel.(8)
Isothermal transformation curves of the specimens held at 853K, 873K, 893K, 933K and 973K, respectively, show that the reverse austenite can form and grow isothermally. The transformation can be ascribed to a temperature and time dependent one. It is connected with a hot-activation process.
During subsequent air cooling, the reverse austenite of specimens aged below 893K is stable, but in the specimen aged above 893K a secondary transformation of reverse austenite into martensite occurs. It is shown clearly also at dilatometric curve. The amount of secondary martensite (M_s) and $(Ms)_s$ temperature increase with aging temperature:

aging temperature (K)	853	873	893	933	973
$(Ms)_s$ temperature (K)	/	/	428	498	523

3. Microstructure

After quenching, the steel consists of lath martensite(8). TEM observation reveals that the reverse austenite formed during

aging in this steel has two morphologies: strip and bulk. The strip austenite forms at and grows along with the boundaries of lath martensite, whereas the bulk austenite generally forms at the original austenite boundaries and martensite group boundaries. Stacking faults and sparse dislocation networks can be observed in reverse austenite. Fig.3 is TEM image of the specimen aged at 853K for a short time, showing nucleation of reverse austenite at boundaries. From Fig.4 and Fig.5 the substructure of reverse austenite can be seen clearly and the orientation relationship between a strip austenite and martensite is corresponding with K-S relation as shown in Fig.5.
Some areas with dense dislocations appear in a bulk reverse austenite after aging at 923K for 2h as shown in Fig.6. The index of SAD pattern evinces [111] zone of martensite, which is resulted by a secondary transformation. The similar structure change can be found also in strip austenite when aging temperature is higher than 893K. This observation is in correspondence with the result of dilatometric curve.
With the help of a high temperature microscope, martensitic surface reliefs can be observed during cooling when aging temperature exceeds 893K. The transformation of martensite into austenite during heating causes also change of surface, but it has different character from martensitic relief under interference phase contrast and it is due to volume effect.

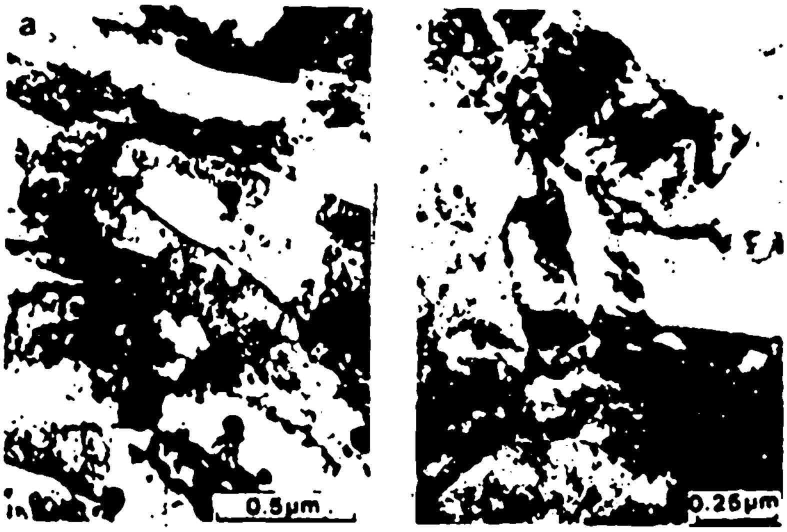

Fig. 3 electron transmission image of 853K, 15 min. tempered specimen

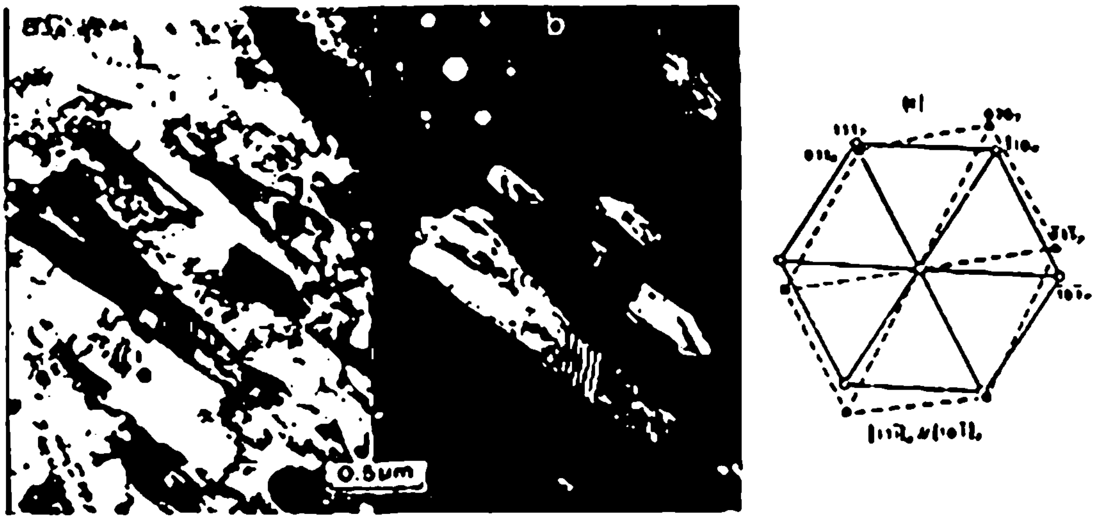

Fig.5 Electron transmission image and selected-area electron diffraction pattern of 853K 4 h tempered specimen
(a) Bright field image;
(b) Selected-area diffraction pattern and dark field image originated in (020)γ diffraction spot;
(c) Indexing of selected-area diffraction pattern

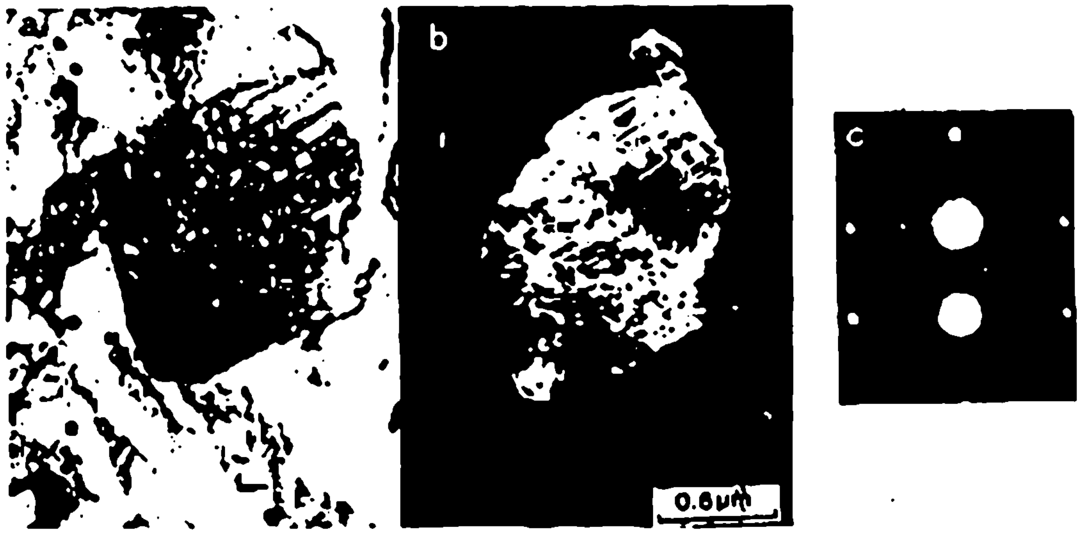

Fig.6 Electron transmission image and selected-area electron diffraction pattern of 933K 2 h tempered specimen
(a) Bright field image;
(b) Dark field image;
(c) Selected-area diffraction pattern

Discussion

1. The Effect of Reverse Austenite on Mechanical Properties

Mechanical properties of the steel after aging at 573K-973K are influenced by a series of factors, mainly by precipitation and phase transformation. When aging temperature is lower than 823K, the change of strength is mainly due to dispersive precipitates and then overaging because of absence of reverse austenite at this stage. But strength (especialy yield strength) decreases rapidly and toughness increases at temperature range 823K-893K, that is attributable not only to overaging but also to the transformation of martensite into austenite.

Mechanical properties as a function of amount of reverse austenite (or secondary martensite) is shown in Fig.7. The solid line

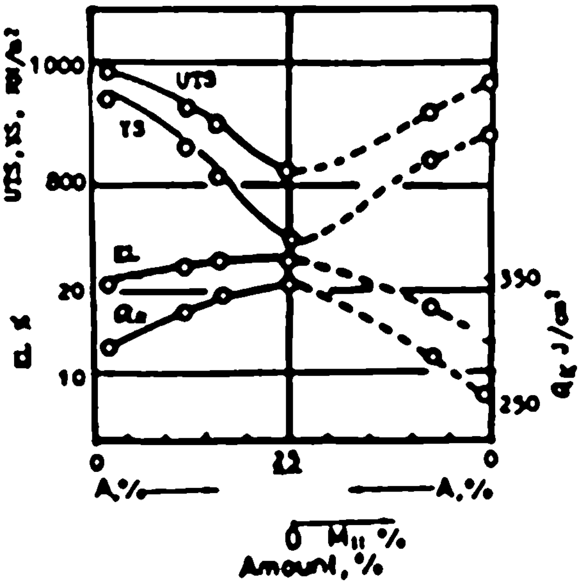

Fig.7 Relationship between mechanical properties and amount of reverted austenite or secondary martensite

represents the change of properties with increace of reverse austenite from 2.5% to 25% (correspond to aging temperature from 823K to 893K) and the dotted line represents that with secondary martensite. Every 10% increment of reverse austenite corresponds to a decrement of 50-70 MN/m^2 in ultimate strength and 100-120 MN/m^2 in yield strength.

In some alloys martensite-austenite transformation is beneficial to strength because the reverse austenite is a dispersive phase(1) or it inherites high dense defects of martensite.(2,9) But the reverse austenite in $00Cr_{13}Ni_6MoNb$ steel is not so. It is a soft phase, that is easier to cause the formation of microvoid during streesing and lowes strength level of the steel. However, a soft phase at boundaries of lath martensite can relax the stress concentration caused by dislocation piling during plastic deformation and reduce crack propagation rate, therefore, increase toughness of steel. As aging temperature exceeds 893K, the stability of reverse austenite decreases and a secondary martensitic transformation occurs during sebsequent air cooling. Because the concentration of alloy elements in reverse austenite changed due to diffusion. The secondary martensite enhances strength again and decreases tonghness of the steel.

In order to obtain a good combination of strength and toughness, it seems of benifit to have 10-15% reverse austenite in this steel.

2. Characteristics of Martensite -Austenite Transformation

Austenitization of a equilibrium structure causes formation of globular austenite grains at any heating condition(10). But the transformation of martensite during heating can form globular and strip-like austenite. The formation of strip austenite can be carried out by either shearing or by diffusion mechanism depending on alloy system and heating conditions.(5-7) In the present work the characteristics of the transformation can be summarized as follows:

1). Reverse austenite can grow isothermally. Its amount increases with isothermal temperature and time. Phase transformation temperature depends on heating rate.
2). Reverse austenite does not inherit high dense defects of martensite.
3). Strip austenite nucleates at and grows along with the martensitic boundaries, where the diffusion is much enhanced.
4). Formation of reverse austenite is not accompany by martensitic surface reliefs.
5). A secondary martensitic transformation takes place due to the instability of reverse austenite and its transformation temperature increases with isothermal temperature.
These characteristics suggest that the reverse austenite in this steel is not formed by a shear mechanism, but by a diffusion controlled process.

Conclusions:

1. Partial transformation of martensite into austenite in $00Cr_{13}Ni_6MoNb$ steel takes place during aging at 823K-973K. The reverse austenite has two morphologies: strip and bulk. The strip austenite forms at and grows along with the lath martensite boundaries, whereas, the bulk one at original austenite boundaries or martensite group boundaries.

2. Stacking faults or sparse dislocation networks can be observed in the reverse austenite. The exist of austenite is benefit to toughness, but decreases the strength of this steel.

3. Martensite-austenite transformation in this steel is a diffusion controlled process.

4. As aging temperature exceeds 893K, a secondary martensitic transformation occurs during sebsequent cooling, which causes an increment in strength and a decrement in toughness.

Acknowledgments

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