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EFFECT OF STRESS ON THE VARIANT SELECTION IN MARTENSITIC TRANSFORMATION

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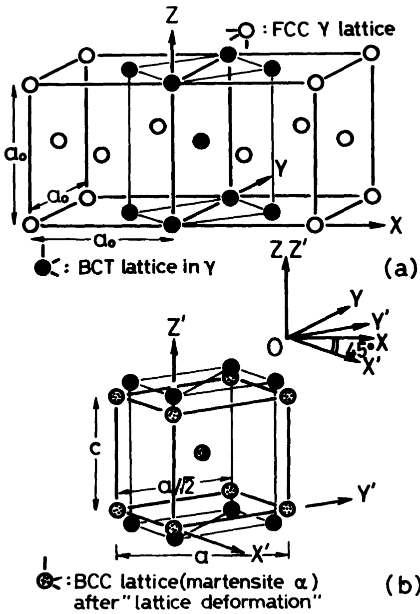
The anisotropic constraint stress will be induced in the specimens of thin sheets, when they are quenched below Ms temperature without external stress. The characteristics of variant selection phenomenon were studied under these conditions. The texture of γ and α of ferrous alloys were analyzed with X-ray method. The results obtained could be explained satisfactorily with the Bain Strain model as follows:
(1) Variant selection phenomenon depends on the orientation of the parent phase and on the Bain strain associated with martensitic transformation.
(2) Such variants that have the largest Bain strain components to the sheet normal are selected predominantly, because the occurrence of variants are prevented least of all under the anisotropic constraint stress.

1. INTRODUCTION

In the martensitic transformation(denoted as MT hereafter) of ferrous materials, it is well known that the variant of martensite phase is selected, when the external stress is applied during transformation.

Several models concerning the appearence mechanism of variant selection(denoted as VS hereafter) phenomenon have been proposed. They are all concerned with the interaction of applied stress with a strain characteristic to the MT. Among them, successful models were proposed recently by Furubayashi(1) who looked at the interaction between the stress and "lattice deformation" in the phenomenological theory of MT. Austenite lattice(having face centered cubic structure) may also be described as a body centered tetragonal structure with an axial ratio of $\sqrt{2}$ as seen in Fig.1. Bain proposed that the MT merely involves the deformation of about 20% compression to the c axis([001] direction) and about 12% expansion to the perpendicular directions of the austenite unit cell, as shown in Fig.1. This deforma-



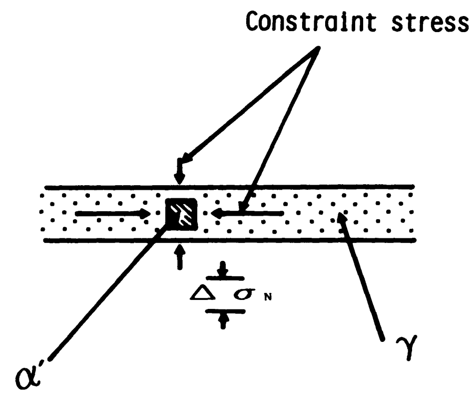


Figure 2 Anisotropy of the constraint stress induced in thin sheet from the surrounding parent phase which acts to prevent the strain associated with the martensitic transformation.

Figure 1 (a) Lattice correspondence and (b) Bain strain associated with martensitic transformation from γ to α in ferrous alloys.

tion(strain) is defined as the characteristic strain of transformation. There are three ways of choosing this type of tetragonal lattice in the austenite lattice, that is, the direction of c axis can be taken parallel to either one of X, Y or Z axis respectively, and Furubayashi(1) considered that such a variant as the deformation associated with MT is assisted most effectively by the applied stress (the work done by the stress is maximum), is chosen. This view will be called "Bain Strain(BS) model" hereafter. Satisfactory explanations were obtained in the VS for deformation-induced transformation by rolling(2).

On the other hand, Hashimoto, Satoh and Tanaka(3) claimed that the VS phenomenon occurs in thin sheet of steel even without external stress, because the anisotropy of internal stress due to constraint by the surrounding parent phase makes an effect at the MT. Such a stress will be abbreviated as "constraint stress", as shown in Fig.2. They thought that the constraint stress due to transformation strain would be weaker in the normal direction of the sheet than others.

In the present study, the orientation of martensite crystals of ferrous alloys formed in thin sheet by quenching them without external stress was studied, and the possibilities of VS under anisotropic constraint stress were discussed in the light of the Bain Strain model.

2. EXPERIMENTAL PROCEDURE

In order to study the VS phenomenon by means of texture analysis of the phase before and after transformation, it is necessary to prepare the specimens satisfying the following conditions:
(1) Ms temperature has to be near the room temperature so as to get appropriate amount of both (parent and transformation) phases at room temperature.
(2) The well defined texture of parent phase should be developed in the thin sheet.

The authors prepared two alloys, expecting the different effects which were caused by both initial orientation of the sheets and Bain strain associated with MT, as described below. Table 1 shows the chemical composition.

3.5 kg ingots were prepared by melting the raw materials in a vacuum induction furnace and then hot rolling to sheet 12 mm thick. They were cold rolled by 95% into thin sheets after homogenization treatment, and annealed to recrystallize to form well developed texture. The ausaging treatment was added to the latter specimen to increase the martensite tetragonality(4), which makes possible to differentiate the Bain strain in the MT from that of Fe-30Ni alloy(cubic martensite). The specimens were chemically thinned to 40 μm thick, and subzero-quenched into liquid nitrogen to induce MT.

(001) pole figure of austenite and martensite were measured by X-ray Schulz(reflection) or Decker(transmission) method, using Co target. Pole densities were shown by relative X-ray intensity with respect to a random sample and are indicated by arabic numerals in the pole figures.

The lattice constants of austenite and tetragonal martensite of Fe-27Ni-4Al-12Co-0.8C alloy were measured at room temperature by X-ray diffractometer to calculate the Bain strain associated with MT. Those of Fe-30Ni alloy used were already known(5).

Table 1 Chemical composition of alloys (wt %)

Alloy	Ni	Al	Co	C	Others			
Fe-30Ni	29.67	0.025	—	0.001	N:0.001	Mn:0.085	Si:0.002	S:0.003
Fe-27Ni-4Al-12Co-0.8C	26.92	4.10	12.18	0.81	N:0.001	Mn:0.001	Si:0.002	S:0.002

3. EXPERIMENTAL RESULTS

3. 1. Fe-30Ni alloy

(001) pole figure of austenite is shown in Fig.3(a). Austenite has well developed cube texture. (001) pole figure of martensite is shown in Fig.3(b). Pole of all possible martensite orientations, which may be related to ideal (001)[100] γ orientation by the Bain relation, are also shown schematically in the figure.

By comparing these figures, one may find that only one component of the three variants appeared in Fig.3(b) actually. It is proved in this way that the only variant formed is of Z component. That is, the operative martensite variant is such that whose c axis(compression axis) in Bain deformation is oriented to the normal direction of the sheet(see Fig.1).

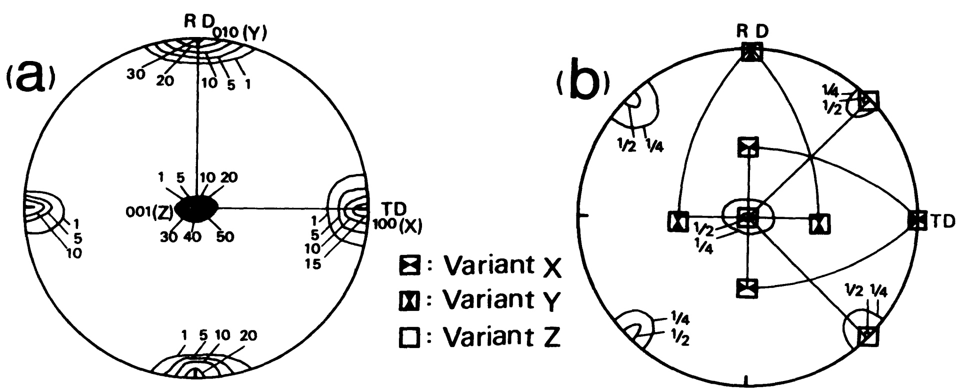


Figure 3 (001) pole figure of Fe-30Ni alloy. (a) austenite, (b) martensite transformed from cube-textured austenite in (a) together with the schematic pole of all variants transformed according to Bain relation.

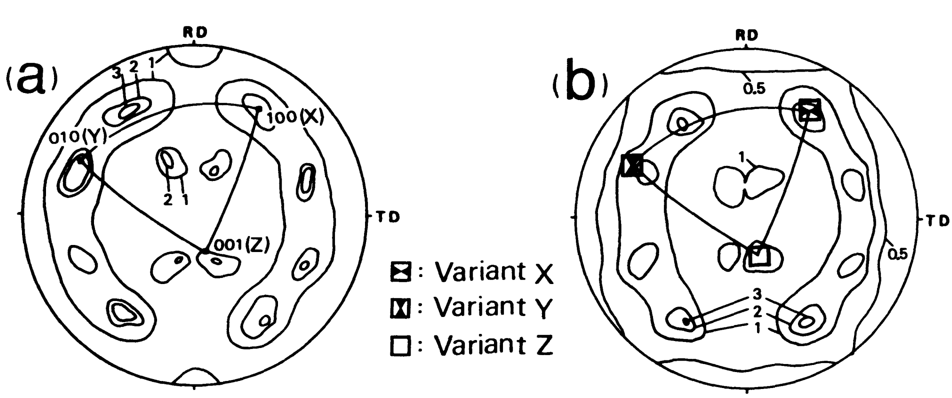


Figure 4 (001) pole figure of Fe-27Ni-4Al-12Co-0.8C alloy. (a) austenite, (b) martensite transformed from (113)[2$\bar{1}\bar{1}$] textured austenite in (a) together with the schematic pole of (001) (or c axis) of all variants transformed according to Bain relation.

3. 2. Fe-27Ni-4Al-12Co-0.8C alloy

Unfortunately, the cube texture was not developed in this alloy. { 001} pole figure of austenite is shown in Fig.4(a). Austenite has well developed (113)[21$\bar{1}$] texture. (001) pole figure(i. e. pole of c axis) of the tetragonal martensite is shown in Fig.4(b).

In Bain relation, each of the three < 100 > axis of austenite may surve as Bain compression axis, or the rotation axis of Bain relation, and is transformed into (001) poles of the martensite. In the tetragonal martensite, (001) poles should be strictly distinguished with the (100) and/or (010) poles(i. e. pole of a axis). From the very similarlity of Fig.4(b) with Fig.4(a), it is seen that all of the poles of (001) appeared similarly, that is, the VS did not appeared in this case.

The Bain strain was calculated from the experimental lattice constants of austenite and martensite as shown in Table 2 in comparison with those for Fe-30Ni alloy(fcc→ bcc).

4. DISCUSSION

As reported in the previous paper(6), the characteristic strain in BS model may be described in the following way. Let an austenite lattice(lattice parameter a_0) be transformed into a tetragonal lattice(c and a) as a result of the Bain deformation. The characteristic strain, ε_1 along the Bain compression axis and that ε_2 along the perpendicular axes will be described by Eqs.(1) and (2).

$$\varepsilon_1 = (c-a_0)/a_0 \quad (1)$$

$$\varepsilon_2 = \{a-(a_0/\sqrt{2})\} /(a_0/\sqrt{2}) \quad (2)$$

Now, when the constraint stress along the normal direction of the sheet diminishes by $\Delta\sigma_N$ according to BS model, as shown in Fig.2, the work W done by it decreases by

$$\Delta W = \Delta\sigma_N \cos\theta \cdot \varepsilon_1 + \Delta\sigma_N \sin\theta \cdot \varepsilon_2 \quad (3)$$

where θ is the angle between the Bain compression axis and the normal stress direction of the sheet, and $\Delta\sigma_N$ is positive for compressive strain and negative for expansive strain, because it always acts to prevent the strain. According to Eq.(3), the value of ΔW differs depending on the initial orientation θ and Bain strain component ε_1 and ε_2. That is, the variant associated with the Bain strain whose component along the normal direction of the sheet is large enough, is selected.

It is clear that the value of ΔW in Fe-30Ni alloy (i. e. cube texture, ε_1 =-0.2, ε_2 =0.12) was 0.2 $\Delta\sigma_N$ in the variant Z and 0.12$\Delta\sigma_N$ in the variant X or variant Y,

Table 2 Comparison of the calculated ΔW in the Eq.(3) and the observed Bain variant

alloy	initial orientation	Bain variant	Θ (degree)	Bain strain ε_1	Bain strain ε_2	ΔW ($\times \Delta\sigma_N$)	Bain variant observed
Fe-30Ni	cube texture	X	90	−0.20	0.12	0.12	—
		Y	90			0.12	—
		Z	0			0.2	yes
Fe-27Ni-4Al -12Co-0.8C	(113)[$21\bar{1}$]	X	72.5	−0.14	0.09	0.13	yes
		Y	72.5			0.13	yes
		Z	25.2			0.16	yes

respectively, as shown in Table 2. Accordingly, the variant Z is most operative in the MT.

On the other hand, the values of θ of the variants X, Y and Z in Fe-27Ni-4Al-12Co-0.8C alloy(i. e. (113)[$21\bar{1}$] texture, ε_1= -0.14, ε_2 = 0.09) are 72.5°, 72.5° or 25.2°, respectively. Accordingly, the value of ΔW was $0.13\Delta\sigma_N$ in the variant X and variant Y, and $0.16\Delta\sigma_N$ in the variant Z, respectively, from Eq.(3).

The differences between them are not so large as in the Fe-30Ni alloy. The result that all of the three variants were equally selected in this case is very probable, as seen in Fig.4(b).

5. CONCLUSION

The Bain strain model, in an original sense, refers to the effect of the "applied external stress" on the lattice deformation associated with MT. In the present study, the effects of the orientation of the sheet before transformation and of the magnitude of Bain strain associated with the MT were examined. From these studies, it became clear that the "constraint stress(or internal stress)" also affects the VS phenomenon as well as external stress. The VS phenomenon observed in thin sheet can be explained satisfactorily with the present Bain strain model, if one paraphrases the VS raw as follows; such a variant is chosen that the deformation associated with MT is prevented least of all by the constraint stress.

References:

1) E. Furubayashi, Tetsu-To-Hagané, 71, 1155; ibid. 1359(1985)
2) H. Miyaji, M. Nobuki, N. Sakuma, T. Mitsui, H. Nakajima and E. Furubayashi, Proc. Inter. Conf. on Physical Metallurgy of Thermomechanical Processing of Steels and Other Metals, 815(1988)
3) O. Hashimoto, S. Satoh and T. Tanaka, Tetsu-To-Hagané, 66, 102(1980)
4) H. Ohtsuka and S. Kajiwara, MRS Int'l. Mtg. on Adv. Mats., 9, 469(1989)
5) J. F. Breedis and C. M. Wayman, Trans. AIME, 224, 1128(1962)
6) H. Miyaji and E. Furubayashi, Textures and Microstructures, 12, 189(1990)