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Internal Friction of Metastable Austenitic Stainless Steel SUS 301

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Abstract. Anelastic measurements in the low frequency range have been made on a nickel reduced type metastable austenitic stainless steel SUS 301. Cold working of various degrees was given by rolling after austenitizing heat treatment. Three internal friction peaks, P_1 , P_2 , P_3 from the lower temperatures, were observed. The sharp peak P_2 and the broad one P_3 disappeared by austenitization and reappeared by cold rolling. Peak P_2 was a single relaxation type with an activation energy of about 0.5 eV. Electrical resistivity and thermopower were measured; it was revealed that the latter was more sensitive to the martensitic transformation than the former.

1. INTRODUCTION

A stainless steel SUS 301 is known to harden remarkably by rolling at or above room temperature because of its rather high M_s temperature, and it is widely used for purposes where a high strength is required. The content of the γ phase stabilizing element nickel is reduced compared with SUS 304, the so-called 18-8 stainless steel; therefore, a martensitic transformation takes place in this steel more easily than in SUS 304. Several works [1-4] have been reported on the internal friction of SUS 304, but no work on SUS 301, whose austenite is more unstable than SUS 304, and martensitic transformations occur progressively with lowering of temperature. It is of interest to know how mechanical properties, especially internal friction, change with temperature.

Purpose of the present work was to clarify how the internal friction of SUS 301 is influenced by the state of austenite phase and the amount of martensite which has already transformed. Another purpose was to investigate how the physical properties such as resistivity or thermopower are influenced by the phase transition. Since thermopower is sensitive to the electronic state it was expected to obtain more information by the measurement of thermopower than by resistivity.

2. EXPERIMENTALS

2.1 Specimen preparation

A commercial stainless steel sheet SUS 301 of thickness 1 mm was used. The chemical composition of the alloy is shown in the Table 1. Specimens were prepared by either rolling the starting material at room temperature or by rolling after austenitizing. In the table 2 are shown the reductions in rolling for each specimen. Specimen A was prepared by austenitizing the starting material at 1373K for 1800s. Specimens B, C and D were prepared by cold rolling specimen A, and F and G by cold rolling specimen E which was the starting material. Specimens of the width 1 mm were slit from the sheet and served for the internal friction and electrical measurements.

2.2 Method of measurement

2.2.1 Internal Friction

A low-frequency inverted torsion pendulum of Ke type (Sinku-Riko IFM 1500-L) was used. Measurements were made during thermal cycling between 100 and 300K. The cooling and heating rate was mostly 2K min⁻¹, and the frequency was 0.9~1.5 Hz. The calculation of the internal friction from the decay of oscillation and the recording of data were made automatically; the internal friction and the square of the frequency of oscillation versus temperature were plotted by a desk-top computer.

2.2.2 Electrical Resistivity and Thermopower

The electrical resistivity was measured on the same specimen as the internal friction by the dc four probe method. The thermopower was also measured on the same specimen. A temperature difference of few degrees was produced between two points along the specimen and the thermal electromotive force was measured.

3. RESULTS AND DISCUSSION

3.1 Internal friction

3.1.1 Specimens E and A

Figure 1 shows the internal friction Q^{-1} and the elastic modulus (the square of the frequency of torsional oscillation f^2 is used instead) of the specimen E, which is the as obtained starting material. The internal friction spectrum seems to consist of a sharp peak at 205K and broader peaks which are not well defined. A modulus defect was observed corresponding to the 205K sharp peak, but to broader peaks it is difficult to identify any distinctive modulus defect.

Figure 2 shows the result on the specimen A, which was fully austenitized. The sharp peak observed in the specimen E disappeared completely. A low broad peak was observed at lower temperatures (note that the ordinate scale is four times that of Figure 1).

TABLE 1: Chemical composition (mass %)

C	Si	Mn	Ni	Cr	N
0.06	0.46	1.23	7.23	17.14	0.083

TABLE 2: Reduction in cold rolling of specimens from the specimen E

Sp.	Cold Rolling
A	Austenitized
B	A + 6.06% CR
C	A + 8.16
D	A + 10.7
E	Mill product
F	E + 10.0% CR
G	E + 15

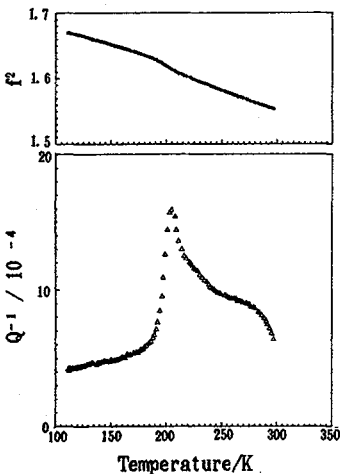


Figure 1: Internal friction and rigidity of specimen E.

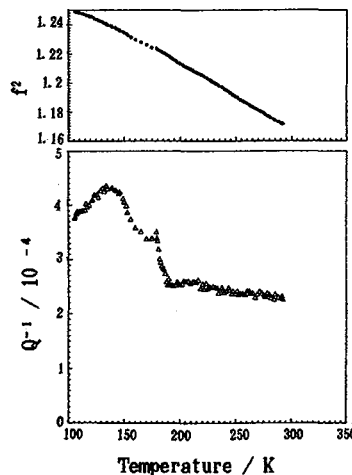


Figure 2: Internal friction and rigidity of specimen A.

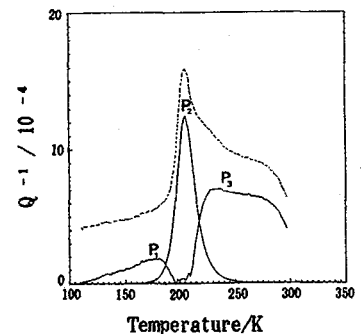


Figure 3: Decomposition of peak; specimen E.

In order to investigate the nature of these internal friction peaks, we tried to decompose the spectrum assuming a background values. From figure 2 it is seen that the observed internal friction of specimen A at temperatures higher than 200K vary almost linearly and very slowly with temperature, and the values are fairly small; therefore, we extrapolated them to lower temperatures and assumed them as the base line of internal friction data. Values of this base line were subtracted from the observed values of specimen E, and then a single relaxation curve was assumed for the sharp peak at 205K. Best fitting was made by adjusting three parameters, the peak temperature T_p , the height H and half width w of the peak. By subtracting the single relaxation curve from the observed curve, two broad peaks were identified as shown in the figure 3. We call these peaks P_1 , P_2 and P_3 , respectively from the lowest temperature one.

For a single relaxation peak, the relaxation strength Δ , activation energy E , and the pre-exponential factor of relaxation time τ_0 are determined using T_p , H and w as follow.

$$\Delta = 2H \quad (1)$$

$$E = 2.634 k T_p^2 / w \quad (2)$$

$$\tau_0 = \exp(-E/kT_p) / \omega, \quad (3)$$

where k and ω are the Boltzmann constant and the angular frequency, respectively.

For P_2 peak of the specimen E, we obtained the following results;

$$\Delta = 25 \times 10^{-4}, \quad E = 0.5 \text{ eV}, \quad \tau_0 = 6.4 \times 10^{-14}$$

For peaks P_1 and P_3 it was impossible to decompose them any more; probably they consist of a group of small peaks which occur in succession.

A similar procedure of decomposition was applied to the specimen A. The result is shown in the figure 4. The P_3 peak has completely disappeared but the P_1 peak remained almost unchanged. A small sharp peak was observed at 179K, but it is not certain whether it is actually the same P_2 peak as in the specimen E, because its half width is very small (8K) and the assessed activation energy is 0.9 eV, nearly twice the size of that of the specimen E. A corresponding modulus defect was not observed also, therefore it shall be called P_2' peak for a while. This peak was observed only on cooling, and not on heating.

It is presumed that peaks P_2 and P_3 were produced by cold rolling and disappeared by annealing, while the peak P_2' is different in nature.

3.1.2 Specimens B, C, F and G

The specimen A was given a strain by cold rolling to prepare specimens B and C, the reductions being 6 or 8%, respectively. On cold rolling peaks P_2 and P_3 reappeared. In the figure 5 we show the peak decomposition result on the specimen C. Three peaks P_1 , P_2 and P_3 , quite similar to the specimen E, were observed, but the height of peak P_2 was considerably lower than that of the specimen E.

Measurements were made on specimens which were given a further strain to the specimen E; i.e., F(10%) and G(15%). Both results were similar to the specimen E, but G was a little bit different. The figure 6 shows the peak decomposition result on the specimen G. It is remarkable that a small additional peak was observed at a lower temperature than P_2 of the specimen E. Its activation energy

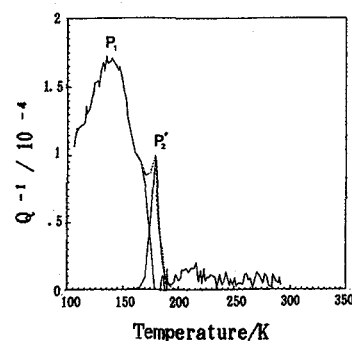


Figure 4: Decomposition of peak; specimen A.

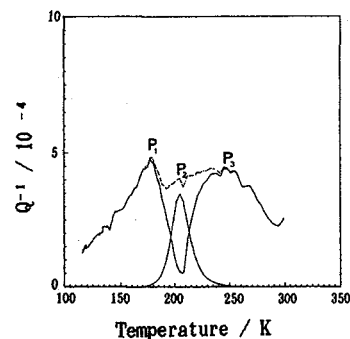


Figure 5: Decomposition of peak; specimen C.

was calculated as 0.43 eV, a similar value to that of the specimen E. If we assume that this lower temperature peak was of relaxational origin, its activation energy would be 0.73 eV, rather similar to the peak P_2' of the specimen A. This peak was not observed on heating.

3.1.3 Discussion

Metastable austenitic stainless steel undergoes a martensitic transformation, and internal friction peaks occur [5]. Peak P_3 occurred only in strained specimens presumably due to this mechanism. This explains why the specimen A lacks P_3 , because austenite phase in A is more stabilized than in strained specimens. According to Pickering's equation [6], M_s temperature is estimated at 186K, while Tanino's equation [7] gives 148K. Although exact M_s temperature is difficult to determine, peak P_1 roughly corresponds to M_s , and will be interpreted in the same way as P_3 , i.e., it occurs from progressing transformations. Peak P_2 is relaxational type accompanied with modulus defect, and is considered due to dislocations which have been created by preceding martensitic transformations. Peak P_2' is probably different from P_2 in its nature. We now presume that it is connected with some kind of martensitic transformation, and is not observed on heating because the inverse transformation does not occur at the same temperature.

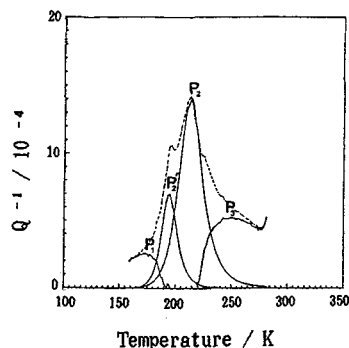


Figure 6: Decomposition of peak; specimen G.

3.2 Electrical Resistivity and Thermopower

The resistivity increased almost linearly with temperature, and any appreciable difference between specimens E and A was not observed, but in contrast the thermopower showed a remarkably different behaviour. As shown in the figure 7, the absolute value of the thermopower of the specimen A is smaller than that of the specimen E, which is qualitatively explained as the result of the difference between A and E in the temperature variation of the amount of martensite.

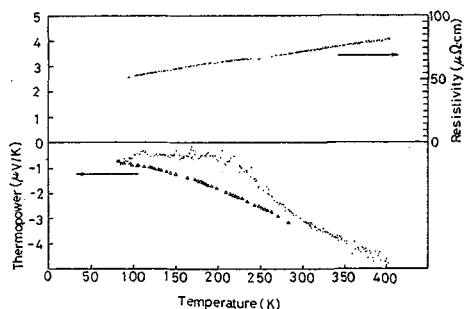


Figure 7: Electrical resistivity, specimen A, and thermopowers, A(dots) and E(triangles).

4. CONCLUSION

Several internal friction peaks were observed in metastable austenitic stainless steel SUS 301. Broad peaks P_2 and P_1 were interpreted as due to successively occurring martensitic transformations, while a sharp peak P_2' , which was missing in the fully austenitized specimen, was considered a single relaxational peak with the activation energy of about 0.5 eV.

A remarkable difference was observed between thermopowers of austenitized and strained specimens. A possibility is pointed out that the thermopower can be a sensible method of detecting the amount of transformed phase.

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