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Effect of high magnetic field and uniaxial stress at cryogenic temperatures on phase stability of some austenitic stainless steels

T. Fukuda [a,*], T. Kakeshita [a], K. Kindo [b]

[a] Department of Materials Science and Engineering, Graduate School of Engineering, Osaka University, 2-1, Yamada-oka, Suita, Osaka 565-0871, Japan

[b] Research Center for Materials Science at Extreme Conditions, Osaka University, 1-1, Machikaneyama-cho, Toyonaka, Osaka 560-0043, Japan

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Abstract

We have examined effects of external fields, such as temperature, magnetic field, stress and combination of them on martensitic transformation of SUS304, SUS304L, SUS316 and SUS316L austenitic stainless steels, and obtained the following results. (i) An athermal martensitic transformation does not occur for all the solution-treated and the sensitized specimens, and the γ-phase exhibits an antiferromagnetic transition at a temperature between 20 and 50 K. On the other hand, an isothermal transformation occurs in solution-treated SUS304L steel ($\gamma \rightarrow \varepsilon' \rightarrow \alpha'$), sensitized SUS304L steel ($\gamma \rightarrow \varepsilon' \rightarrow \alpha'$ and $\gamma \rightarrow \alpha'$) and sensitized SUS304 steel ($\gamma \rightarrow \alpha'$). (ii) A magnetic field-induced $\varepsilon' \rightarrow \alpha'$ transformation occurs at 77 K in ε' martensite of SUS304L steel, which is induced by isothermal holding beforehand, but does not occur in other steels under a pulsed magnetic field up to 30 MA/m. (iii) A deformation-induced $\gamma \rightarrow \varepsilon' \rightarrow \alpha'$ martensitic transformation occurs at 77 K for all the solution-treated and sensitized specimens. The amount of deformation-induced α' is the largest in SUS304L steel and the smallest in SUS316L steel. (iv) A magnetic field-induced $\varepsilon' \rightarrow \alpha'$ transformation does not occur in deformation-induced ε' martensite of any steel.

Keywords: Martensite; Magnetic field; Stainless steel; Isothermal transformation

1. Introduction

Austenitic stainless steels are popular structural materials, including at cryogenic temperatures [1–3], because of their excellent mechanical properties, good workability, superior weldability, high corrosion resistance and nonmagnetic character. In near future, austenitic steels are expected to be used widely under a combined environment of low temperature, high stress and high magnetic field. However, in such an environment, many of the excellent properties will be lost if the austenitic phase transforms to a martensite phase. For example, the nonmagnetic property is lost when α'-phase forms. Moreover, if the transformation is accelerated under the combined environment, the volume change (∼4%) associated with the transformation will promote the nucleation and growth of cracks, resulting in the fracture of the material. However, there is few study on them.

In the present study, therefore, we will examine the effect of the combined environment on the stability of the austenitic phase of four representative austenitic stainless steels: SUS304, SUS304L, SUS316 and SUS316L.

2. Experimental procedure

Four austenitic stainless steels, SUS304, SUS304L, SUS316 and SUS316L, compositions of which are shown in Table 1, are used in the present study. Every specimen was cold-rolled and then solution-treated at 1323 K for 0.5 h followed by quenching into iced water. Some of the specimens were sensitized by heat-treatment at 973 K for 10 or 100 h. The oxidized surface layer was eliminated by electropolishing.

The stability of stainless steels at low temperatures was examined by two methods: one is a magnetic susceptibility measurement with a constant cooling and heating rate of 1 K/min, and the other is an isothermal holding test at 77 K with a maximum holding time of 10^6 s. Effect of a high magnetic field was examined by using a pulsed magnet [4] with a maximum magnetic field of 30 MA/m. The size of the specimen used for the pulsed field application is 2 mm × 12 mm × 0.3 mm, which is calculated to be suitable for neglecting the effect of eddy current. Since it is well known that deformation at low temperature

* Corresponding author. Tel.: +81 6 6879 7483; fax: +81 6 6879 7522.
E-mail address: fukuda@mat.eng.osaka-u.ac.jp (T. Fukuda).

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Table 1
Composition of austenitic stainless steels used (mass%)

Type	C	Si	Mn	P	S	Ni	Cr	Mo	Fe
SUS304	0.06	0.67	1.01	0.029	0.009	8.50	18.10	–	Bal.
SUS304L	0.023	0.48	1.07	–	0.005	8.47	18.20	–	Bal.
SUS316	0.052	0.67	1.49	0.033	0.005	10.71	16.43	2.12	Bal.
SUS316L	0.015	0.56	0.86	–	0.001	12.36	17.21	2.31	Bal.

induces martensite phase for the present alloys, we examined the relation between the amount of strain given at 77 K and the amount of α′ martensite. In order to examine the effect of combined environment, we applied magnetic filed at 77 or 4.2 K on a specimen which was deformed beforehand at 77 K.

The amount of α′ martensite formed by low temperature holding, etc., was evaluated by a magnetization measurement in a low field range at room temperature, where we assume the spontaneous magnetization of α′ at room temperature to be 1.79 μ_B/atom for SUS304 and SUS304L, 1.70 μ_B/atom for SUS316, and 1.90 μ_B/atom for SUS316L, considering the Slater–Pauling curve and their valence electron concentration. We neglected the magnetization of the γ and ε′ because they are nonmagnetic.

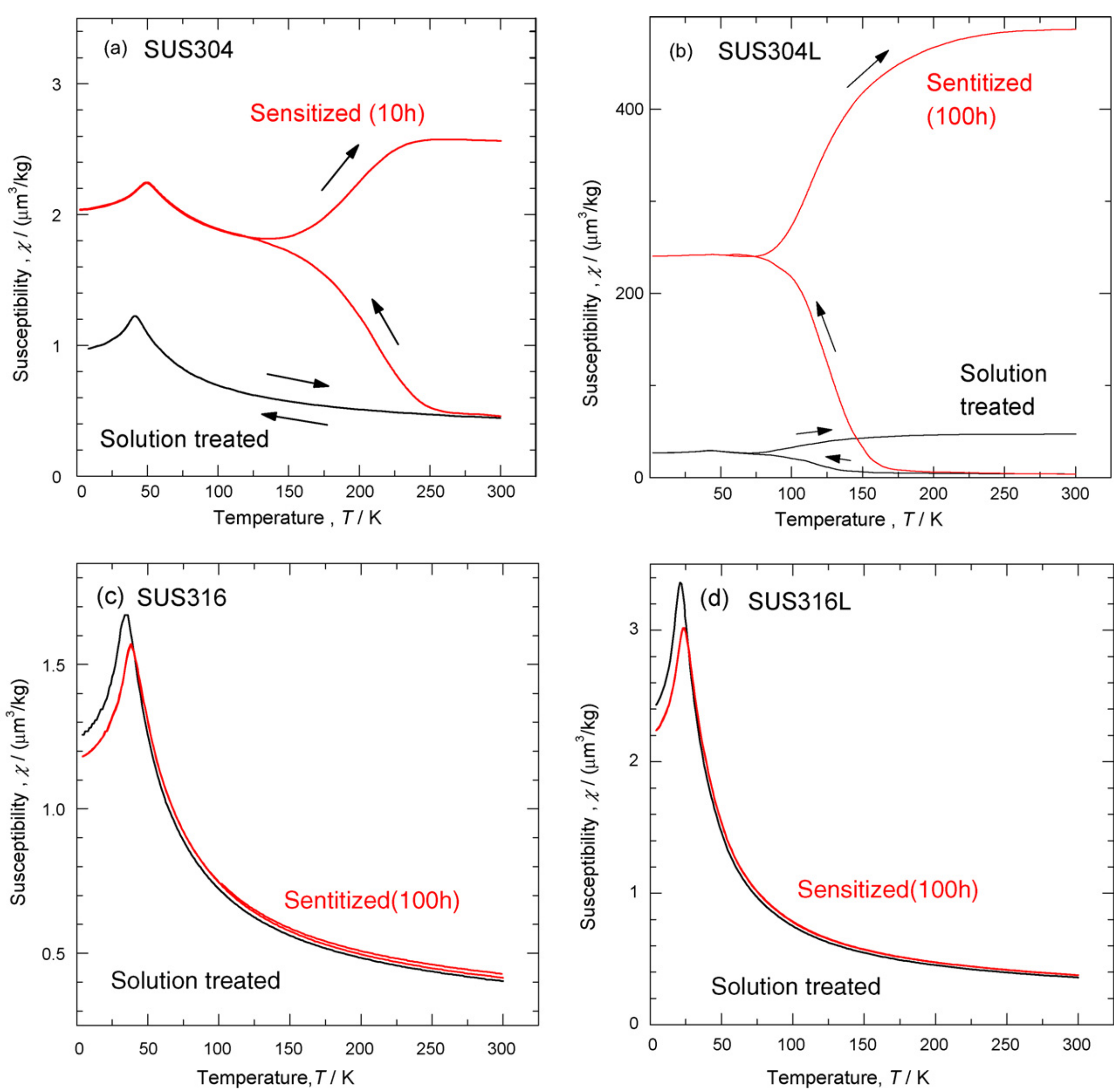

Fig. 1. (a–d) Magnetic susceptibility of solution-treated and sensitized stainless steels. Measurement was made in the cooling process and then in the heating process.