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Effect of Austenite on Mechanical Properties in High Manganese Austenitic Stainless Steel with Two Phase of Martensite and Austenite

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The effect of the austenite phase on mechanical properties of austenitic stainless steels was investigated using specimens with different volume fractions of retained and reversed austenite. Stainless steels with dual-phase co-existing martensite and austenite were successfully synthesized by deformation and reverse transformation treatment in the cold-rolled high manganese austenitic stainless steel and the ultrafine reverse austenite with less than 0.5 μm in size was formed by reverse transformation treatment in the temperature range of 500-750 °C for various times. With the increase of deformation degree, the volume fraction of retained austenite decreased, while that of the reversed austenite increased as the annealing time increased. From the results of the mechanical properties, it was obvious that as the volume fraction of retained and reversed austenite increased, hardness and strength rapidly decreased, while elongation increased. With regard to each austenite, reversed austenite indicated higher value of hardness and strength, while elongation suggested a lower value because of strengthening owing to grain refinement.

Keywords: deformation, retained austenite, mechanical property, transmission electron microscopy (TEM)

1. INTRODUCTION

Austenitic stainless steels are non-magnetic steels, which contain high levels of chromium and nickel, and low levels of carbon. Known for their formability and resistance to corrosion, austenitic stainless steels are the most widely used grade of stainless steel, for items such as industrial equipment, tanks, storage vessels and pipes for corrosive liquids. However, they are restricted in their application as industrial structural materials since they consist of an austenite phase at room temperature, with low yield strength. Accordingly, interest in improving their strength and broadening their applications has been increasing [1-5]. As a method for the mechanical improvement of these materials, solution strengthening by adding alloy elements can be suggested [6]. However, several critical issues such as cost performance by the addition of alloy elements, deterioration of weldability and difficulty in controlling phase transformation, have been anticipated. The only methods to have paid attention to improving strength and ductility have been an ultrafine graining method by reverse transformation, after transformation to martensite phase by working the austenite phase [3,4], and the fabrication of dual phases of martensite and austenite, by working with different temperatures, and working degree and reverse transformation with different temperatures and times [2]. In stainless steels with an austenite phase at room temperature, steels with both martensite and austenite phases can be synthesized with the partial transformation of austenite to a martensite phase (hereinafter referred to as 'retained austenite'), by controlling the working temperature and the working degree. In addition, it is possible to synthesize the dual-phase steels owing to the reverse transformation of the austenite phase (hereinafter referred to as 'reversed austenite'), after the total transformation of the austenite to the martensite phase [7]. However, it is thought that the mechanical properties would be varied owing to variation of the phase configuration in synthesizing stainless steels with dual phases, by the different methods mentioned above. Studies on the effect of the austenite phase on the mechanical properties in the stainless steels with dual phases are important, but still unsatisfactory for the development of dual-phase structural steels with much greater strength and ductility.

In the present study, the effect of the austenite phase on the mechanical properties of the austenitic stainless steel with dual phases is synthesized not only by working at room temperature but also by reverse transformation after working.

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Table 1. Chemical composition of specimen (wt%)

C	S	P	Si	Mn	Ni	Cr	Cu	Mo	Co
0.06	0.01	0.08	0.6	6.2	5.2	14.2	1.91	0.1	0.16

2. EXPERIMENTAL PROCEDURES

2.1. Materials

The specimen used in this study was a high manganese austenitic stainless steel with chemical composition as shown in Table 1, consisting of an austenite phase at room temperature with 14% Cr, 5% Ni and 6% Mn. It was used to transform most of the austenite to the martensite phase by cold-rolling degree with 70%. For the synthesis of the steel with dual phases, deformation induced martensite and retained austenite cold-rolling, with a variation of working degree was carried out at the same time as that of deformation induced martensite and retained austenite. For the steel with dual phases, deformation induced martensite and reversed austenite was worked by cold-rolling degree of 70% which leads to the transformation of austenite to martensite with more than 97% and then treated by reverse transformation at 500, 550, 600, 650, 700 and 750 °C for 10 min.

2.2. Microstructural observation

Microstructural observations of solution-treated specimen and cold-rolled specimen were conducted by using optical microscopy (Olympus, Gx51-212B) and transmission electron microscopy (TEM, Hitach, 200 kV) as a reference. In addition, the TEM observation of reversed austenite, cold-rolled by different working degree, was carried out after jet-polishing of thin film.

2.3. X-ray diffraction test

The volume fraction of austenite in a cold-rolled specimen, and a reverse-transformed specimen treated at 500 to 750 °C for 10 min after cold-rolling, was evaluated by relative integral intensity calculated from an x-ray diffraction pattern [8]. The measurement used Cu-Kα in a range of 10° to 80° with a scan speed of 1°/min.

2.4. Mechanical properties

Tensile strength and elongation of the specimens reverse-transformed at 500 to 750 °C for 10 min after cold-rolling degree by 70% were evaluated, based on ASTM E-8. The cross-head speed was 2 mm/min. In addition, a hardness test was conducted by Vickers micro-hardness with a load of 1 kg.

3. RESULTS AND DISCUSSION

3.1. Microstructure observation

Figure 1 represents an optical image of the specimen used for the synthesis of dual-phase steel with deformation induced martensite and retained austenite. It was clear that it consisted of single-phase austenite containing twin phases, which are well-known as one of general characteristics in austenitic steels. To synthesize specimens with dual phases, deformation-induced martensite and reversed austenite, cold-rolling degree by 70%, of the specimens was carried out prior to reverse transformation treatment.

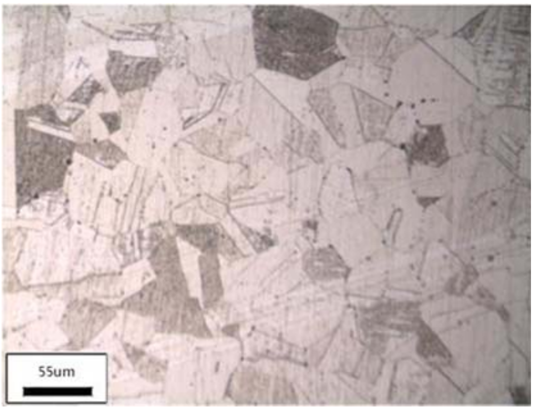

Fig. 1. Optical micrograph of high manganese austenitic stainless steel.

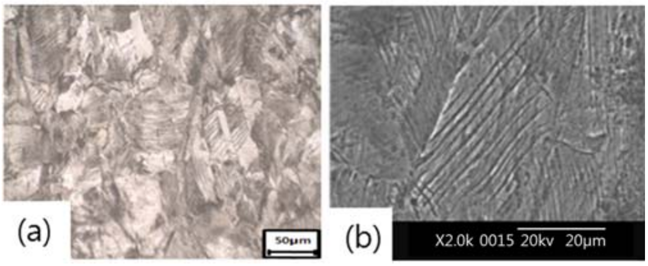

Fig. 2. Micrographs of 70% cold-rolled high manganese austenitic stainless steel: (a) optical and (b) SEM.

Figure 2 shows the optical and SEM image of the specimen, indicating that most of the austenite transformed to martensite by cold-rolling. Furthermore, the martensite was found to have specific orientation and cross-orientation (see Fig. 2(b)), showing the surface relief which is well-known as a phenomenon relating to martensite transformation [9]. To clarify the crystallographic analysis of martensite formed by cold-rolling in detail, TEM micrographs, (a) bright field image and (b) selected area diffraction patterns (SADP) with index of SAD pattern (c) dark field image of the specimen cold-rolled by 30% are shown in Fig. 3. Since some of the austenite transformed to α′-martensite (see (b) SADP) with a BCT crystal structure as a result of cold-deformation, the co-existence two phases, austenite and martensite, was clearly confirmed. In addition, the martensite was formed with a specifically ori-

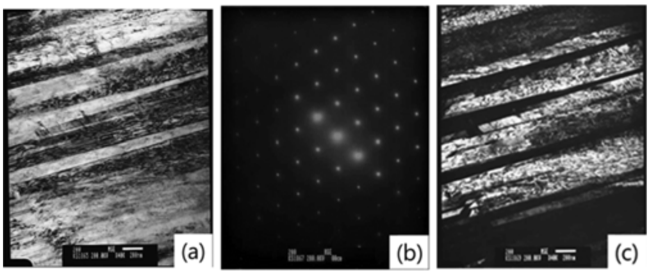

Fig. 3. TEM micrographs showing the deformation-induced martensite in 30% cold-rolled high manganese austenitic stainless steel: (a) bright field, (b) SADP by index, and (c) dark field.

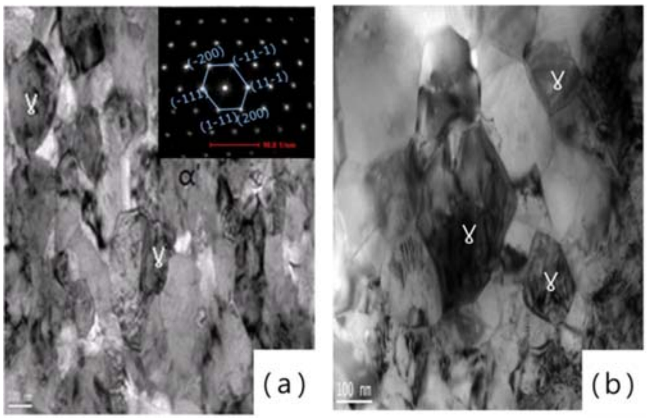

Fig. 4. TEM micrographs showing the effect of reverse treatment temperature in 70% cold-rolled high manganese austenitic stainless steel: (a) 550 °C and (b) 700 °C.

ented band type.

For the investigation of the reversed austenite by reverse transformation treatment, TEM micrographs of the specimen reverse-transformed at 550 °C and 700 °C for 10 min, after 70% cold-rolling was given in Fig. 4. The observation infers that some of martensite formed by cold-rolling was found to be partially reverse-transformed to austenite, with a grain size of 0.2 to 0.5 μm in the reverse-transformed specimen at 550 °C. Moreover, reverse transformation treatment at 700 °C facilitated reverse transformation, and led to the formation of reversed austenite with a single phase [10]. Furthermore, as the temperature increased to 700 °C, the volume fraction of austenite was increased and the size of the reversed austenite increased owing to grain growth.

3.2. Transformation behaviour of retained and reversed austenite

Figure 5 indicates the volume fraction of the retained austenite as a function of the degree of cold-rolling. It was evident that as the cold-work degree increased, the volume fraction of the retained austenite decreased, and then became zero at 70% owing to the formation of deformation induced martensite. Since the volume fraction of martensite transformed from austenite increased with an increase of degree of deformation, that of the retained austenite decreased remarkably.

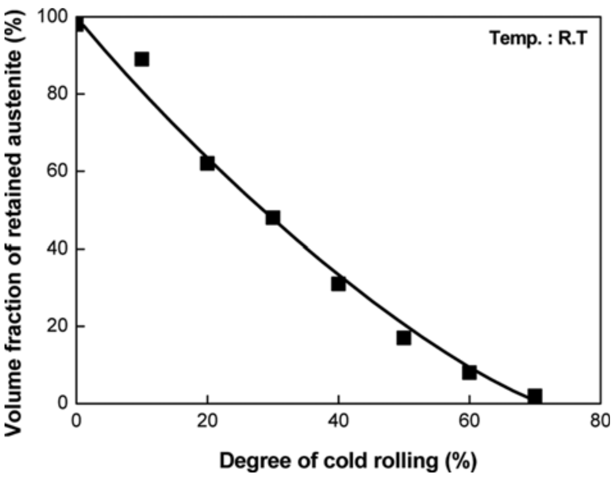

Fig. 5. Volume fraction of retained austenite as a function of degree of cold-rolling in high manganese austenitic stainless steel.

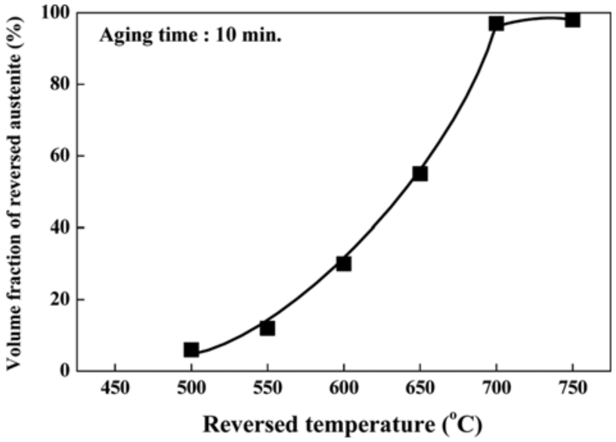

Fig. 6. Volume fraction of retained austenite as a function of reverse treatment temperature in 70% cold-rolled high manganese austenitic stainless steel.

Figure 6 represents the volume fraction of the reversed austenite obtained by annealing treatment at different reverse temperatures, 500 to 750 °C, for 10 min. It was confirmed that with an increase in annealing temperature the volume fraction of reversed austenite increased rapidly and then remained unchanged. From the results of TEM observations and the volume fractions of retained and reversed austenite, it was clarified that it is possible to synthesize structural steels with dual phases, not only by cold-rolling austenitic steels with different deformation degrees and temperatures, but also by reverse transformation after transforming austenite to the martensite phase by cold-deformation with different temperatures and times [7].

3.3. Effect of retained and reversed austenite on mechanical properties

As an evaluation of mechanical properties, a hardness and

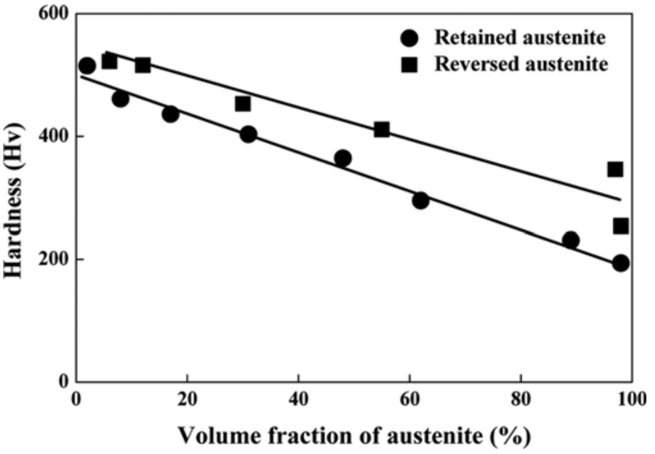

Fig. 7. Effect of retained and reversed austenite on the hardness of high manganese austenitic stainless steel with two phases of martensite and austenite.

tensile test of specimens with retained austenite and reversed austenite was conducted. The reversed austenite specimens were prepared by reverse transformation treatment at 500 to 750 °C, for different times, after cold-rolling by 70% while retained austenite specimens were synthesized by different degrees of cold-deformation.

Figure 7 indicates the hardness as a function of the volume fraction of retained and reversed austenite. It infers that the hardness of both austenite has a tendency to decrease with an increase of the fraction. Moreover, it was clearly confirmed that the hardness of reversed austenite was higher than that of the retained austenite.

Figure 8 shows the yield strength (a), tensile strength (b) and elongation (c) of the specimens with different volume fractions of the retained and the reversed austenite. Like the hardness result, the yield strength decreased with an increase in the retained and reversed austenite, while the yield strength of the specimen with the reversed austenite was higher than that of the specimen with the retained austenite. With regards of the tensile strength of the specimens with different volume fractions of the retained and the reversed austenite, it showed a similar tendency to decrease as the volume fraction of retained and reversed austenite increased, while the tensile strength of the specimen with reversed austenite was higher than that of the specimen with retained austenite. In contrast to the yield and tensile strength, elongations of each specimen indicated a tendency to increase, as shown in Fig. 8(c), revealing that it slowly increased up to 20%, but steeply increased above 20%. As noted previously, hardness, yield and tensile strength decreased while elongation increased, as volume fractions of retained and reversed austenite increased. This variation can be explained by fact that an increase of austenite may lead to a decrease in the volume fraction of martensite with higher hardness and strength [11]. In addition, the reason that the hardness and strength of reversed austenite are higher than those of retained austenite is because the reversed austenite has considerably finer grains with less than 0.5 μm, which leads to strengthening owing to grain refinement [3,4]. Previous studies [12,13] have shown that grain size is an important factor in stainless steels with regard to mechanical properties. Since the reversed austenite was transformed from cold-rolled martensite containing many defects and dislocations, moreover, it may result in increase of hardness and strength.

4. CONCLUSION

In order to clarify the effect of the retained and the reversed austenite on their mechanical properties, the austenitic stainless steels with dual phases, martensite and austenite, were synthesized by two different methods, cold-rolling by different cold-rolling degrees and reverse transformation treatment.

TEM observation inferred that steels with dual-phase coexisting martensite and austenite were successfully synthesized by deformation and reverse transformation treatment in the cold-rolled high manganese austenitic stainless steel and the ultrafine reverse austenite with less than 0.5 μm in size was formed by reverse transformation treatment in the temperature range of 500-750 °C.

In terms of mechanical properties as a function of the austenite volume fraction, it was found that with an increase of the retained and the reversed austenite, the hardness and strength was decreased, while elongation increased. Owing to effect

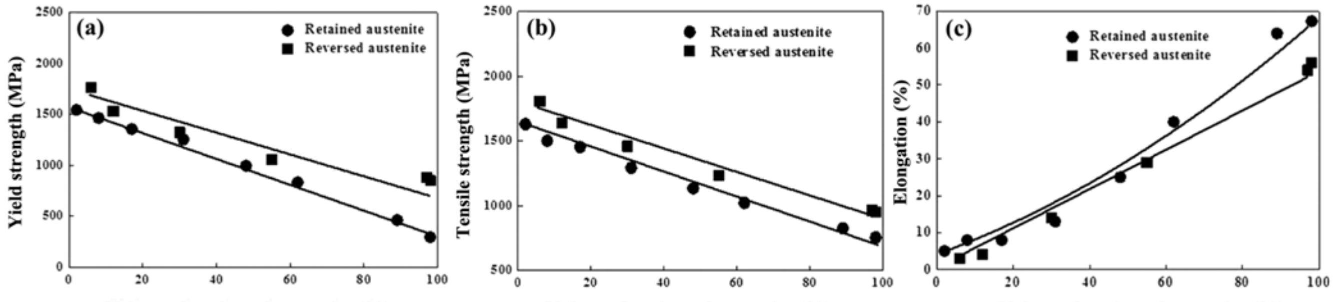

Fig. 8. Effect of retained and reversed austenite on (a) the tensile strength, (b) elongation, and (c) Yield strength in high manganese austenitic stainless steel with two phases of martensite and austenite.

of grain refinement and defects induced by reverse treatment, in addition, the reversed austenite indicated higher hardness and strength, but lower elongation than the retained austenite.

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