In-situ deformation behavior of Retained Austenite on TRIP steel

Kwang Kyun Park¹, Seung Taik Oh¹, Suk Min Baeck¹, Dong Ik Kim¹, Jun Hyun Han¹, Heung Nam Han², Sung-Ho Park², Chang Gil Lee³, Sung-Joon Kim³ and Kyu Hwan Oh¹

¹ School of Materials Science and Engineering, Seoul National University, Seoul, Korea
² Technical Research Laboratories, POSCO, Pohang, 790-785, Korea
³ Korea Institute of Machinery and Materials, Changwon, 641-010, Korea

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Abstract. To investigate the stability of retained austenite under plastic deformation and the change of volume fractions of each phase, the microstructural characterization such as shape and orientation of retained austenite as uniaxial tension tests, including HR-EBSD observations, for TRIP steel made by POSCO have been carried out. In-situ and ex-situ mechanical test with EBSD measurement revealed the deformation sequence of multi phase steels and predicted the stability of retained austenite with its size. The granular type (>1µm) of retained austenite transformed faster than that of lath or film type (<1µm), which is well known from TEM measurement.

Introduction

In Transformation Induced Plasticity (TRIP) steels, typically four phases are existing during services, such as ferrite, bainite, retained austenite and martensite. TRIP steels make use of the transformation induced plasticity effect, such that retained austenite is metastable at room temperature and will be transformed to martensite during straining [1]. TRIP steels for room temperature services have been developed by adding manganese and silicon as major alloying elements in order to control transformation behavior. Quenching after intercritical annealing is performed to an intermediate temperature above the martensite-start temperature, which allows the bainite transformation to occur during the isothermal holding. The remaining austenite, generally called retained austenite, is further enriched with solute carbon, which can shift the martensite start temperature below room temperature. A typical phase distribution of TRIP steel in the as-shipped condition is about 60 vol.% ferrite, 30-35 vol.% bainite, and 5-10 vol.% retained austenite. During services, the retained austenite will transform to martensite, which brings about a high resistance to local necking, and thus high uniform elongation values and enhanced formability. It has been recognized that the stability of retained austenite is crucial in terms of enhancing TRIP effect. The mechanical stability of retained austenite depends not only on its chemical stability, such as carbon and manganese contents, but also on some other stabilizing effects attributed to the differences in particle size, and the surrounding phases.

The Electron Back Scattered Diffraction (EBSD) technique can be used to get an orientation information together with position information and EBSD has been predominately for the determination of crystallographic textures [2-3], which can give the statistical data of texture, grain boundary, etc. The application of EBSD to determine the microtexture analysis of single phases is widely used. In case of multiphase material, the crystallographic structure of the measured point can be determined by indexing the obtained Kikuchi patterns [4-5]. Positional and orientation information together with phase identification can be obtained at a given measuring position and mapping can give the information over the whole area, from which the mechanical properties of the mapped area can be evaluated in various ways.

During straining of TRIP steels, the transformation mechanism from the retained austenite transforms to martensite can be analyzed after straining, generally in TEM ; i.e. ex-situ experiment. EBSD measurement equipped with straining equipment can give in-situ information of the transformation. The in-situ experiment with EBSD mapping can give basic informations on the phase transformation.

In this study, in-situ experiment of the TRIP steels was carried out to investigate the stability of retained austenite during deformation. The transformation characteristics were analyzed with its size and shape. The
mechanical stability of the film type and granular type of retained austenite was discussed together with their grain size.

**Experimental Procedure**

Materials used in this study were the TRIP steel from POSCO and the chemical composition was 0.16C-1.8Si-1.5Mn-0.04Al-0.044Nb-0.0048N. The starting materials were reheated at 1250°C and hot rolled to 3.0mm thickness. The finishing temperature of hot rolling was 870°C and coiled at 400°C.

The in-situ tensile specimens were mechanically polished parallel to the rolling direction and electropolished in 30% perchloric acid at −10°C by Struers Tenupol-3 electropolisher. The INCA CRYSTAL EBSD system from Oxford Instrument, installed on JEOL-6500F, was used to get EBSD mapping data.

A specially designed deformation stage was installed in EBSD. To get a high quality EBSD mapping data, the surface of tensile specimen was carefully prepared and set to in-situ deformation stage mechanically and electrically stable. Each EBSD mapping was carried out after the straining at the in-situ deformation stage. The volume fraction and distribution of retained austenite and ferrite phase were observed using EBSD.

**Results and Discussion**

Fig. 1 shows the EBSD phase maps of in-situ strained TRIP steel at the same position. The ferrite phases probably composed of polygonal ferrite and bainite acts as continuous matrix phase. The retained austenite phase has two types of granular(polygonal) type and film(lath) type. The granular type located between ferrite grains and film type located in the ferrite matrix, which is believed to be located between bainite matrixes. The volume fraction of retained austenite decreased with increasing the strain. As the nominal strain increased from 0% to 26%, the volume fraction of retained austenite decreased from 14.9% to 5.6%. This phenomenon shows the typical TRIP effect. At the beginning of tensile straining, the granular type retained austenite transformed into martensite and film type remained as shown in Fig 1(b). With increasing tensile strain, the remaining granular type retained austenite transformed into martensite upto the tensile strain of 26%, at which the film type retained austenite still remained as shown in Fig 1-(c, d).

Fig. 2 shows the experimentally measured flow curves of ex-situ tensile deformation along longitudinal and transverse directions of TRIP steels. The tensile strength and total elongation of longitudinal direction is higher than those of transverse direction. Fig. 3 shows the EBSD measured volume fractions of retained austenite.
along longitudinal and transverse direction during ex-situ deformation and that during in-situ deformation. In ex-situ deformation, the volume fraction of retained austenite along longitudinal direction is higher than that along transverse direction in whole tensile deformation range. These differences between the volume fractions of longitudinal and transverse specimen can be a possible reason of the difference of tensile strength and total elongation as shown in Fig. 2. The volume fraction of retained austenite decreased with increasing strain at in-situ and ex-situ deformation. As shown in Fig. 3 the volume fraction of retained austenite stop to decrease after 15% straining, which can be seen in Fig 1-(c) and (d). After 15% straining, the granular retained austenite transforms into martensite and the decrease of volume fraction is mainly due to the transformation of granular type of retained austenite. Due to local necking of in-situ specimen, further measurement could not be carried out. The high value of volume fraction at the starting strain and during straining is probably related to the local variation of volume fraction. To get statistically reliable data, larger area or multiple mapping is required.

![Fig. 2 Experimentally Measured Stress-Strain curves of TRIP Steels](image)

Fig. 4 shows the inverse pole figures of sample normal of retained austenite with the strain of each step during in-situ deformation on TRIP steel at 0%, 5.2%, 14.7% and 26.0% strain, respectively. In-situ tensile specimen has initially several orientation components of major {691}<1 2 11>, Copper orientation {112}<111>, Goss orientation {110}<001>, R orientation {123}<412>, Brass orientation {110}<112>. During straining, {691}<1 2 11> and Copper orientation {112}<111> orientation rapidly disappear. Most of orientation remained at 26.0% strain looks like random as shown in Fig.4 (d).
Fig 3. Measured Volume Fraction of TRIP steel obtained from EBSD

Table 1 shows the change of the Equivalent Circle Diameter (ECD) of retained austenite during in-situ deformation. ECD during in-situ deformation was a maximum value of $3.69 \mu m$ at the initial state, e.g. 0% strain. As the strain proceeds, ECD of retained austenite decreased to the maximum value of $1.16 \mu m$ at 26.0% strain. The decrease of the maximum and average ECDs shows that the granular type retained austenite transforms to martensite during straining.

Most of the retained austenite is located on ferrite-ferrite and/or ferrite-bainite boundaries, or trapped in between lath bainitic ferrite. In the former case, the retained austenite is mostly blocky or plate shaped, and the sizes range from $0.5 \mu m$ to $2 \mu m$. In the latter case, the retained austenite is interlayer lath or film type with $0.1 \mu m$ to $0.5 \mu m$ [6]. These facts suggest that smaller retained austenite has higher stability and transforms to martensite at higher strains. The retained austenite with higher stability (smaller size and higher carbon content) may require the strain accumulation to introduce shear bands or deformation twins as nucleation sites for martensite transformation[7]. For those larger retained austenite, stacking faults have been usually observed, and they can also act as nucleation sites for martensite transformation. The critical strain required for initiating martensite transformation will be smaller since there are already some nucleation sites available.

Fig. 4 Inverse pole figures of retained austenite of in-situ deformation with each strain on TRIP steel at (a) 0%, (b) 5.2%, (c) 14.7% and (d) 26.0%
Table 1. The change of Equivalent Circle Diameter (ECD) and volume fraction of retained austenite during in-situ deformation.

<table>
<thead>
<tr>
<th>Nominal strain</th>
<th>Equivalent Circle Diameter (ECD) of retained austenite (µm)</th>
<th>Vol. fraction of retained austenite (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Granular type (1µm&lt;)</td>
</tr>
<tr>
<td>0 %</td>
<td></td>
<td>0.41~3.69</td>
</tr>
<tr>
<td>5.2 %</td>
<td></td>
<td>0.39~2.96</td>
</tr>
<tr>
<td>14.7 %</td>
<td></td>
<td>0.34~1.37</td>
</tr>
<tr>
<td>26.0 %</td>
<td></td>
<td>0.33~1.16</td>
</tr>
</tbody>
</table>

As above mentioned, the retained austenite can be divided into two categories according to its size such as film type(<1µm) and granular type (>1µm). Most of retained austenite larger than 1µm, called granular type, have transformed to martensite at strain about 15%. Fig. 6 shows the change of volume fraction of retained austenite with increasing straining. As mentioned, the volume fraction of granular retained austenite decreases and that of film type remains unchanged. Most of decrease of the total volume fraction is due to the decrease of granular type, as shown above.

**Conclusion**

The stability of retained austenite with its size was evaluated from in-situ deformation installed in EBSD equipment. As the strain proceeds, the volume fraction and the intensity of \{691\}<1 2 11> and Copper orientation \{112\}<111> texture of retained austenite decreases or disappear. Granular type retained austenite (>1µm) transforms at the beginning of straining and transforms to martensite at about 15% strain. The film type retained austenite (<1µm) can be retained to higher strains. Most of transformation induced plasticity effect at low tensile strain is attributed to granular type retained austenite.

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Fig. 6 The size effect on the stability of retained austenite on TRIP steel during in-situ straining deformation.

References