Transformation Behavior of Retained Austenite in Hydroformed TRIP Steel
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Abstract. Tube hydroforming process as an optimum process for manufacturing structural parts of automotive and TRIP steel as a material of best strength-ductility balance have drawn increasing attention in the automotive industry. Employment of the TRIP phenomenon to produce steels with higher strength without loss of formability has been the subject of many recent investigations. To evaluate the stability of retained austenite, average volume fraction and micro-texture evolution under the various deformation mode, in-situ and ex-situ uniaxial tensile test and hydroforming test were performed and analyzed by EBSD. Granular type austenite was more rapidly transformed to martensite than film type does. The austenite of bended (for tube making) or hydroformed sample is more unstable than that of uniaxial mode, and thus more rapidly transformed to martensite. As deformation proceeds in uniaxial tension mode, the intensity of Goss and Brass component was gradually decreased.

Introduction
In order to achieve the most economic product with the best performance, it is important to develop proper material suited to user’s purpose and to choose proper manufacturing process. Tube hydroforming process has drawn increasing attention in the automotive industry, because the technology provide a number of advantage over conventional stamping process including reduction in the number of parts, manufacturing costs and increase in dimensional accuracy.

From the development of proper material point of view, employing the TRIP phenomenon to produce steels with higher strength without loss of formability has been the subject of many recent investigations. Most of the published work concentrates on the effects of alloying elements and heat treatment parameters on the properties of cold rolled TRIP steels[1,2]. Characterization for relationship between both material parameters (e.g. phase transformation characteristics, texture, morphology and size of austenite etc.) and process parameters (deformation mode etc.) is required to understand transformation behavior of retained austenite during hydroforming of TRIP steel.

The present study was conducted to investigate the effect of deformation path (uniaxial tension and T-shape hydroforming) on the material characteristics such as retained austenite transformation, texture change during deformation. To examine the austenite phase transformation phenomenon and micro-texture change subjected to the different deformation mode, Electron Back Scattered Diffraction (EBSD) measurement was used.
Fig. 1 Tube making process for Hydroforming Experiment

Experimental Procedure
The chemical composition of the steel investigated in this study is 0.2C-1.6Mn-1.63Si-0.044Nb TRIP steel. The alloy was heated to 1250°C and hot rolled to 3.0mm thickness. The finishing temperature of hot rolling was 870°C and cooled to 400°C at coiling temperature.

Tensile specimens were machined parallel to the rolling direction from the received raw plate. Also, tubes for hydroforming experiment were fabricated through U-O bending technique, with their longitudinal axes parallel to the rolling direction as shown in Fig. 1. Tooling for T-shape hydroforming is shown in Fig. 2. The internal pressure forces the tube to form to the shape of the die cavity, and the axial force is exerted at the end of the tube to feed material during forming.

The specimens for EBSD observation were cut out from the deformed material, and after a mechanical polishing, electro-polished in 30% perchloric acid at -10 °C. The volume fraction and distribution of retained austenite phase were analyzed using an electron back scattering patterns (EBSP). According to the EBSP pattern each point could be identified as ferrite or austenite. The EBSD measurement was done by INCA crystal, which is installed on JEOL 6500F FEG-SEM.

Results and Discussion
Fig. 3 shows phase identification of both tensile strained specimens((a) to (d)) and pipe((e)) made by U-O bending. At tensile test and pipe making, the vol.% of retained austenite decreased with increasing the strain. For the specimens which was subjected to uniaxial tension mode, as
the strain increase from 0% to fracture strain, volume fraction of retained austenite decrease from 6.3% to 3.4%. In case of pipe which was subjected to about 4% strain by bending or plane strain deformation mode, the volume fraction of retained austenite is 4.8%, which corresponds to that of specimen strained to 10~15% under uniaxial deformation mode. In hydroformed sample (H part of Fig. 2), all retained austenite was transformed to martensite. This fact shows that the austenite to martensite transformation behavior of TRIP steel by deformation is depends on deformation mode. The austenite of specimen which was subjected to plain or bending mode seems to be more unstable than that of uniaxial tension mode. Patel studied the deformation mode dependency of transformation behavior of TRIP steel under the stress state point of view[3]. He considered that the driving force of transformation of austenite is a sum of both that caused by shear stress applied to habit plane (crystal lattice shear mechanism) and that caused by normal stress (volume expansion). When the specimen subjected to multi-axial stress state, the driving force can be divided to effective stress ($\sigma_{eq}$) term and hydrostatic stress ($\sigma_m$) term. Under the same equivalent strain ($\varepsilon_{eq}$), the equivalent stress of plane strain and uniaxial mode is similar to each other, but the hydrostatic stress of plane strain mode is about 2 times higher than that of uniaxial deformation mode. Therefore, the austenite subjected to uniaxial tension mode is more stable than that subjected to bending mode.

![Fig. 3 EBSD maps showing the strain induced transformation of retained austenite](image)

(a) 0% (6.3% R.A), (b) 5.0% (6.1% R.A), (c) 10.0% (6.4% R.A), (d) 20.0% (3.9% R.A) strained tensile specimen and (e) pipe (4.8% R.A) R.A : retained austenite
Fig. 4 shows the volume fraction of retained austenite measured by EBSD during in-situ and ex-situ tensile deformation. Ex-situ deformation means the deformation by typical uniaxial tensile test, and in-situ deformation means the deformation by the special in-situ deformation stage in EBSD equipment. Since the same area can be observed during in-situ deformation, it can be seen that volume fraction of the austenite gradually decreases with increasing strain. The volume fraction of retained austenite during in-situ deformation decreases faster than that during ex-situ deformation. After 20~25% tensile deformation, the volume fraction of retained austenite is almost the same in two cases. The volume fraction of ex-situ deformation is an average value over whole specimen and that of in-situ deformation is measured at local area of EBSD measurement, which can give inhomogeneous transformation behavior of retained austenite to martensite during in-situ deformation. This local inhomogeneity during deformation and localized measurement seems to be related with faster decrease of volume fraction at during in-situ deformation. The relation between austenite stability and austenite morphology can be analyzed from in-situ tensile test in EBSD equipment. Fig. 5 shows the phase map during in-situ deformation. It can be seen that granular type austenite is located on the ferrite-ferrite and/or ferrite-bainite boundary, and the film type austenite is located on interlayer between lath bainitic ferrite. During deformation, granular austenite (circled region) located on ferrite-ferrite or ferrite-bainite boundary starts to transform to martensite. At about 15% strain, most of granular type austenite transforms to martensite. The film type austenite located between lath bainitic ferrites...
remains at strain of 17.4%. A Film type austenite which is surrounded by a hard phase such as bainite or martensite difficult to be deformed at the initial stage of deformation when ferrite matrix of soft phase is transformed predominantly. As the specimen heavily deformed, the shear bands or deformation twins as nucleation sites for martensite are introduced in austenite grain[4]. At final stage of deformation at which the ferrite matrix is strain hardened, the film type austenite transforms to martensite. During in-situ deformation as shown in Fig. 5, the film type austenite still remains due to small tensile straining.

Fig. 6 shows the normal direction inverse pole figure from the uniaxial tested specimen to a given strain(0~20%) and pipe. Fig. 7 shows the texture evolution with uniaxial tension strain. Initially TRIP steel has a Brass{110}<112> and Goss {110}<001> component. As deformation proceeds, the intensity of Goss and Brass component gradually decrease. It can be seen from Fig.6 and Fig.7 that above 20% strain, austenite grain is randomly distributed. Pipe has the major component of Copper and minor component of R, Cube and Brass. Since the texture analysis by EBSD is restricted to local area, it is necessary to obtain large area data acquisition and the statistical treatment of those data for the macroscopic texture analysis.
Conclusion
Phase transformation of austenite to martensite (phase stability) and micro texture change subjected to different deformation mode (uniaxial tension, in-situ tension and T-shape hydroforming test) was studied by high resolution EBSD. As strain increases, the volume fraction of the retained austenite decreased and granular type austenite is more rapidly transformed to martensite than film type austenite. Because hydrostatic stress of plane strain mode is higher than that of uniaxial deformation mode, the austenite of bended (for tube making) or hydroformed sample is more unstable than that of uniaxial mode, and thus more rapidly transformed to martensite. As deformation proceeds in uniaxial tension mode, the intensity of Goss and Brass component gradually decreases and become to be random.

References