実験報告書様式（一般利用課題・成果公開利用）

（ ※本報告書は英語で記述してください。ただし、産業利用課題として採択されている方は日本語で記述していただいても結構です。）

MLF Experimental Report

提出日 Date of Report	
課題番号 Project No. 2017A0136 実験課題名 Title of experiment In-situ neutron diffraction analysis for transformation-induced plasticity effect of ultrafine-grained metastable austenitic steel 実験責任者名 Name of principal investigator Akinobu Shibata 所属 Affiliation Kyoto University	装置責任者 Name of responsible person Kazuya Aizawa 装置名 Name of Instrument/（BL No.） BL19 実施日 Date of Experiment 6/26-27

試料、実験方法、利用の結果得られた主なデータ、考察、結論等を、記述して下さい。（適宜、図表添付のこと）

Please report your samples, experimental method and results, discussion and conclusions. Please add figures and tables for better explanation.

1. 試料 Name of sample(s) and chemical formula, or compositions including physical form.

Fe-24Ni-0.3C (mass%) alloy

2. 実験方法及び結果（実験がうまくいかなかった場合、その理由を記述してください。）

Experimental method and results. If you failed to conduct experiment as planned, please describe reasons.

In general, structural materials, particularly steels, are desired to manage both high strength and large ductility. Transformation-induced plasticity (TRIP) effect is one of the promising ways to achieve simultaneously high strength and large ductility by utilizing deformation-induced γ (fcc phase) $\rightarrow$ α' (bcc or bct phase) martensitic transformation. Deformation-induced martensitic transformation is a phenomenon that martensitic transformation occurs during deformation. Although TRIP steels exhibit good mechanical properties and have been applied to automobile steel sheets, it is an important technical challenge in the steel society to further improve mechanical properties of TRIP steels from the recent environmental and economic points of view.

The present study investigated TRIP effect of metastable austenitic steels with grain sizes of 1 μm, 4 μm, and 34 μm by *in-situ* neutron diffraction. The results of the specimen with grain size of 34 μm was obtained in our previous beamtime (2016E0003). **Figure 1** shows nominal stress-strain curves of the specimens with various grain sizes. With decreasing the grain size from 35 μm to 1 μm, the yield strength increases from 180 MPa to 420 MPa and the total elongation also increases from 83 % to 104 %, while the ultimate tensile strength slightly decreases from 1100 MPa to 950 MPa. The ultrafine- and fine-grained specimens (d_γ = 1 μm and 4 μm) exhibit a better combination of strength and ductility than that of the coarse-grained specimen (d_γ = 35 μm). Work-hardening rates and volume fractions of martensite are presented in **Figure 2(a) and (b)**, respectively, as a function of the true

2. 実験方法及び結果（つづき） Experimental method and results (continued)

strain. For all the three specimens, the work-hardening rates firstly decrease, then start to increase at certain strains, which depend on grain size. We find that the increase of the strain hardening rate is attributed to the deformation-induced martensitic transformation, because the strain, at which the martensitic transformation starts, corresponds very well with the strain where the strain hardening increases. However, the enhancement of the strain hardening rate decreases with decreasing the grain size of austenite. This is because stability of austenite increases by grain refinement.

Figure 3 shows changes of lattice strain of (111) austenite plane and (110) martensite plane of the specimens with different grain sizes as a function of the applied stress. Before the onset of deformation-induced martensitic transformation, the lattice strains of (111) austenite plane have a linear relationship with the applied stress. After the occurrence of deformation-induced martensitic transformation, the lattice strains of (111) austenite plane become lower than the linear relationship due to the stress partitioning of martensite. On the other hand, the lattice strains of (011) martensite plane quickly increase with increasing of the strain, suggesting that the phase stress of martensite increases.

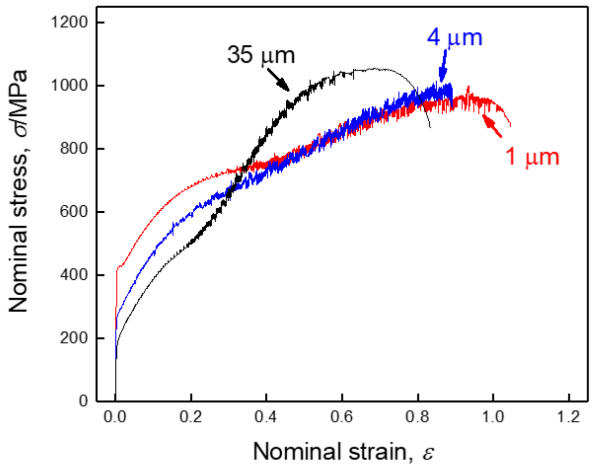

Figure 1 Nominal stress-strain curves of the specimen with different grain sizes.

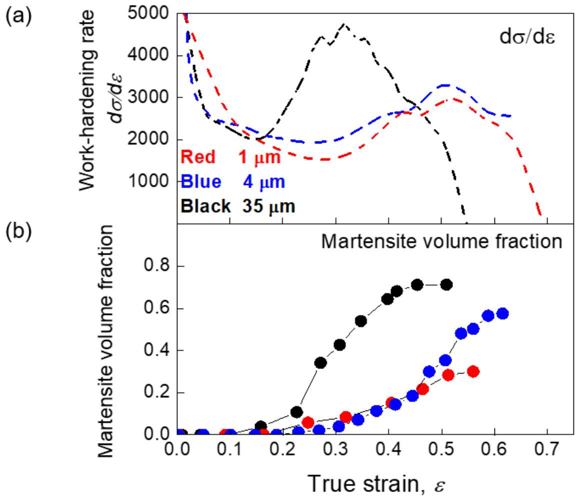

Figure 2 (a) Work-hardening rate curves and (b) changes in martensite volume fractions of the specimens with different grain sizes, plotted as a function of true stress

The phase stress was roughly estimated by the following equation: $\sigma_{phase} = E_{hkl}\ \varepsilon_{hkl}$, where σ_{phase} is phase stress, ε_{hkl} is lattice strain of (hkl) plane, and E_{hkl} is diffraction elastic constant of (h k l) plane. The total stress of specimen was calculated by rule of mixture: $\sigma_{total} = \sigma_{mart}\ f_{mart} + \sigma_{aust}\,(1 - f_{mart})$. The results are summarized in **Figure 4**, which reveal that the flow stress of the specimen could be formulated well by the rule of mixture. For all the three specimens, the phase stress of martensite is much larger than that of austenite. As shown in **Figures 3 and 4**, with decreasing the grain size, the phase stress of austenite at a given strain increases due to the grain refinement strengthening. The phase stresses of martensite in the specimens with grain sizes of 35 μm and 4 μm are almost the

2. 実験方法及び結果（つづき） Experimental method and results (continued)

same. However, when the grain size decreases to 1 μm, the lattice strain of martensite significantly increases with increasing of the strain. This result suggests that the ultrafine-grained specimen exhibit large work hardening due to the large phase stress of martensite, even though deformation-induced martensitic transformation is suppressed to some extent by grain refinement.

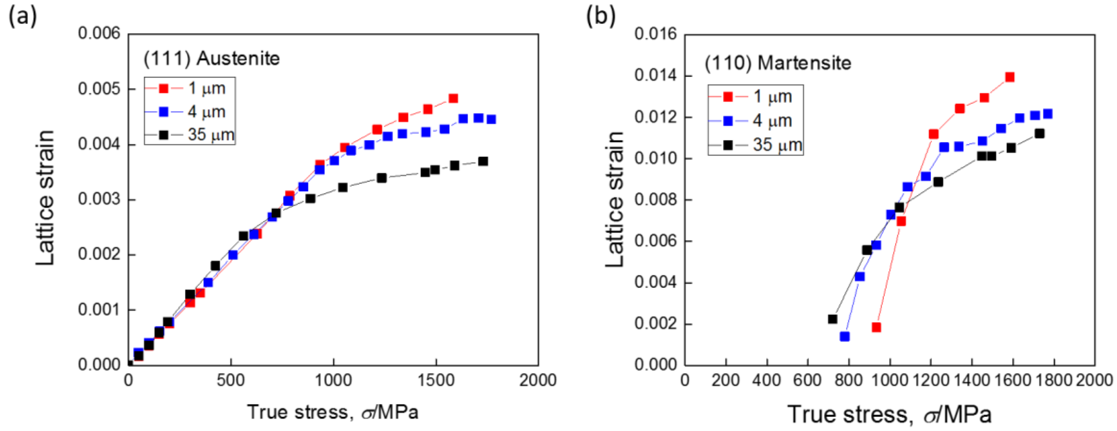

Figure 3 Changes of lattice strains of (a) (111) austenite plane and (b) (110) martensite plane as a function of true stress.

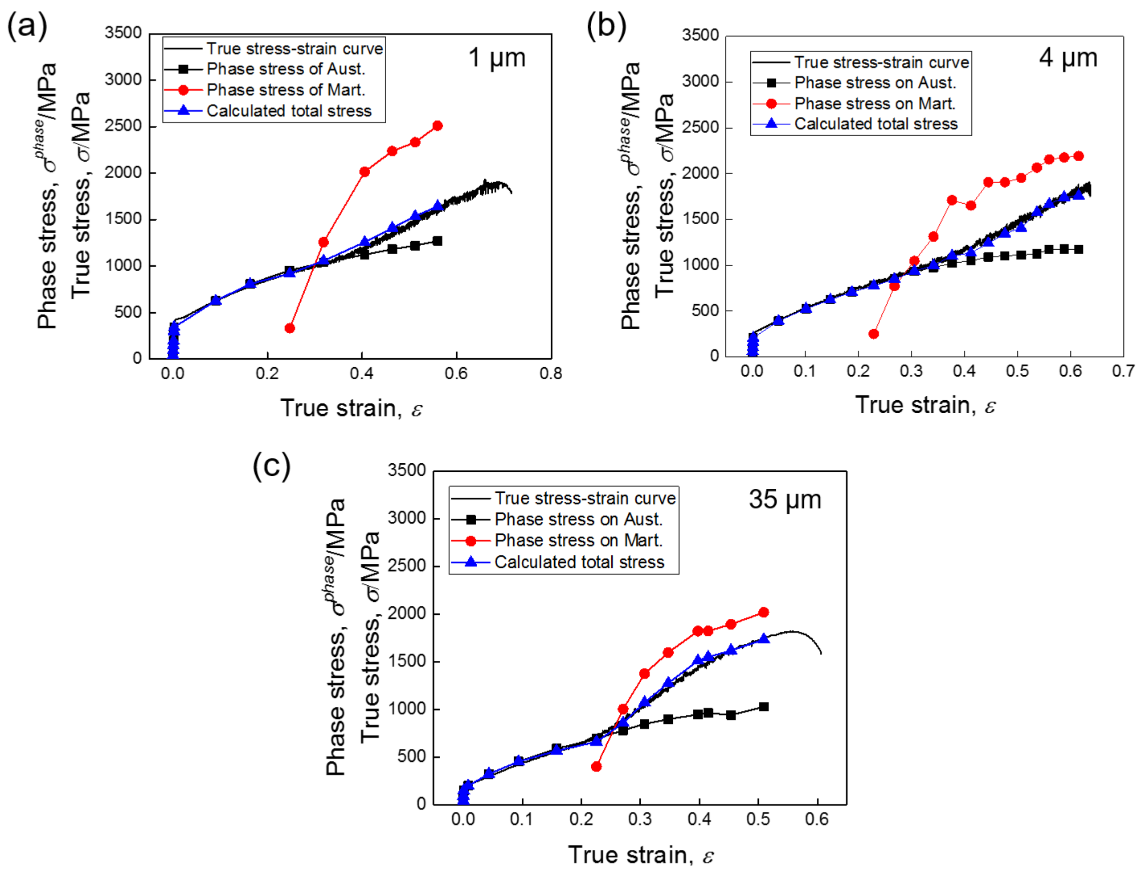

Figure 4 Changes of phase stress of austenite, phase stress of martensite, and total stress of the specimens with different grain sizes; (a) 1 μm; (b) 2 μm; (c) 35 μm.