（ ※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. 2015A0294 実験課題名 Title of experiment Investigation of Visco-Elasto-Plastic Deformation Behavior through In-situ Measurement of Dislocation Density Evolution in Plastic Deformation Process of High-Strength Steel Sheets 実験責任者名 Name of principal investigator Masato Takamura 所属 Affiliation RIKEN	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 2-4, November, 2015

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.

Cold-rolled steel sheets with the strength of 270(IF steel), 590(HSLA), 780(HSLA) and 980(Dual Phase) MPa.

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.

EXPERIMENTAL METHOD:

In-situ measurement of diffraction profile for the analysis of lattice strain and dislocation density during the stress relaxation process was performed. The test pieces for uniaxial tension of mild and high-strength steel with the thickness ranging from 1.04 to 3.36 mm in rolling direction were used. The geometry of the sample is shown in **Fig. 1**. The measurement was performed during the uniaxial tension phase with strain rates ranging from 1.0 x 10^{-5} $s^{-1}$to 1.0 x 10^{-3} s^{-1}, and the crosshead stops after uniaxial tension with 5%, 10%, 15% and 20% elongation. Each measurement was carried out at each strain rate and elongation level before and after crosshead stops. The measurement time during the stress relaxation processes were ranging 2 hours. The experimental conditions are listed in **table 1**. Definition of the measurement time of sample deformation phases are shown in **Fig. 2**.

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

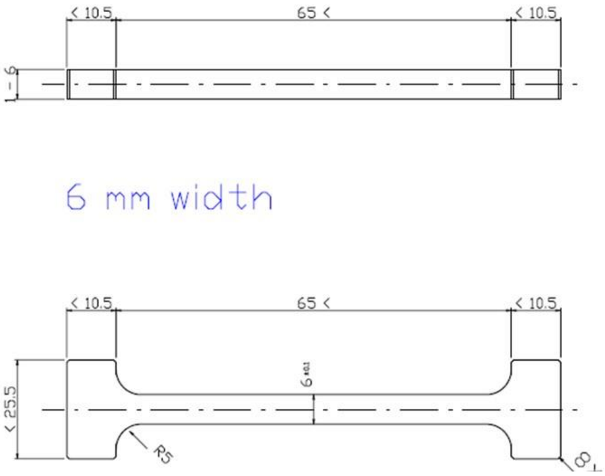


Fig. 1. Geometry of samples

Table 1. Experimental conditions

Experiment No	1	2	3	4	5	6	7	8	9	10
Material	780	590	IF	780	IF	IF	590	980	IF	IF
Strain rate[/s]	1.00E-03	1.00E-03	1.00E-03	1.00E-04	1.00E-03	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
Width mm	6.055	6.027	5.97	6.056	6	6	6.018	6.002	6.01	6.01
Thickness mm	3.349	3.281	1.06	3.353	1.092	1.047	3.293	1.201	1.055	1.051
Elongation	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.15
Δstep 1 [min]	15	15	15	15	15	15	15	15	30	30
Δstep 2 [s]	5.00E+01	50	50	500	50	500	500	500	1000	1500
Δstep 3 [h]	2	2	2	2	2	2	2	2	2	2
Δstep 4 [min]	15	15	15	15	15	15	15	15	30	30
t4 [sec]	9050	9050	9050	9500	9050	9500	9500	9500	11800	12300

Experiment No	11	12	13	14	15	16	17	18	19	20
Material	780	IF	SS400	SS400	SS400	SCM440	780	980	IF	IF
Strain rate[/s]	1.00E-05	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-03	1.00E-05	1.00E-04
Width mm	6.049	6.009					6.056	6.004	6.007	6.004
Thickness mm	3.357	1.043					3.354	1.211	1.039	1.067
Elongation	0.05	0.2	Maximum	Maximum	Maximum	Maximum	0.05	0.05	0.05	0.05
Δstep 1 [min]	15	30					15	30	30	30
Δstep 2 [s]	5.00E+03	2000					500	50	5000	500
Δstep 3 [h]	2	2						2	2	
Δstep 4 [min]	15	30					30	30	30	30
t4 [sec]	14000	12800						10850	15800	

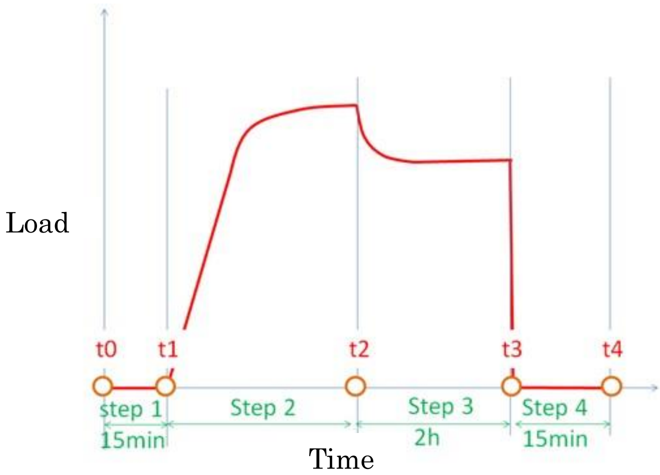


Fig. 2. Definition of measurement time

EXPERIMENTAL RESULTS:

Strain gauges were attached on the center of each sample for the strain measurement. The samples were held in the tension testing machine with a set of attachment brackets, as shown in **Fig. 3**.

The neutron diffraction patterns were obtained by Time-of-Flight method in BL19 (TAKUMI). A radial collimator with the slit width of 5mm. A schematic view and a photograph of the experimental setup is shown in **Fig. 4** and **5**, respectively.

Diffraction profiles were obtained for all the tension-relaxation experiments. **Fig. 6** shows the profiles obtained for samples No. 4 and 17, which correspond to 780 MPa grade HSLA with 5% elongation, strain rate of 1.0 x 10^{-4} s^{-1}.Profiles shown in this figure were obtained immediately after 5% elongation (No. 17), and after 2 hours relaxation (No.4). Profiles obtained with several different accumulation times are also shown in this figure. Diffraction peaks corresponding to the lattice plane (110), (200), (211), (220), (310), (222) and (321) can clearly be observed.

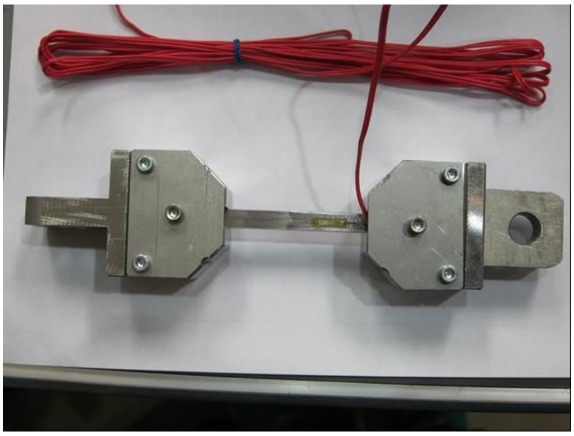


Fig. 3. Sample, strain gauge and brackets

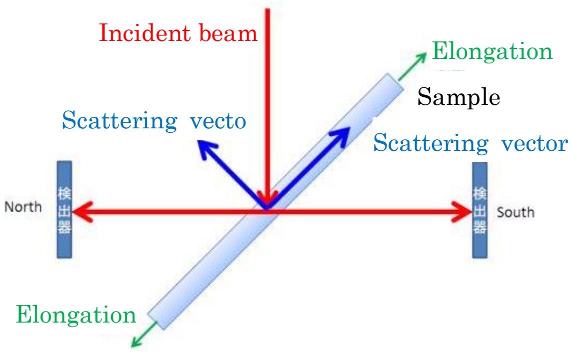


Fig. 4. Schematic view of experimental setup

Fig. 5. Photograph

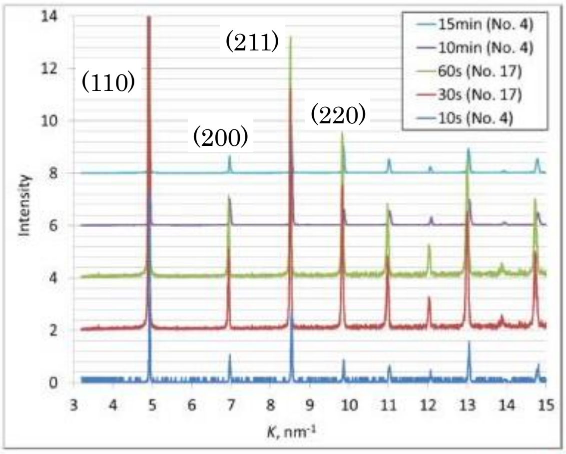
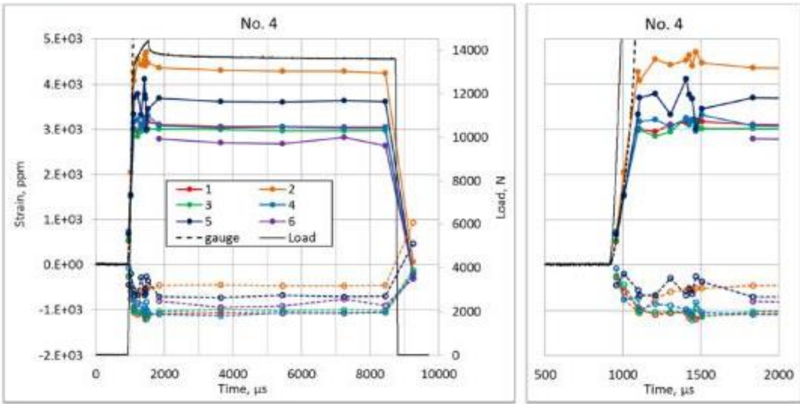


Fig. 6. Profiles obtained for samples No. 4 and 1



Peak	1	2	3	4	5	6
hkl	110	200	211	220	310	222
E, GPa	223	166	223	223	183	251

Fig. 7. Variation of lattice strain

Fig. 7 shows the variation of lattice strain of (110), (200), (211), (220), (310) and (222) planes for the sample No. 6 (IF steel, 5% elongation, 10^{-4} s^{-1} strain rate). Black line shows the load measured by load cell attached on the tension testing machine. By comparing these lattice strains with the strain data obtained by the strain gauges, we can investigate the variation of strains during the stress relaxation stage, with respect to the direction of crystal grains. These results can also be compared with numerical simulations of deformation, such as crystal plasticity finite element method (CP-FEM), in order to understand the mechanics of stress relaxation.

We tried also to investigate the dislocation density by line profile analysis with modified Williamson-Hall / Warren-Averbach method in conjunction with CMWP (Convolutional Multiple Whole Profile) method. The results of IF steel (sample No. 6 and 20) are shown in **Fig. 8**. From these results, the change in dislocation density before and after elongation can be observed. However, we need more precise analysis to detect the variation of the dislocation density in stress relaxation stage.

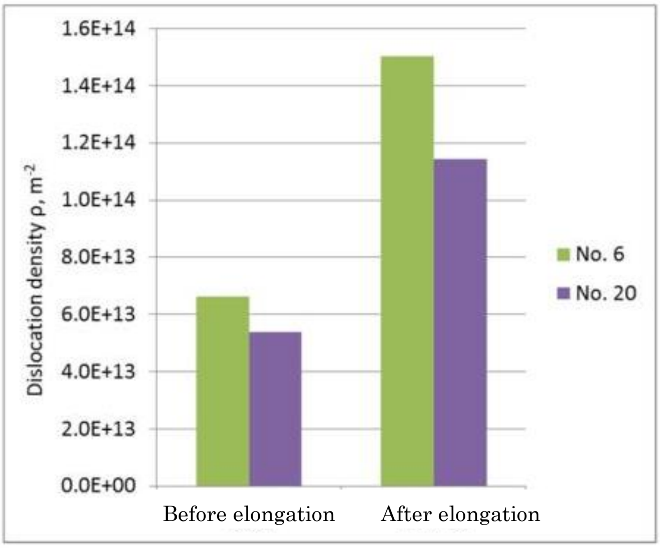


Fig. 8. Results of line profile anaysis

CONCLUSIONS:

- Variation in lattice strain for various lattice plane during stress relaxation was successfully detected.
- Variation in dislocation density between before and after deformation was able to be detected.
- We need to perform more precise analyses to detect the variation of the dislocation density in stress relaxation stage.