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# Influence of carbon content on cold rolling and recrystallization texture in polycrystalline 3% Si-Fe

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**Abstract.** The influence of carbon content on cold rolling and recrystallization texture in polycrystalline 3%Si-Fe under the relatively high rolling reduction condition has been investigated. The main component of recrystallization texture was {554}<225> orientation in ultra low carbon (ULC) 3%Si-Fe and {411}<148> orientation in low carbon (LC) 3%Si-Fe. The origin of {411}<148> recrystallization texture development in LC 3%Si-Fe is discussed in terms of the rotation of deformation twin from {100}<011> to {411}<148> orientation with the generation of the slip bands inside the neighboring matrix grain {111}<011>. The rotation axis of this crystal rotation was estimated <112> axis. Assuming the single slip system activation in BCC metal, crystal rotation around <112> axis indicates an activation of {110}<111> slip system. In terms of Schmid factor, {112}<111> slip system must be activated in {100}<011> matrix. This is not in agreement with the estimation of {110}<111> slip system activation. Detailed observation on the cold rolled sample revealed that common slip plane passed through the deformation twin and surrounding deformed matrix grains. It is considered that slip plane matching (SPM) with neighboring grains activates the lower Schmid factor slip system in deformation twin. These results suggest that not only Schmid factor but also SPM with neighboring grains should be considered to decide the active slip systems in polycrystalline metals.

## Introduction

Recrystallization textures of cold rolled and annealed steels strongly influence their mechanical and magnetic properties. Development of <111>//ND fiber texture contributes the superior deep-drawability, which is preferred for automobile and white goods steels [1]-[3]. Development of near <100>//ND texture, for example, {100}<001> or {411}<148> improves the magnetic properties, which is preferred for electrical steels [4]-[5].

It is well known that the main component of recrystallization texture changes from <111>//ND fiber to {110}<001> orientation with increasing the carbon content in deep drawing steel (Si is not added intentionally) [6]-[8]. In the previous studies using single crystal, {110}<001> recrystallized grains nucleated from the shear bands in cold rolled specimen [9][10]. Ordinary steel sheets have polycrystalline microstructure, so it is important to investigate the deformation and recrystallization behavior in polycrystalline specimen. Furthermore, most previous studies were conducted under relatively low cold rolling reduction. Reducing the thickness effectively improves the iron loss of electrical steel products [11][12], so it is important to investigate the deformation and recrystallization behavior under high cold rolling reduction.

In our previous investigation, the influence of carbon content on recrystallization texture in polycrystalline 3%Si-Fe under relatively high cold rolling reduction has been investigated [13]. In this work, to further clarify the mechanism of {411}<148> recrystallization texture evolution under the above condition, more detailed investigation has been conducted by applying SEM-electron backscattered diffraction pattern (EBSP) analysis.

## Experimental procedure

The experiments were carried out using two kinds of materials, Ti bearing ultra low carbon (ULC) 3%Si-Fe (Fe-2.96%Si-0.07%Mn-0.001%C-0.075%Ti (mass%)) and low carbon (LC) 3%Si-Fe (Fe-2.99%Si-0.07%Mn-0.018%C (mass%)). Two cast ingots were hot rolled to 3.0mm thickness after soaking at 1200°C. After the hot rolling, specimens were pre-cold rolled to 2.0mm to randomize the initial texture. These specimens were normalized at 1150°C for 60s in dry nitrogen atmosphere and cooled to room temperature by 50°C/s so that ample amount of carbon was kept solute. Grain sizes of the normalized specimens were about

1.2mm and both specimens have almost random texture. Normalized specimens were cold rolled to 0.2mm thickness (cold rolling reduction: 90%), followed by two types of annealing in dry nitrogen atmosphere, partial recrystallization annealing (annealed up to 625°C and $N_2$ gas cooled) and complete recrystallization annealing (annealed at 840°C for 120s and $N_2$ gas cooled). Textural characterization was performed using X-ray diffraction (XRD) analysis, and its orientation distribution function (ODF) was calculated using the discrete method [14]. SEM- EBSP analysis was used for microstructural study.

## Results and discussion

Fig. 1 shows the orientation image maps of cold rolled specimens measured by SEM-EBSP analysis. In ULC 3%Si-Fe, uniform deformation occurred and slip bands propagated with increasing cold rolling reduction. On the other hand, deformation twins were generated in the early stage of cold rolling in LC 3%Si-Fe. Many of those twins had {100}<011> orientation. Increasing the cold rolling reduction, slip bands passed over those twins. Fig.2 shows the cold rolled and complete recrystallization textures [13]. The main component of recrystallization texture of ULC 3%Si-Fe was {554}<225> orientation. These results are almost the same as those obtained using deep drawing steel [8]. On the other hand, the main component of recrystallization texture of LC 3%Si-Fe was {411}<148> orientation.

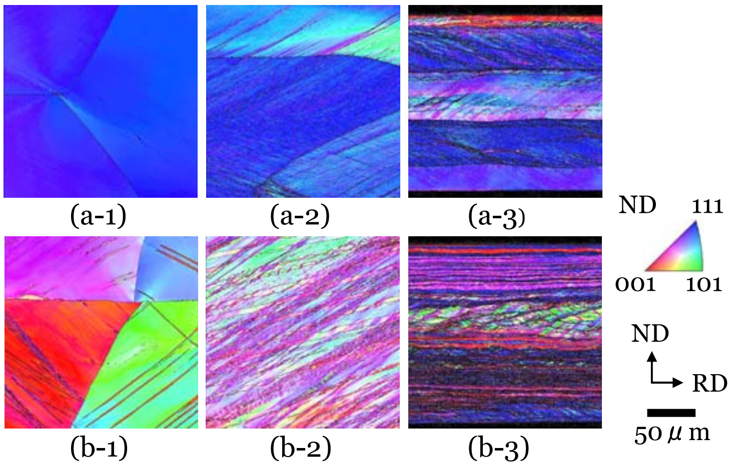


Fig. 1 Orientation image maps of cold rolled specimens. : (a) ultra low carbon 3%Si-Fe, (b) low carbon 3%Si-Fe, (-1) cold rolling reduction 20%, (-2) cold rolling reduction 60%, (-3) cold rolling reduction 90%.

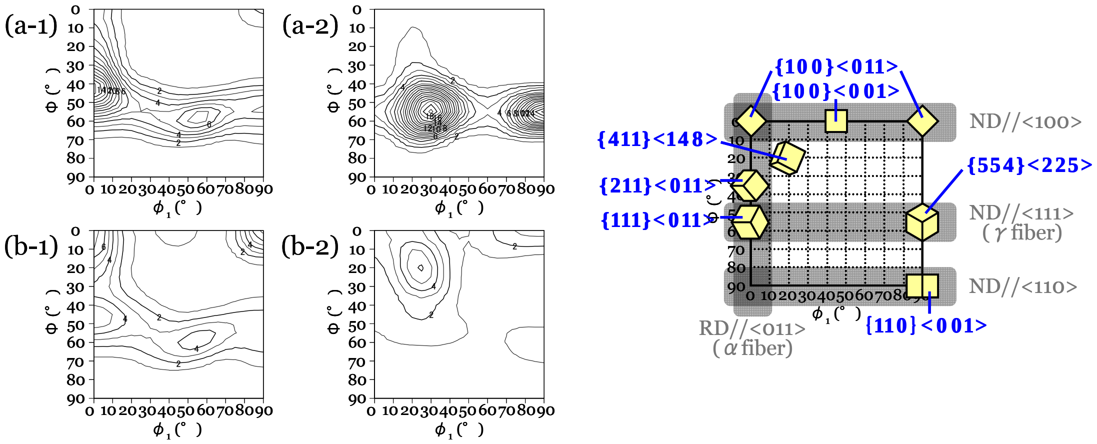


Fig. 2 Cold rolled and recrystallization textures of a) ultra low carbon 3%Si-Fe, (b) low carbon 3%Si-Fe, (-1) cold rolled specimens (cold rolling reduction 90%) (-2) completely recrystallized specimens [13] (Center layer; Bunge's ODF (φ2=45° cross-section)).

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Some {411}<148> micro regions are observed around the crossing areas of the {100}<011> deformation twins and the slip bands in cold rolled LC 3%Si-Fe. Fig. 3(a) shows the orientation image map of cold rolled LC 3%Si-Fe measured by SEM-EBSP analysis. The orientations of deformation twin ({100}<011>) and {411}<148> micro region are shown by (211) pole figure of Fig. 3(b). It is found that there is a common <112> axis between deformation twin and {411}<148> micro region. In general, rotation axis is perpendicular to both slip plane normal and slip direction assuming the single slip system. Considering this relationship and the fact that main slip systems are {110}<111> and {112}<111> in BCC metal, crystal rotation around <112> axis indicates an activation of {110}<111> slip system. The orientations of deformation twin ({100}<011>) and neighboring grain ({111}<011>) are shown by (110) pole figure of Fig. 3(c). It is found that there is a common {110} plane between deformation twin and neighboring grain. This result confirms the activity of {110}<111> slip system in both deformation twin and neighboring grain. In terms of Schmid factor, {112}<111> slip systems must be activated in {100}<011> grains [15]. This is not in agreement with the result of {110}<111> slip system activation. It is considered that slip plane matching (SPM) with neighboring grains activates the relatively lower Schmid factor slip system [16]. Honma et al. also suggests that grain boundary plays an important role to nucleate the {411}<148> recrystallized grains [17]. These results suggest that not only Schmid factor but also SPM with neighboring grains should be considered to decide the active slip system in polycrystalline metals.

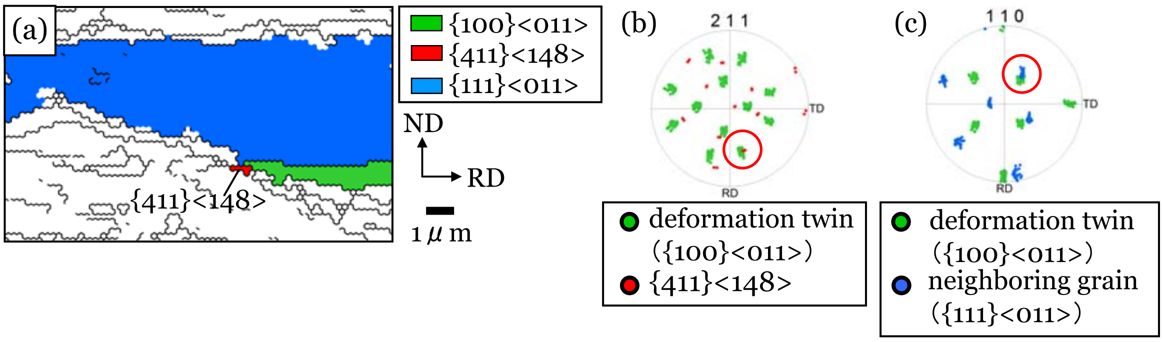


Fig. 3 EBSP analysis of cold rolled (rolling reduction 90%) specimen of low carbon 3%Si-Fe, (a) highlight only main orientations, (b) (211) pole figure, (c) (110) pole figure.

Fig. 4 shows the orientation image map of partially recrystallized LC 3%Si-Fe measured by SEM-EBSP analysis. {411}<148> recrystallized grain nucleated from {100}<011> deformation twin in the vicinity of slip bands inside the neighboring matrix grain. This result is strongly in agreement with SPM mechanism of {411}<148> recrystallization texture development in LC 3%Si-Fe.

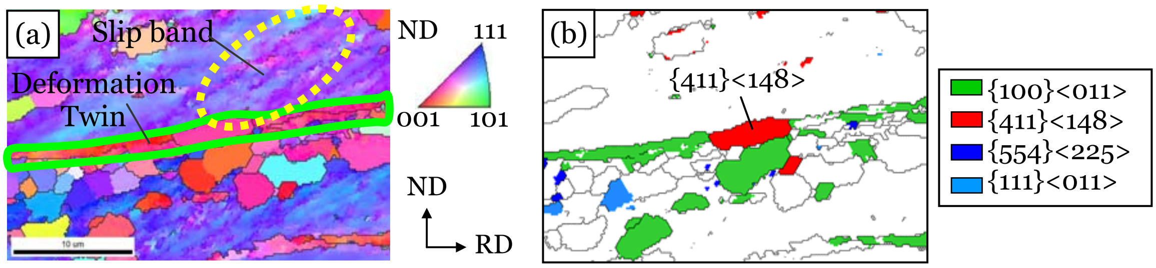


Fig.4 EBSP analysis of partially recrystallized (annealed up to 625°C and $N_2$ gas cooled) low carbon 3%Si-Fe, (a) orientation image map, (b) highlight only main orientations.

The mechanism of {411}<148> recrystallization texture development in 3%Si-Fe with increasing the carbon content is shown in Fig. 5. Increasing the carbon content induces the deformation twins in the early stage of cold rolling. SPM arises between deformation twin and neighboring grains with increasing cold rolling reduction. As a result, {110}<111> slip system is activated and {411}<148> micro regions are formed in the {100}<011> deformation twins. These results suggest that not only Schmid factor but also slip plane matching with neighboring grain should be considered to decide the active slip system in polycrystalline metals.

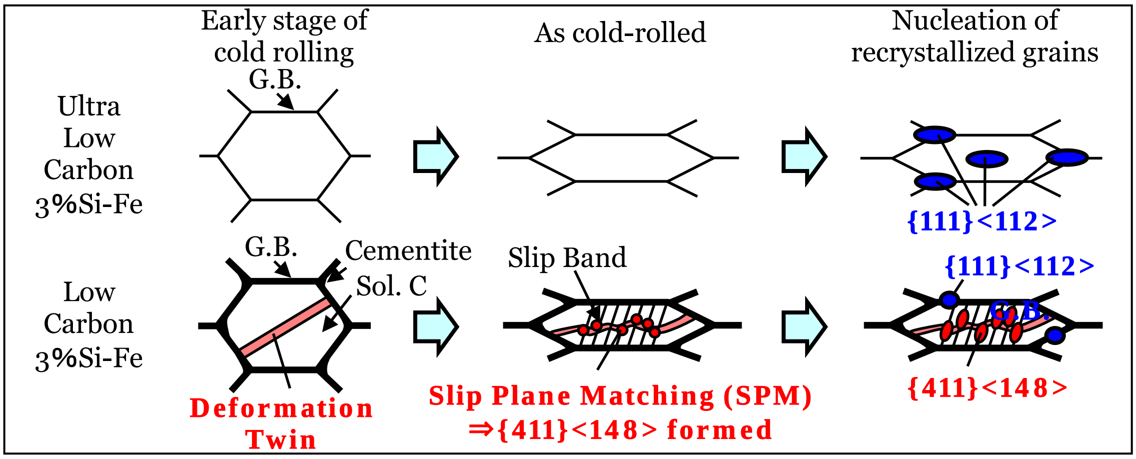


Fig. 5 Schematic drawing showing the mechanism of texture development in 3%Si-Fe with increasing the carbon content.

## Conclusions

The mechanism of {411}<148> recrystallization texture development in 3%Si-Fe with increasing the carbon content has been investigated. Increasing the carbon content induces the deformation twins in the early stage of cold rolling. Slip plane matching arises between deformation twins and neighboring grains with increasing cold rolling reduction. As a result, {110}<111> slip systems are activated and {411}<148> micro regions are formed in the {100}<011> deformation twins.

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