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Microstructure characterization based on the type of deformed grains in cold-rolled, Cu-added, bake-hardenable steel

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ABSTRACT

The electron backscatter diffraction technique has been used to characterize the microstructure of deformed grains in cold-rolled, Cu-added, bake-hardenable steel. A new scheme based on the kind and number of average orientations, as determined from a unique grain map of the deformed grains, was developed in order to classify deformed grains by type. The α-fiber components, γ-fiber components and random orientations, those which could not be assigned to either γ-fiber or α-fiber components, were used to define the average orientation of unique grains within individual deformed grains. The microstructures of deformed grains in as-rolled specimens were analyzed based on the Taylor factor, stored energy, and misorientation. The relative levels and distributions of the Taylor factor, the stored energy and the misorientation were examined in terms of the types of deformed grains.

1. Introduction

Cu-added, bake-hardenable (BH) steel has been developed for application in exposed auto-body parts [1–3]. The key metallurgical requirements for the BH steel are that the C content be kept as low as 0.0015 wt.% and that a small amount of Cu content is added in order to improve the yield strength. The main requirement of BH steels is that they have good formability during the press-forming operation [4,5]. It is well understood that formability of extra-low-carbon steels is dependent on the crystallographic texture of a fully annealed specimen [6–10]. Many experimental studies have been focused on elucidating the cold-rolled state of extra-low-carbon steels through the use of a transmission electron microscope (TEM), electron backscatter diffraction (EBSD), X-ray diffraction, and neutron diffraction [10–15]. In particular, EBSD technology installed in a field emission scanning electron microscope (FE-SEM) has been widely used to explain the evolution of the spatial distribution of a crystallographic orientation as well as the grain morphology during deformation [16–22]. Severe deformation that would be characterized by a reduction ratio of greater than 50% during cold-rolling induces the inhomogeneous distribution of the crystallographic orientation, the stored energy, and the substructure in deformed grains [11,12,23,24]. In particular, the spatial distribution of stored energy in deformed grains is an important factor that determines the kinetics of static recrystallization during the annealing process [25,26].

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Table 1 – Chemical composition of Cu-added BH steel [wt.%].

C	Mn	Si	P	S	Soluble Al	Cu	N	Fe
0.0015	0.12	0.02	0.06	0.01	0.035	0.09	0.0022	Bal.

EBSD coupled with *in-situ* heating revealed that the recrystallization kinetics of extra-low-carbon steels is strongly dependent on the state of the deformed grains [27–29]. However, in most research, the heterogeneity of the crystallographic orientation, the stored energy, and the substructure in heavily deformed grains has not been successfully correlated with recrystallization kinetics during *in-situ* annealing. In order to effectively understand the recrystallization kinetics during the annealing process, an accurate description and classification of heavily deformed grains is required.

In the present work, a new scheme was suggested in order to classify the types of deformed grains in cold-rolled, Cu-added, BH steel. The kind and number of average orientations, as determined from a unique grain (UG) map of deformed grains, were used to classify the types of deformed grains in cold-rolled specimens. The Taylor factor (TF), stored energy (SE), and misorientation were all analyzed for different types of deformed grains. A subgrain method based on the subgrain structure was used to calculate the orientation-dependent SE in cold-rolled, Cu-added, BH steel. This research is expected to help in understanding the effects that deformed grains exert on recrystallization kinetics during *in-situ* annealing [30].

2. Experimental

To analyze the evolution of microtexture during cold-rolling, a hot-rolled steel sheet with a thickness of 3 mm was cut from a hot-coil manufactured by POSCO (Pohang Iron & Steel Co., Ltd.). The chemical composition of the Cu-added, BH steel used in the present investigation is shown in Table 1. A rectangular, hot-rolled plate with dimensions of 100 cm × 200 cm was pickled with HCl acid and then subsequently cold-rolled to a reduction ratio of 80% *via* two reductions using two high mills. The microtexture of the cold-rolled, Cu-added, BH steel was analyzed using the EBSD technique. EBSD specimens for the intermediate stage were prepared by mechanical polishing using a diamond suspension and colloidal silica as the polishing medium. EBSD

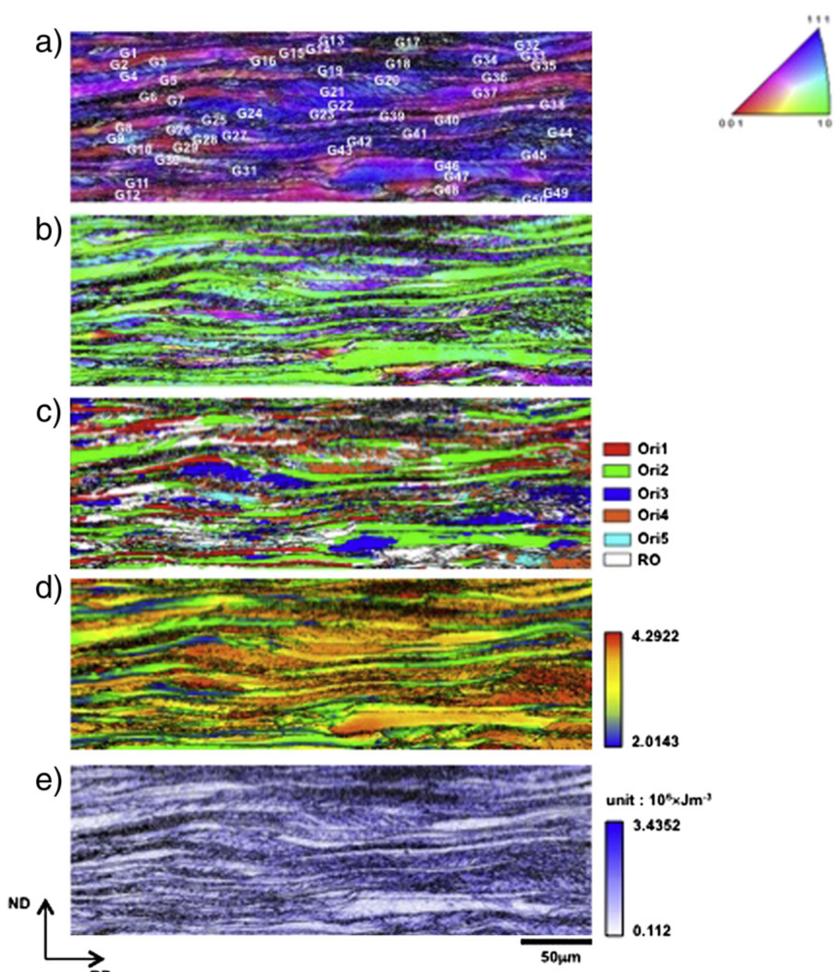

Fig. 1 – (a) ND-IPF, (b) TC, (c) TF and (d) SE maps of the cold-rolled Cu-added BH steel. The numbers (G1–G50) depicted in (a) represent grain numbers considered in the classification of deformed grains.