

Two-Step Rolling Process Optimization for Enhanced Formability and Reduced Springback in Thin CP Titanium Sheets for Fuel Cell Bipolar Plates

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Titanium bipolar plates are promising for fuel cell stacks because their corrosion resistance and high specific strength can improve durability and reduce stack weight. However, commercial-purity titanium thin sheets show limited formability and severe springback problem due to their hexagonal close-packed crystal structure, strong anisotropy, and restricted slip systems. In bipolar plate forming, these characteristics limit complex micro-channel fabrication and deteriorate dimensional accuracy after unloading.

This study investigated a two-step rolling process with intermediate annealing to improve formability and reduce springback of 0.1 mm CP Ti Grade 1 thin sheet for fuel cell bipolar plates. The conventional one-step rolling process was modified by inserting intermediate recrystallization annealing before the second rolling step. The purpose of the intermediate annealing was to relieve internal stress and form recrystallized grains, while the second rolling step imposed compressive deformation to induce twinning. Four rolling conditions were prepared to compare the one-step rolled sheet and two-step rolled sheets with different second-step reduction ratios. Final recrystallization annealing was conducted at 600 to 700 °C for 5 to 15 min.

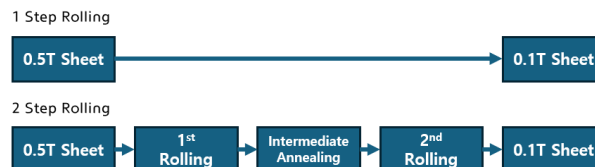


Fig. 1 Schematic comparison of one-step and two-step rolling processes.

Before final recrystallization annealing, electron backscatter diffraction analysis showed that the one-step rolled sheet consisted of very fine grains and contained few identifiable twins. In contrast, the two-step rolled sheets had relatively larger and more uniform grains due to intermediate annealing, and $\{11\bar{2}2\}$ and $\{10\bar{1}2\}$ twins were generated during the second rolling step. Texture analysis confirmed that the induced twins dispersed the typical TD basal split texture, and this texture dispersion became more pronounced as the second-step reduction ratio increased.

After final recrystallization annealing, both one-step and two-step rolled sheets showed uniformly grown recrystallized grains, and grain size increased with annealing temperature and time. Under identical annealing conditions, the two-step rolled sheets exhibited larger grains than the one-step rolled sheet. Kernel average misorientation analysis indicated that this behavior was associated with higher stored deformation energy and enhanced strain-induced boundary migration during recrystallization.

Mechanical testing showed that yield strength and tensile strength decreased as final annealing temperature and time increased. The difference between rolling-direction and transverse-direction R-values was smaller in the two-step rolled sheets than in the one-step rolled sheet, indicating reduced anisotropy. The R-value difference decreased further as the second-step reduction ratio increased, suggesting improved formability through texture and anisotropy control.

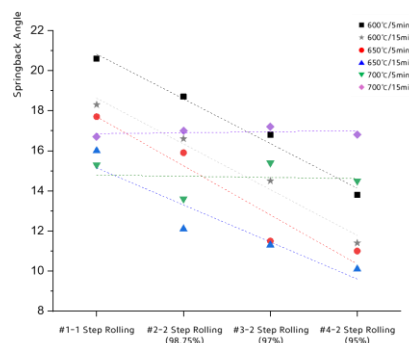


Fig. 2 V-bending springback results after final recrystallization annealing.

V-bending tests based on ASTM E290 demonstrated that the two-step rolled sheets exhibited lower springback than the conventional one-step rolled sheet. Springback decreased as the second-step reduction ratio increased, following the same tendency as the reduction in R-value difference. The lowest springback was obtained for the high-reduction two-step rolled sheet after final recrystallization annealing at 650 °C for 15 min. At 700 °C or higher, the difference in springback among rolling conditions became less distinct.

In conclusion, intermediate annealing-assisted two-step rolling effectively induced deformation twins, dispersed the rolling texture, reduced anisotropy, and improved springback behavior in thin CP titanium sheet. The optimized rolling and annealing condition provides a practical process route for improving the manufacturability of titanium bipolar plates for fuel cell applications.