Development of Fe-based mille-feuille materials and evaluation of their mechanical properties

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In recent years, the introduction of kink deformation bands and the resulting improvements in strength and ductility have been achieved by subjecting Mg-, Al-, and Ti-based mille-feuille materials to compressive deformation [1-3]. These materials are characterized by an alternating stacking structure of hard and soft phases. In this study, we aimed to create Fe-based mille-feuille materials and introduce kink deformation bands through compression testing, thereby improving strength and ductility, by performing directional solidification on Fe-based alloys, which are widely used as practical structural materials.

Two types of Fe-based eutectic alloys, i.e., Fe-Ti and Fe-Nb, were prepared by arc melting, and microstructural orientation was achieved through directional solidification (DS) using the Bridgman method. Microstructural observations were performed using an optical microscope and a scanning electron microscope (SEM), and the constituent phases were identified using SEM-EBSD and EDS. Compression tests were performed on the prepared alloys at temperatures ranging from room temperature to 800°C, and changes in crystal orientation accompanying deformation were investigated using SEM-EBSD.

In the Fe-Ti and Fe-Nb alloys, layered and rod-like microstructures oriented along the growth direction were observed due to DS. Crystal orientation analysis with EBSD revealed that both the a-Fe/Fe_2Ti and a-Fe/Fe_2Nb phase pairs exhibit an orientation relationship of (110) // $(11\bar{2}0)$. The results of the compression tests showed that both the alloys achieved high yield stress of over 1 GPa at room temperature. Although the yield stress decreased with increasing test temperature for both the alloys, the high strengths were maintained at 600°C. In the Fe-Nb alloy, kink deformation bands formed during the test conducted at 800°C, suggesting the possibility of simultaneously improvement of strength and ductility. The yield stress tended to be higher in the Fe-Ti alloy than the Fe-Nb alloy. Although this trend was not reproduced by the short-fiber composite rule, it became possible to estimate values close to the experimental data by incorporating the degree of microstructural orientation defined in this study. This clearly demonstrates that the degree of orientation in the microstructure of mille-feuille materials is critical to their mechanical properties.

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