High Strength Copper-Silver Conductors for Magnets

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Because of such desirable properties as high mechanical strength and electrical conductivity, Cu–Ag nano-structured sheets are used, not only in high-field DC magnets in general but also in the insert for our 45T hybrid magnet. In these applications, the property anisotropy of these sheets (which researchers in the MagLab have previously identified) must be taken into account. We have now further studied this anisotropic behavior, evaluated the strain-hardening or strain-softening capacity of these sheets and correlated this capacity with their microstructure.

We found overall softening in both longitudinal and transversal samples. In regions with highly strained slip bands, we discovered strain-hardening in transversal tensile samples but strain-softening in longitudinal ones. This anisotropy of plasticity occurred only in very local necking regions (~ 1.4mm in width). We observed many shear bands in the longitudinal, but not transversal, cross-sections. Microscale examination revealed shear bands running 8°-15° off the {111} crystal orientation. In longitudinal cross-section samples, we observed stacking faults and twins within the shear bands, indicating severe plastic deformation resulting mainly from the propagation of partial dislocations (see Figure). We found that measurable strain-hardening and strain-softening were both dependent on rolling direction, which introduced complex interrelationships among shear band orientations, crystallographic orientations, and interface orientations. Strain-softening in longitudinal tensile samples resulted from the presence of “favorable” angles (i.e., angles at which materials are especially easy to deform) within shear bands between the maximum shear stress direction and the existing slip system on {111}. Conversely, strain-hardening in transversal tensile samples was the result of the absence of such angles.

These findings helped us to better understand the mechanical properties of the conductor sheets that are used in our magnets.

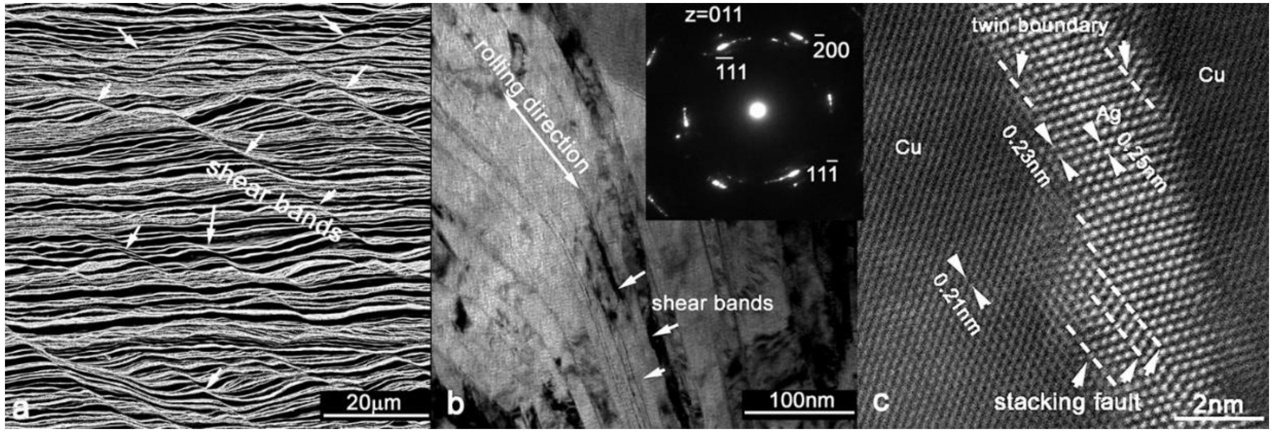

Figure 1: Microscopy images on longitudinal x-section. **a**. Scanning electron microscopy image of shear bands, indicated by white arrows. **b**. Transmission electron microscopy image of the lamellar structure and shear bands (some of which are indicated by white arrows) on the longitudinal x-section. The average lamellar spacing is ~ 35nm. Lamellae in shear band areas are finer than in other areas: the width of Ag lamellae is <2nm, and Cu lamellae < 6nm. The inset shows a selected area diffraction pattern in the shear band. The short, curved diffraction spots in {111} or {200} indicate the presence of textured nano lamellae. Of the two opposing pairs of {111} diffraction spots, the maximum of one pair is about 8°-15° off the rolling direction and of the other is about 55° -67° off the rolling direction. **c**. Atomic resolution, High Angle Annular Dark Field (HAADF) image within the shear band showing stack faults and twinning in one Ag lamella surrounded by Cu lamellae. The <111> interplanar spacing of the Ag lamella (0.25nm) is 1.12 times that of the Cu lamellae (0.21nm).

Facilities and instrumentation used: The work was undertaken by researchers in MST using the mechanical test machines and microscopies hosted by the MagLab.

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