Application Note

Effects of Temperature and Magnetic Field on Amperium® Wire Performance

AMSC's Amperium wire is a high temperature superconductor (HTS) wire designed and engineered for use in large-scale power applications such as generator coils and power cables. As with all superconductors, its in-use electrical properties depend on many factors associated with an application's operating conditions. This technical note describes some of the effects that temperature and external magnetic fields have on the critical current performance of Amperium wire.

Amperium wire is made with the yttrium-barium-copper-oxide (YBCO) high temperature superconductor. The YBCO ceramic film is deposited on an oxide-buffered nickel-tungsten (Ni-W) alloy substrate that is laminated and soldered between two metal strips, as shown in Figure 1. The metal stabilizer strips may be copper, brass or stainless steel and provide physical protection and electrical stability for the HTS layer.

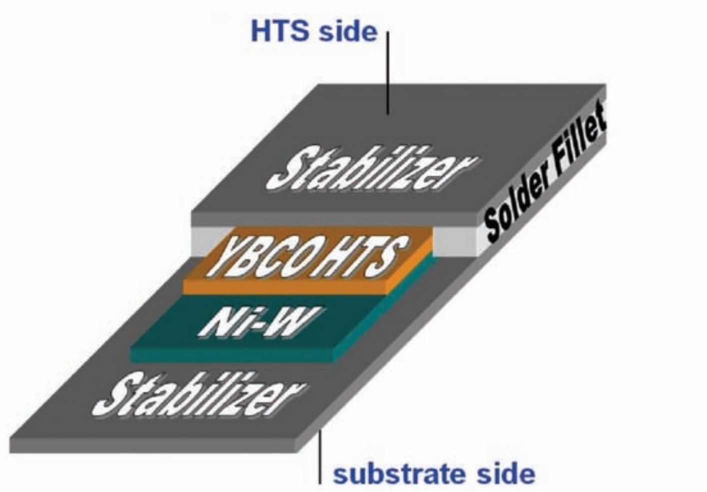


Figure 1. Structure of Amperium Wire

Figure 2 shows a cross-section micrograph of copper laminated Amperium® wire. The "HTS insert" is the Ni-W substrate with the oxide buffer layers and YBCO film, all encapsulated in a thin silver coating. The wire dimensions are approximately 4.8 mm wide by 0.2 mm (200 μm) thick. The YBCO layer is about 1 μm thick, i.e., it occupies only 1/200th of the wire's total thickness.

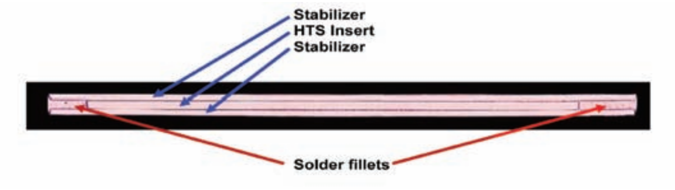


Figure 2. Cross-section micrograph of copper laminated 4.8 Amperium wire

The superconducting transition temperature (TC) of YBCO in zero magnetic field is about 90 K. Its critical current (I_C) has a significant temperature dependence and improves substantially as the operating temperature is reduced below 90 K. The critical current in YBCO is also affected by magnetic fields and decreases with increasing magnetic field intensity.

As mentioned above, the HTS layer in Amperium wire is about 1 μm thick. The width of the HTS layer is either 4 mm or 10 mm, depending on the wire type. These very high aspect ratios combined with the anisotropic properties inherent to YBCO lead to a strong orientation dependence for I_C when the wire is exposed to a magnetic field. In the presence of externally applied fields, Amperium wire's I_C retention is highest when the field is parallel to the tape face and lowest when the field is perpendicular to the tape face.

The key to improving I_C performance in the presence of an external magnetic field is to reduce the movement of any magnetic flux lines that penetrate the superconductor. Flux line motion within the superconductor is driven by Lorentz forces that result from the transport current density *J* interacting with the magnetic field *B*, as shown in Figure 3. The force acting on the flux lines is the cross product of current density and magnetic field intensity, and thus its value is greatest when the field is perpendicular to the direction of current flow.

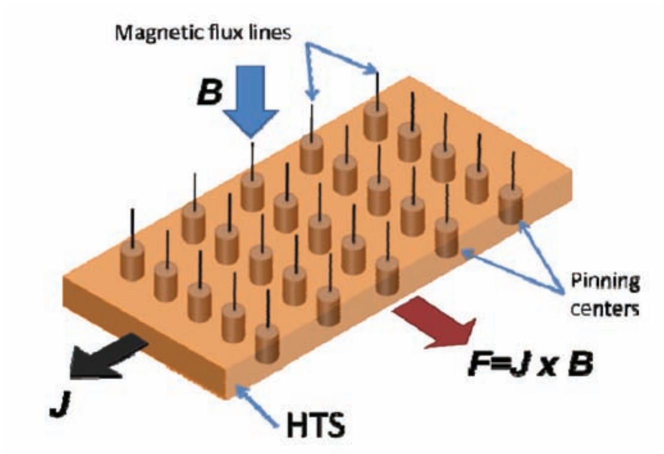


Figure 3. Magnetic flux line penetration, Lorentz forces, and pinning center interactions in an HTS wire.

The presence of "flux-pinning" features in HTS materials reduces flux line motion and enhances the superconductor's critical current performance. Such flux-pinning sites are very small, non-superconducting areas within the HTS. In YBCO, flux pinning is achieved by adding small amounts of secondary materials (e.g., rare-earth oxides) to the HTS during processing or through controlled manufacturing techniques that introduce microstructure features that will serve as pinning centers.

AMSC's Amperium wire is manufactured for enhanced in-field I_C performance in two ways. The first involves the addition of oxide nano-particles to the YBCO film. This type of pinning site is most beneficial for field orientations perpendicular to the tape face. The second approach involves manufacturing processes designed to generate flux-pinning microstructural features through the thickness of the YBCO film. This type of pinning site is most beneficial for field orientations parallel to the tape face.

The experimental results discussed below are intended to provide guidance on the temperature and DC magnetic field dependence of critical current behavior in Amperium wire made with a single HTS insert strip. These data are believed to be typical for all Amperium wire types but should not be taken as a performance guarantee for any particular product.

Measurement Details

Short HTS wire samples were mounted on a variable temperature cryogenic probe designed to rotate in the presence of an externally applied magnetic field. Critical current was measured by the standard four-point probe using a 1 μV/cm criterion. The I_C dependence was measured with the applied magnetic field at three different angles relative to the plane of the HTS wire but always perpendicular to the current flow direction (see Figure 4). The temperature range covered was 20 K to 80 K with applied fields ranging from 0 T to 5.5 T.

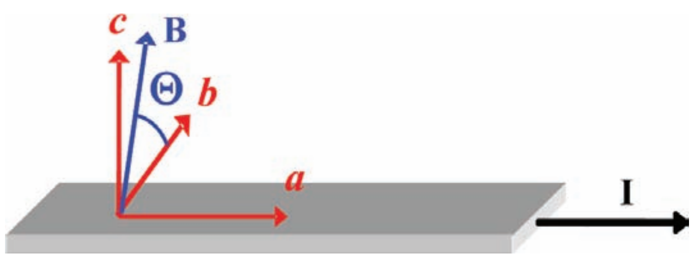


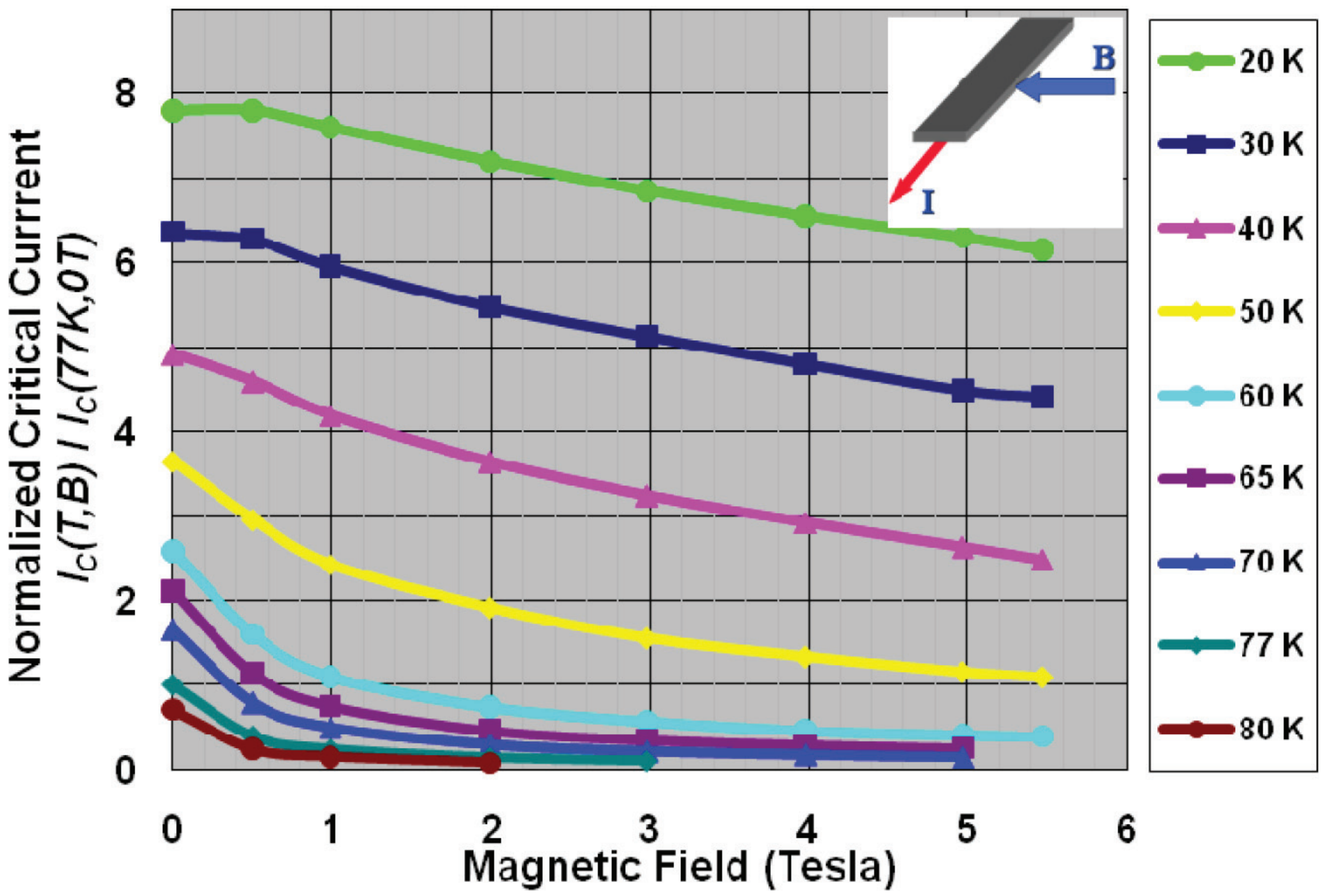
Figure 4. HTS crystal directions (red), relative magnetic field orientation (blue) and transport current direction used to measure Amperium wire performance.

Results and Discussion

In order to compensate for the large temperature dependence of I_C and to allow for easier comparison of different wires under different experimental conditions, all I_C data for each temperature and field orientation have been normalized to the I_C value measured at 77 K with no externally applied field. Thus, the normalized I_C value at 77 K, zero field, in each Figure shown below is 1.0.

1. Magnetic Fields Parallel to the Tape

Figure 5 shows the magnetic field strength dependence of I_C at temperatures ranging from 20 K to 80 K for fields parallel to the plane of the tape. This orientation exhibits the weakest dependence on applied magnetic field at all temperatures.



Performance data courtesy Railway Technical Reseach Inistitute, Tokyo, Japan

Figure 5. Amperium® wire I_C performance with magnetic field parallel to tape surface

2. Magnetic Fields at Off-Axis Angles to the Tape

Figure 6 shows the I_C performance when the applied field is 30 degrees off the plane of the tape (20K data not available). I_C retention as a function of field strength falls off much more rapidly than for the parallel field orientation.

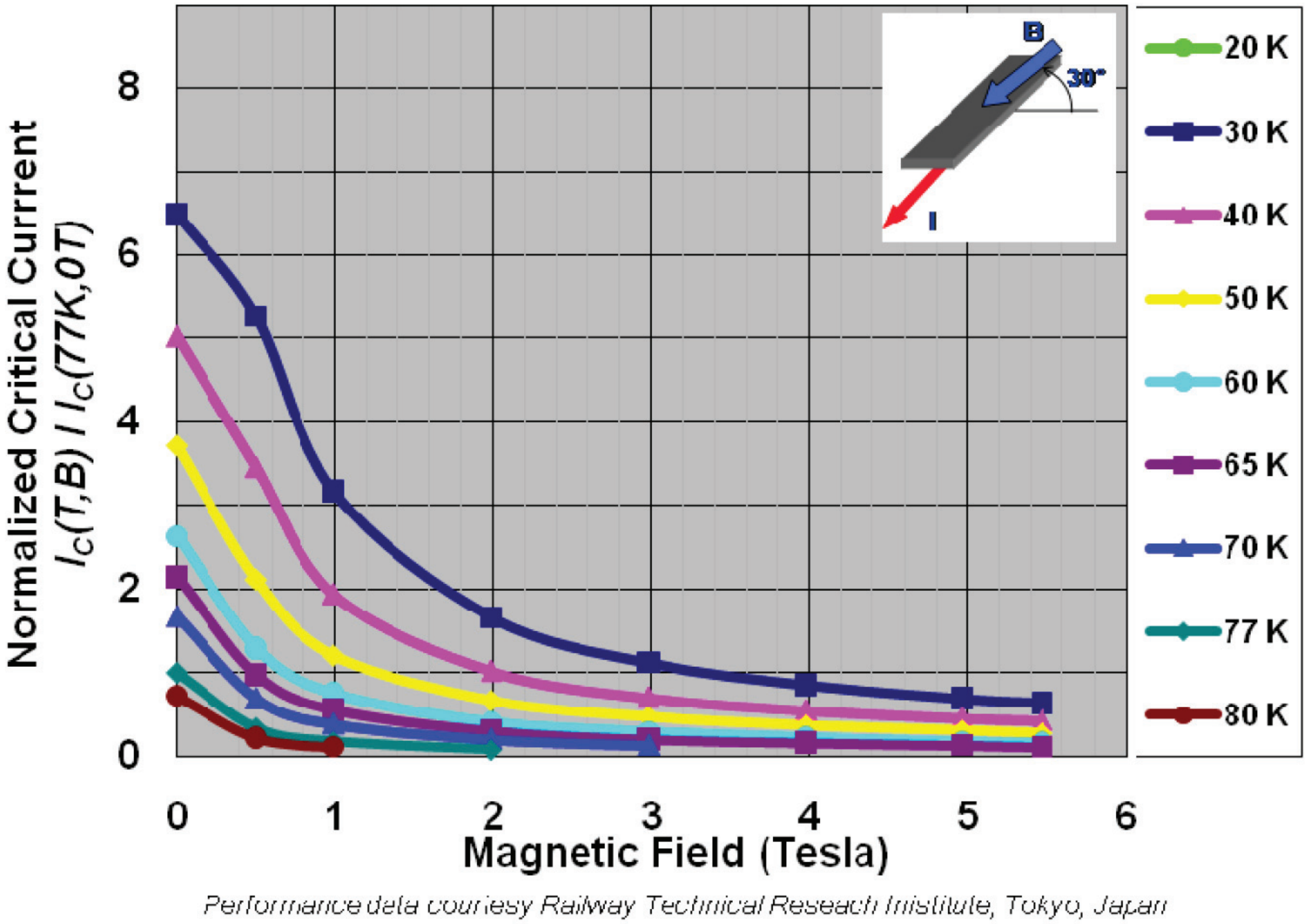


Figure 6. Amperium wire I_C performance with magnetic field at 30° to the tape surface

3. Magnetic Fields Perpendicular to the Tape

Figure 7 shows the magnetic field dependence of I_c at temperatures ranging from 20 K to 80 K for fields perpendicular to the plane of the tape. This field orientation has the strongest effect on I_c retention.

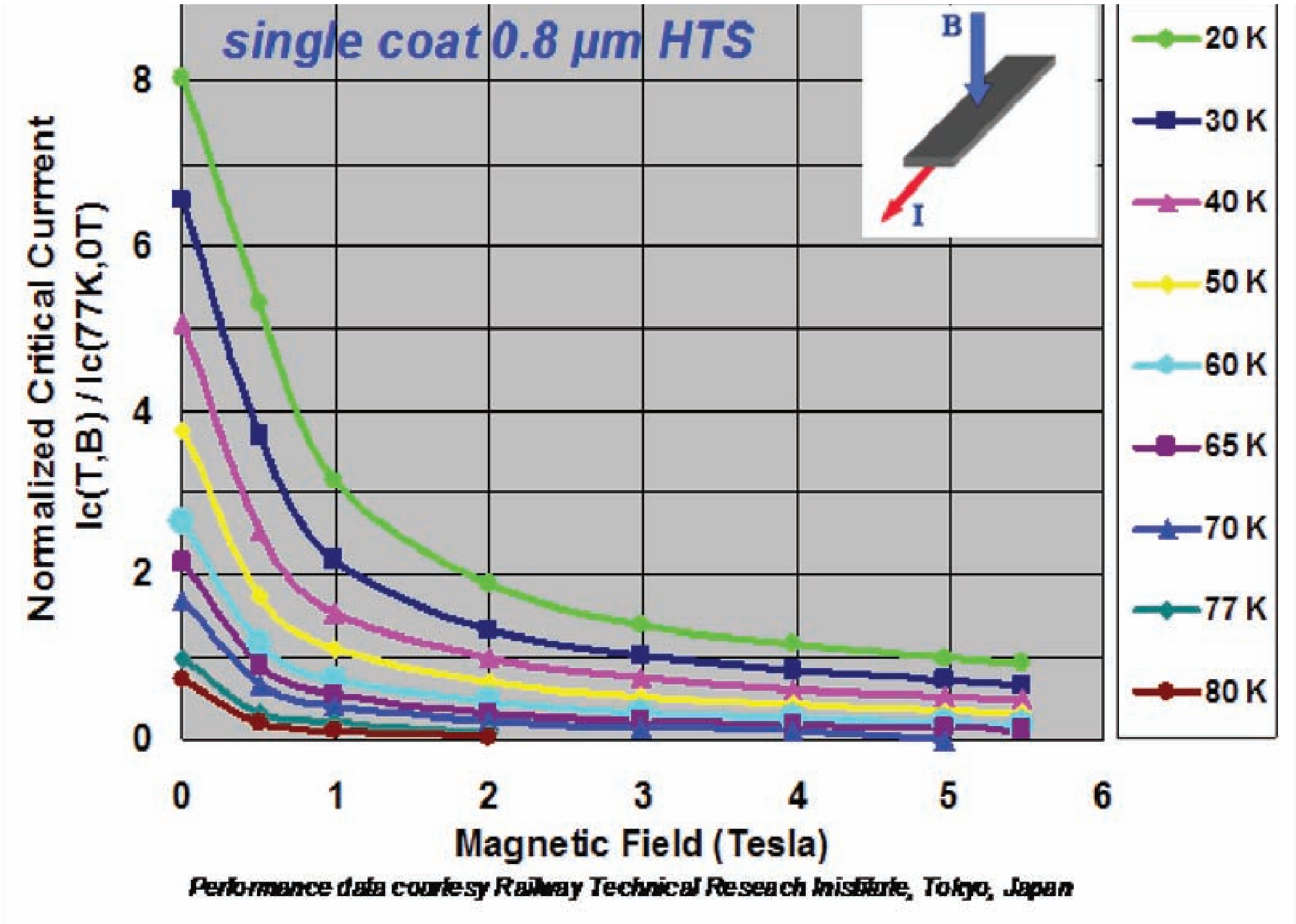


Figure 7. Amperium wire I_c performance with magnetic field perpendicular to tape surface

Summary

The temperature and magnetic field dependence of Amperium wire was evaluated at temperatures ranging from 20K to 80K with applied magnetic fields ranging from 0 T to 5.5 T for three different field orientations relative to the plane of the wire. As expected, I_c retention is highest when the field is parallel to the plane of the tape, declines quickly as the field angle moves away from being parallel to the tape plane, and is lowest when the field is oriented perpendicular to the tape plane.

These results provide an approximate guide for the performance that can be expected from Amperium wires in various temperature and magnetic field conditions. These data are representative of the average performance observed for Amperium wire. Some degree of variability can be expected in production wires.

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