Influence of Twisting and Bending on the Jc and n-value of Multifilamentary MgB2 Strands

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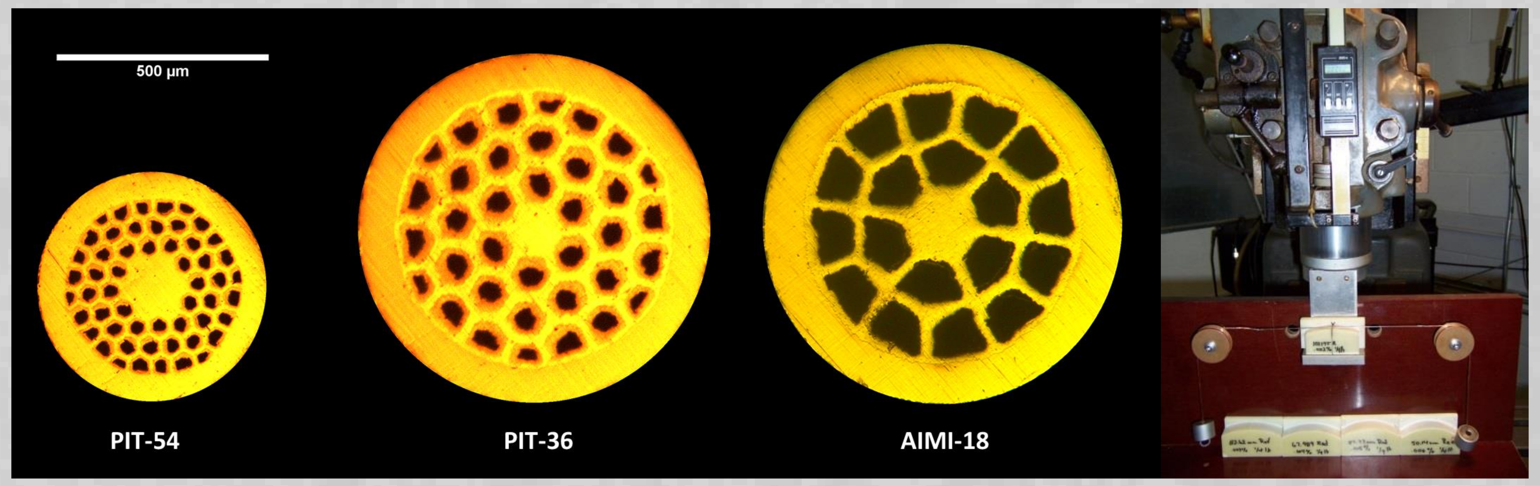
Introduction

The influence of strand twisting and bending (applied at room temperature) on the critical current densities, J_c, and *n*-values of MgB_2 multifilamentary strands were evaluated at 4.2 K as function of applied field strength, B. Three types of MgB_2 strand were evaluated: (i) advanced internal magnesium infiltration (AIMI)-processed strands with 18 filaments (AIMI-18), (ii) powder-in-tube (PIT) strands processed using a continuous tube forming and filling (CTFF) technique with 36 filaments (PIT-36) and (iii) CTFF processed PIT strands with 54 filaments (PIT-54). Transport measurements of $J_c(B)$ and *n*-value at 4.2 K in fields of up to 10 T were made on PIT-54 after it was twisted (at room temperature) to twist pitch values, Lp, of 10-100 mm. Transport measurements of $J_c(B)$ and *n*-value were performed at 4.2 K on AIMI-18 and PIT-36 after applying bending strains up to 0.8% at room temperature. Measurements of PIT-36 showed J_c,4.2K as well as their associated *n*-values to be independent of bend strain out to 0.4%, with degradation at higher bending strains. Measurements of AIMI-18 showed increases in J_c,4.2K with bend strain up to 0.3% followed by a decrease to the starting value at 0.5% and a further decrease with strain out to 0.6%. The strain dependence of *n*-value showed considerable scatter.

Experimental Design



The AIMI strand, AIMI-18, had 18 sub-filaments, each of which made by placing a Mg rod along the axis of a B-power-filled Nb tube. These filaments, along with a central Nb filament, were bundled and placed inside a Nb/Monel® bi-layer tube. The composite was then drawn to an OD of 0.83 mm. The two PIT strands, PIT-36 and PIT-54, were fabricated using the continuous tube forming and filling (CTFF) process [11] and drawn to 0.84 mm and 0.55 mm, respectively. Commercial Mg powder (99%, 20-25 µm particle size) was used for the PIT strands; the B powder was mostly amorphous, 50-100 nm in size, manufactured by Specialty Metals Inc. Undoped B was used in PIT-54, and 2% C pre-doped B was used in AIMI-18 and PIT-36. For all strands, a heat treatment of 675 oC for 60 min under flowing Ar was applied.

Table I: Specifications and properties of the strands

Name	Filament No.	Chemical Barrier	Outer sheath	Central filament	B source	Mg:B ratio	OD, mm	% area under Nb barrier	J_c(4.2K,5 T) 10^5 A/cm^2	Test
PIT-54	54	Nb	Cu10Ni	Cu10Ni	SMI	1:2	0.55	14.5	0.6	twist
PIT-36	36	Nb	Monel®	Cu	2%C SMI	1:2	0.84	12.9	2	bend
AIMI-18	18	Nb	Monel®	Nb	2%C SMI	1.37:2	0.83	28.2	2	bend

Twist-tolerance tests were performed on pre-reacted PIT-54. Bend-tolerance tests were performed on PIT-36 and AIMI-18 strands after reaction. The strands were straight during reaction; afterwards they were uniformly bent in a controlled manner at room temperature. To do this, a set of arc-shape dies made with G-10 material was used to control the bending process, Fig. 2. Assuming the neutral axis was at the geometric centroid of the strands, the maximum bending strain was defined as:

$$\text{Max Bending Strain} = R_w/(R_w+R_B)$$

where R_w is the strand radius and R_B is the radius of G-10 die. The value of R_B and the corresponding maximal bending strains are listed in Table II. The strand was then allowed to relax mechanically, mounted onto the J_c test probe (without straightening even if deformation remained), cooled to temperature, and measured. This method was used to replicate the kind of deformation the strand might experience during react-and-wind coil fabrication or cable winding followed by operation at cryogenic temperatures. The present tests were designed to evaluate the tolerance of the strand to bending during magnet winding or cabling fabrication.

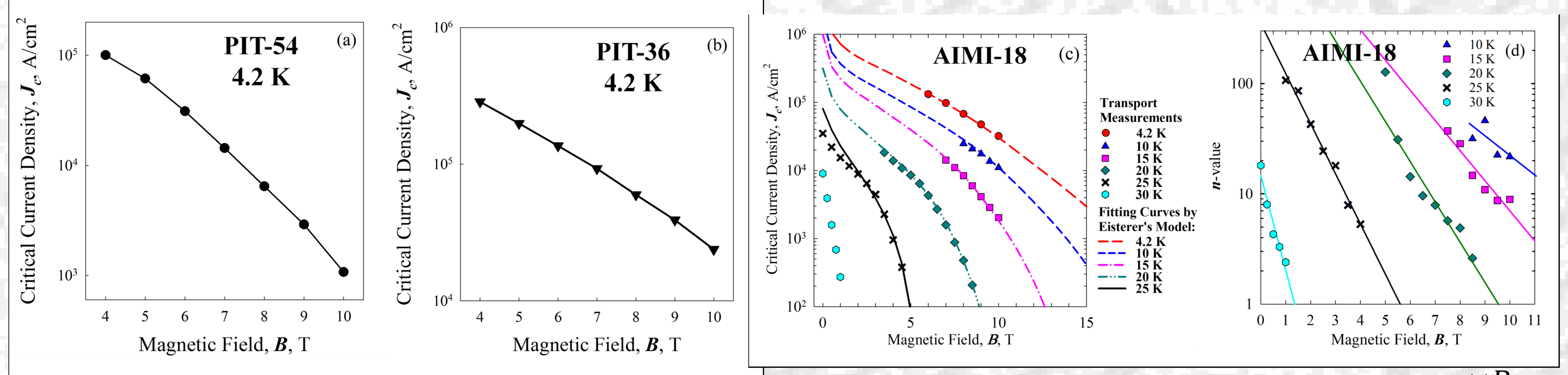
Table II: Bending radius and bending strain

Bending radius, R_B, mm	Maximum bending strain, %
Inf..	0
379.3	0.1
180	0.2
125.5	0.3
94.6	0.4
76.3	0.5
63.1	0.6

Transport J_c measurements were performed on all samples at 4.2 K in pool boiling liquid helium in transverse magnetic fields ranging from 0 T to 12 T on 3 cm long samples. The gauge length was 5 mm, and the electric field criterion for transport J_c was 1 µV/cm.

Results of the Measurements

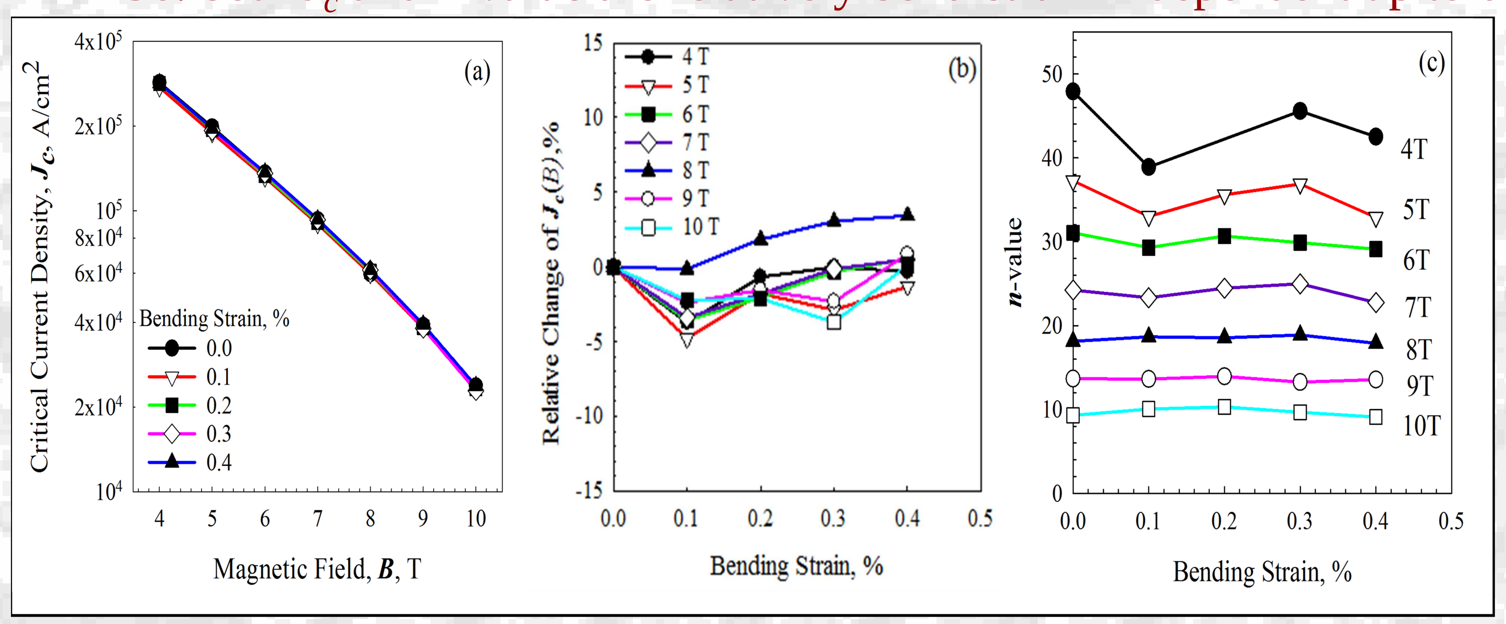
Transport Properties of the Starting Strands:



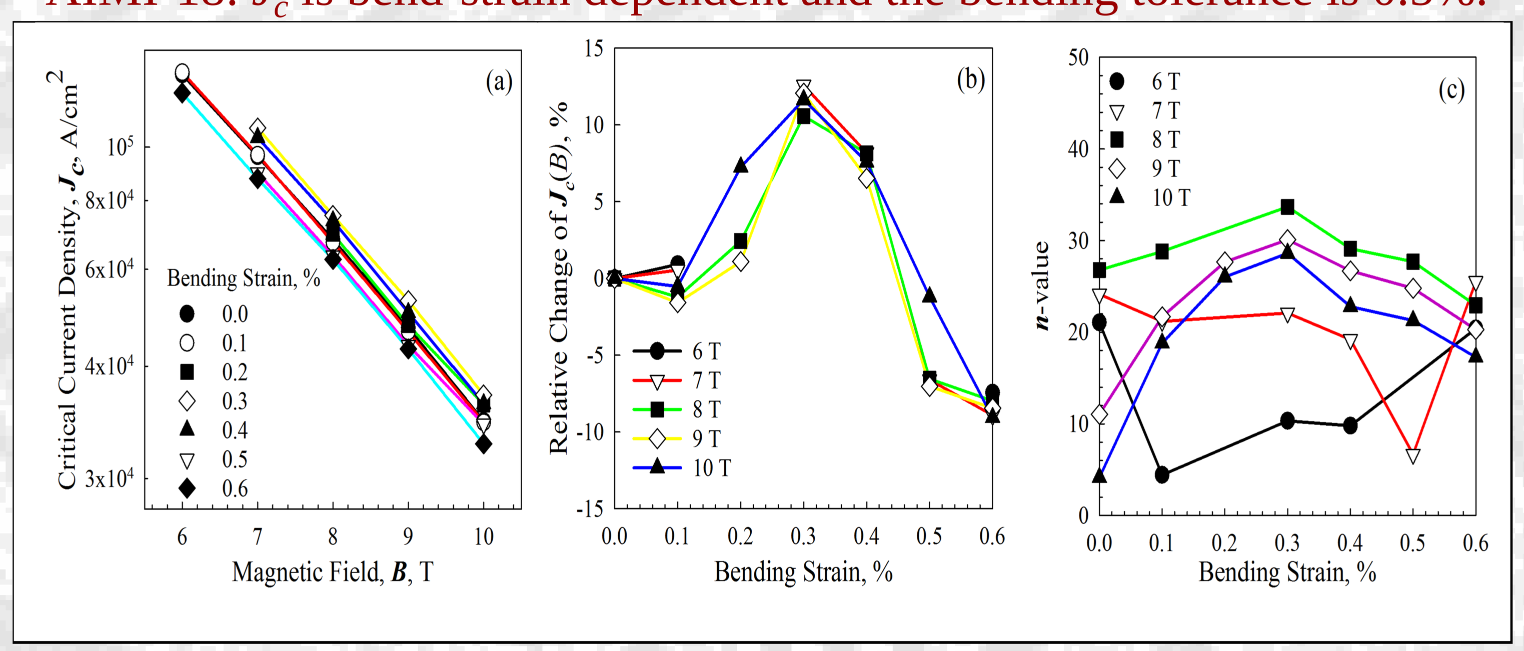
$$n \propto e^{-m \times B}$$

Influence of Bending on Transport Properties:

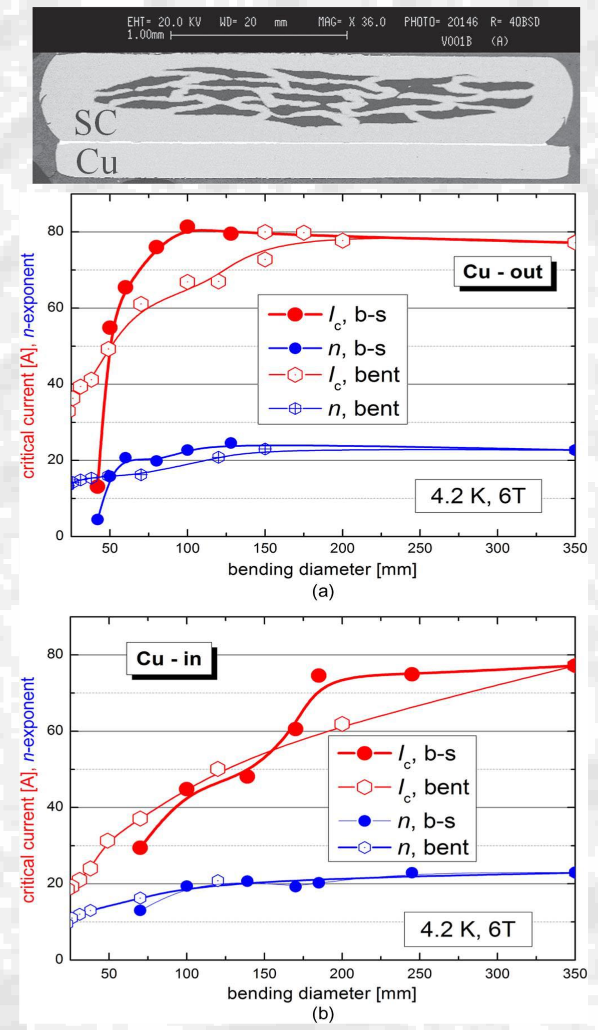
PIT-36: both J_c and *n*-value are relatively bend-strain independent up to 0.4%.



AIMI-18: J_c is bend-strain dependent and the bending tolerance is 0.5%.



19-filamentMgB2/Ni/Cu tape made by Columbus Superconductors for comparison.



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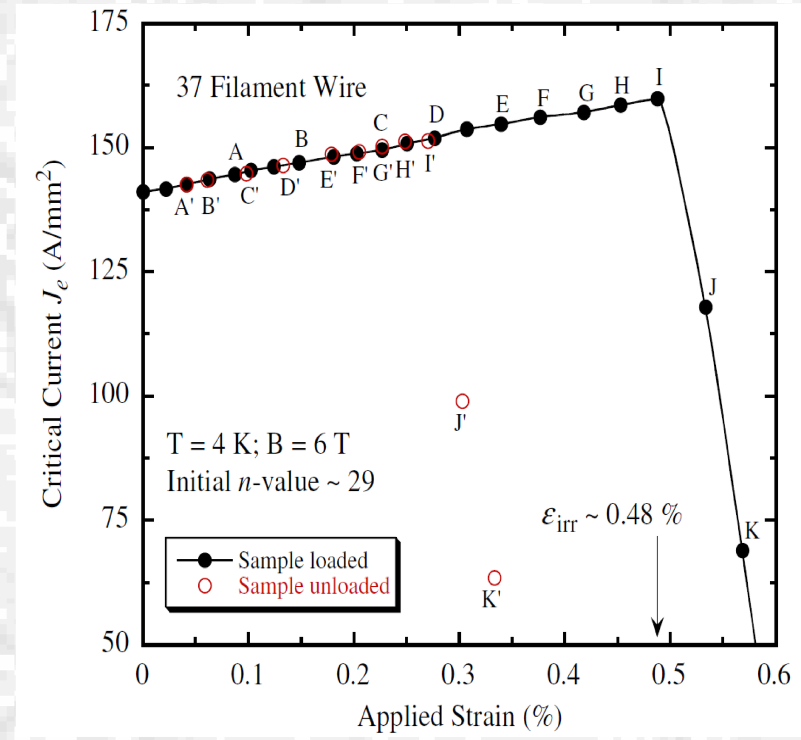
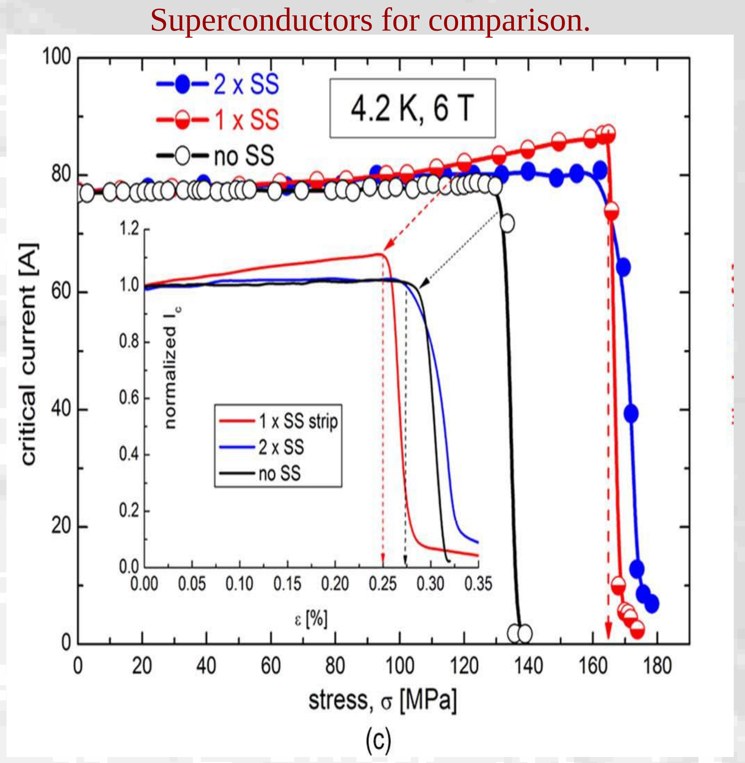
Influence of Tensile Strain on Transport Properties:

PIT-36 made by Hyper Tech Reseach



N. Cheggour and J. W. Ekin, "Electromechanical properties of MgB2 superconductors,"(to be published).

19-filamentMgB2/Ni/Cu tape made by Columbus Superconductors for comparison.



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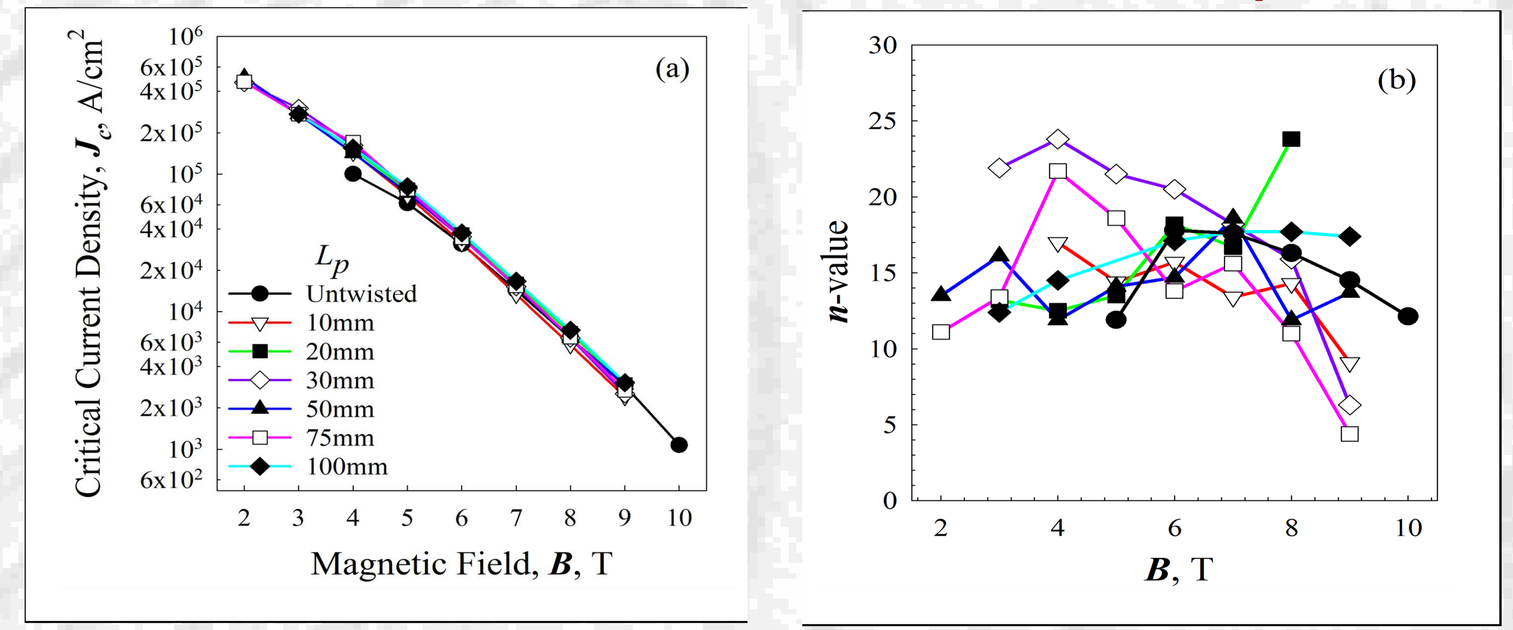
Influence of Twisting on Transport Properties:

PIT-54: no degradation in J_c and *n*-value iss observed even at L_p =10 mm.



Summary and Conclusion

The 4.2 K, 5 T, non-barrier Jcs of PIT-54, PIT-36, and AIMI-18 were, respectively, 0.6, 2.0, and 2.0x10^5 A/cm2. Given that PIT-36 and AIMI-18 have the same strand ODs but differing non-barrier areas for critical current normalization (13% and 28%, respectively), it is clear that AIMI-type strands have the potential, on an equal non-barrier-area basis for twice the J_c performance of PIT. PIT-54 twisted to pitches of 100 mm down to 10 mm. Over the entire range no degradation in $J_c(B)$ was observed; even the strand with an L_p as small as 10 mm exhibited $J_c(B)$ behavior very close to that of the untwisted control. In examinations of bend strain tolerance bending strains of up to 0.6% were applied at room temperature to PIT-36 and AIMI-18. For PIT-36 both $J_c(B)$ and *n(B)* were found to be independent of bend strain within the above limit. AIMI-18 can be regarded as bend-strain tolerant up to about 0.5% strain. At 8 T J_c rises from 6.7 to 7.5x10^4 A/cm2 at 0.3% strain, drops to the starting value at 0.5% strain and continues to decreases to 6.2x10^4 A/cm^2 at experimental bend-strain limit of 0.6%. The strain dependence of *n*-value shows considerable scatter, only in fields of 8 T and above is any approximation to a trend observable.

Acknowledgements

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