1MP1-13

Tensile and bending stress tolerance on MgB_2 wire made by *in situ* PIT process

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1. Introduction

- It is important to understand how much strong strain leads to I_c degradation on reacted MgB_2 wires at room temperature for fabricating coils by React & Wind.
- The agreement between the critical tensile and bending strain was shown with *ex situ* tape wire [1].
- In this paper, we have studied the details of I_c degradation of the *in situ* round wire and compared the critical tensile strain at room temperature and the critical bending strain. The Young's modulus of filament using mechanical milled powder was compared with other type of MgB_2 filament.

	Analysis of I_c degradation and mechanical properties	Improvement of mechanical property
Previous studies	➢ Stress-Strain curve ➢ Young's modulus, E ➢ I_c/I_{c0} (I_{c0} = I_c of non-stressed wire)	➢ High strength metal sheath [2] ➢ High strength filaments ● IMD [3] ● CHPD [4] ● Mechanical alloyed powder [5]
This study	➢ Stress-Strain curve ➢ Young's modulus, E ➢ I_c/I_{c0} ➢ Shape of I-V curve	➢ High strength filaments ● Mechanical milled powder [6] Related oral presentation 4MO2-02

2. Experimental Details

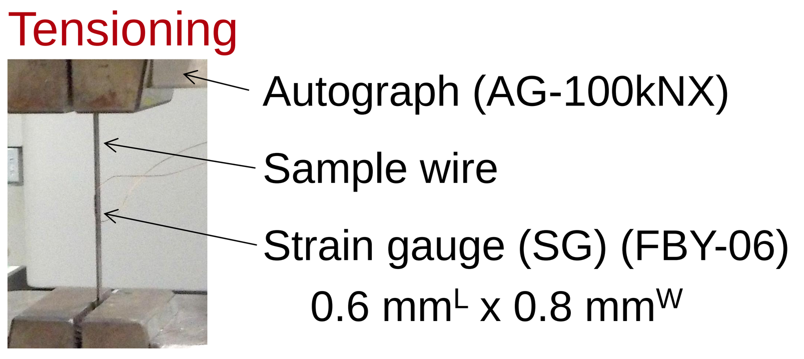
2-1. Sample Wires (made by ourselves)

		Wire Multi [7] *	Wire Mono	Wire MM [6]
Milling		Ball	Ball	Mechanical
Dopant		Coronene	N/A	Coronene
Outer diameter		1.5 mm	1.3 mm	0.5 mm
Volume fraction	Fe	37%	32%	39%
	Cu	21%	34%	-
	Monel	18%	-	-
	MgB_2	24%	34%	61%
Heat treatment		600 ºC x 12 hr	600 ºC x 6 hr	600 ºC x 3 hr

* Wire Multi prefers to W&R

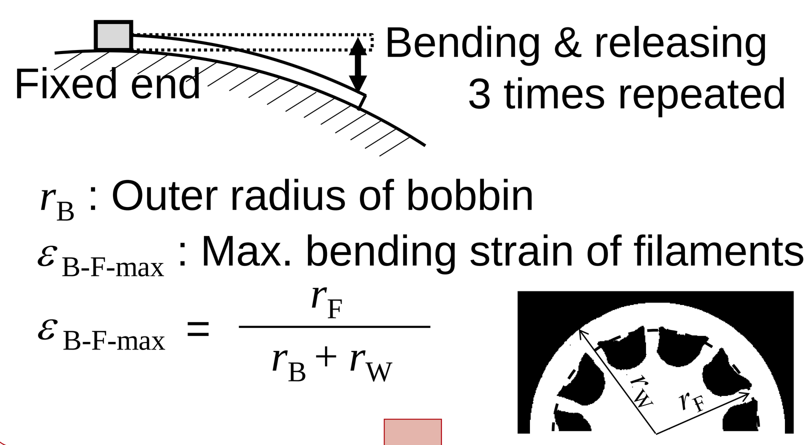
2-2. Tensioning or Bending at RT and I_c Measurement

Tensioning



$\varepsilon_{T\text{-}max}$: Max. tensile strain of each sample
σ_{max} : Stress at the point of $\varepsilon_{T\text{-}max}$

Bending (Wire Multi only)



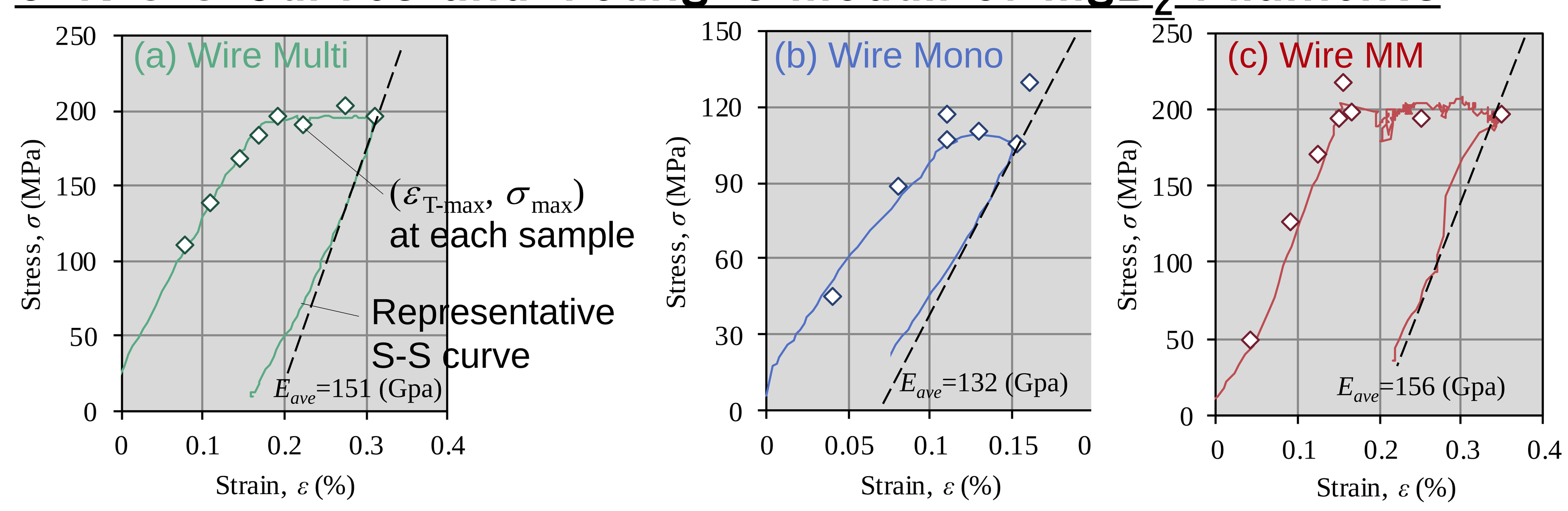
r_B : Outer radius of bobbin
$\varepsilon_{B\text{-}F\text{-}max}$: Max. bending strain of filaments

$$\varepsilon_{B\text{-}F\text{-}max} = \frac{r_F}{r_B + r_W}$$

I_c measurement Voltage tap distance : 5 mm
4.2 K, 7 T for Wire Multi and Wire Mono, 20K, 4.5 T for Wire MM

3. Results and Discussion

3-1. S-S Curves and Young's Moduli of MgB_2 Filaments



Young's moduli of MgB_2 filaments were evaluated by the law of mixtures.

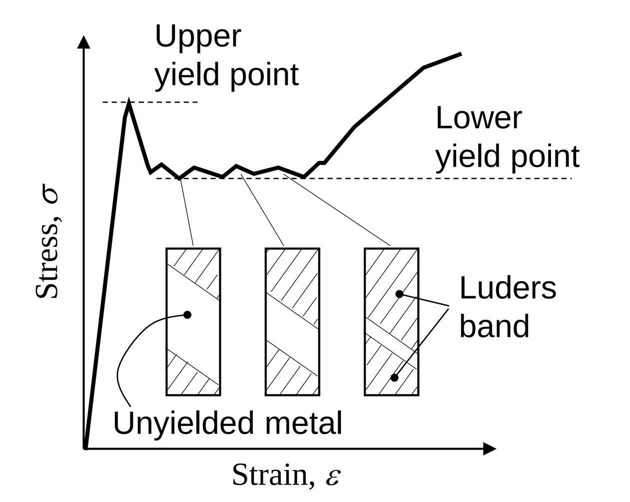
Filament of Wire Multi	Wire Mono	Wire MM
90 GPa	94 GPa	124 GPa

$$E_{MgB2\text{-}filament} = \frac{E_{Wire} - (E_{Fe}V_{Fe} + E_{Cu}V_{Cu} + E_{Monel}V_{Monel})}{V_{MgB2\text{-}filament}}$$

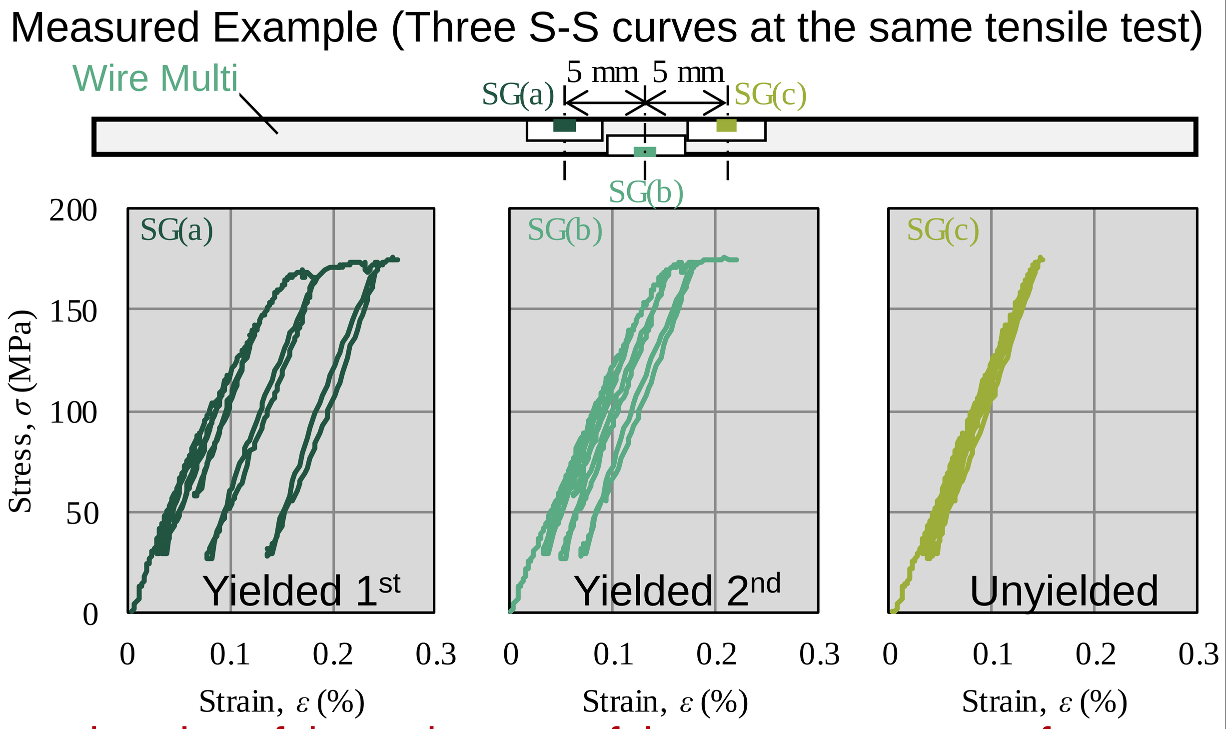
$E_{material}$: Young's modulus
$V_{material}$: Volume fraction

The Young's module of MgB_2 filament using mechanical milled powder was higher than that of ball milled powder.

3-2. Strain Measurement Error by Luders Band Propagation



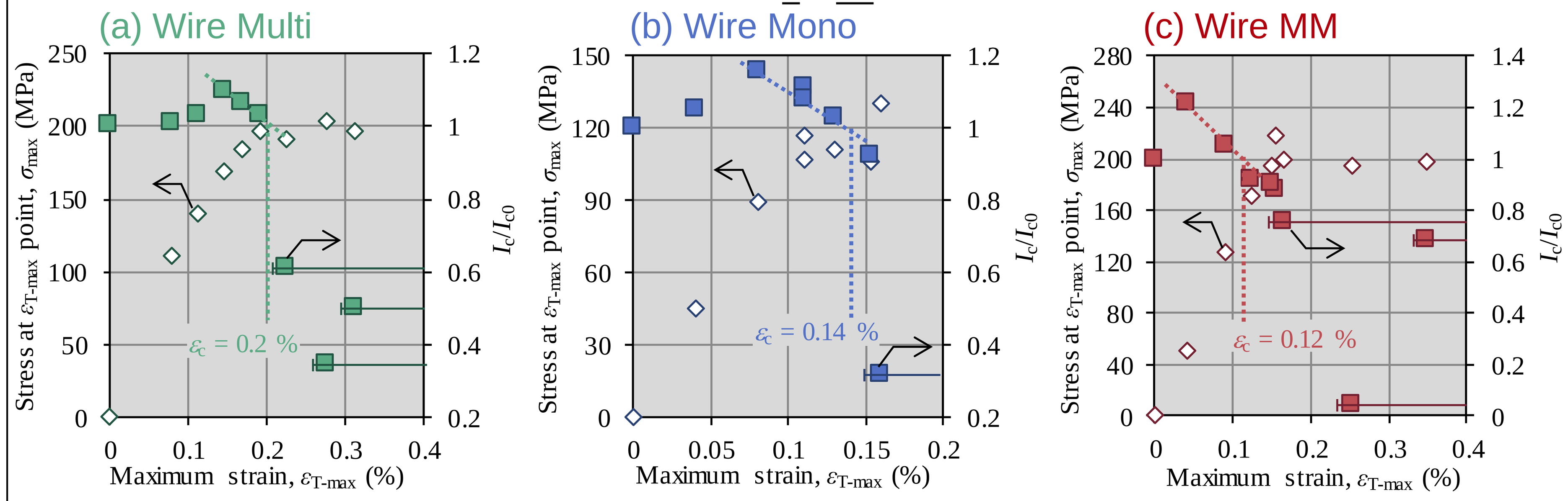
Measured Example (Three S-S curves at the same tensile test)



We could not measure the correct strain value of the entire area of the I_c measurement after iron began yielding, but the strains measured from the unyielded sample wires were correct.

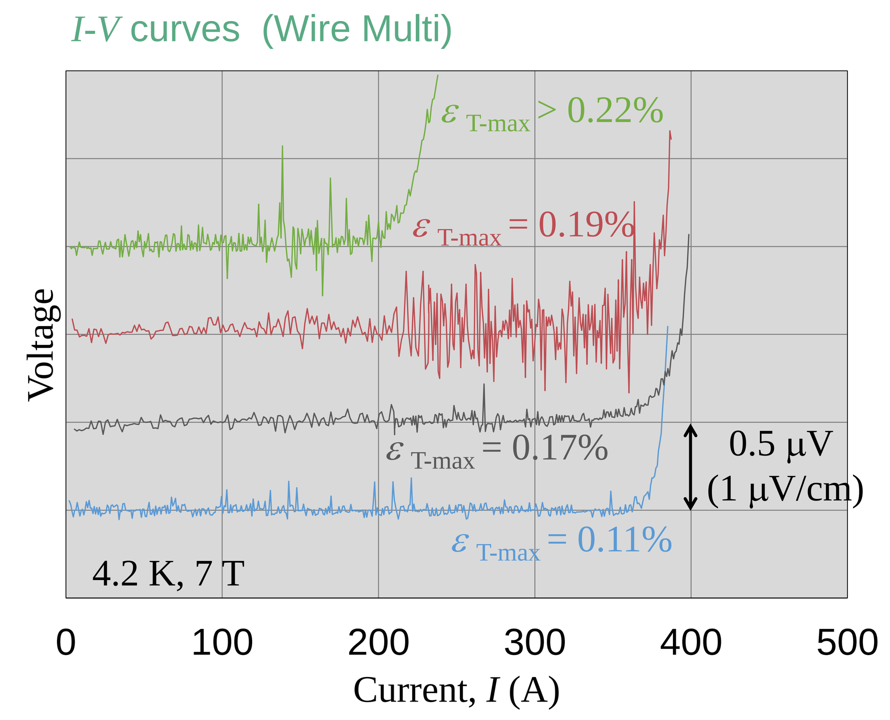
3. Results and Discussion (continued)

3-3. Tensile Strain at RT vs I_c/I_{c0}



We can measure the critical tensile strain at $I_c = I_{c0}$ as the threshold of I_c degradation from the results of $I_c > I_{c0}$, but …

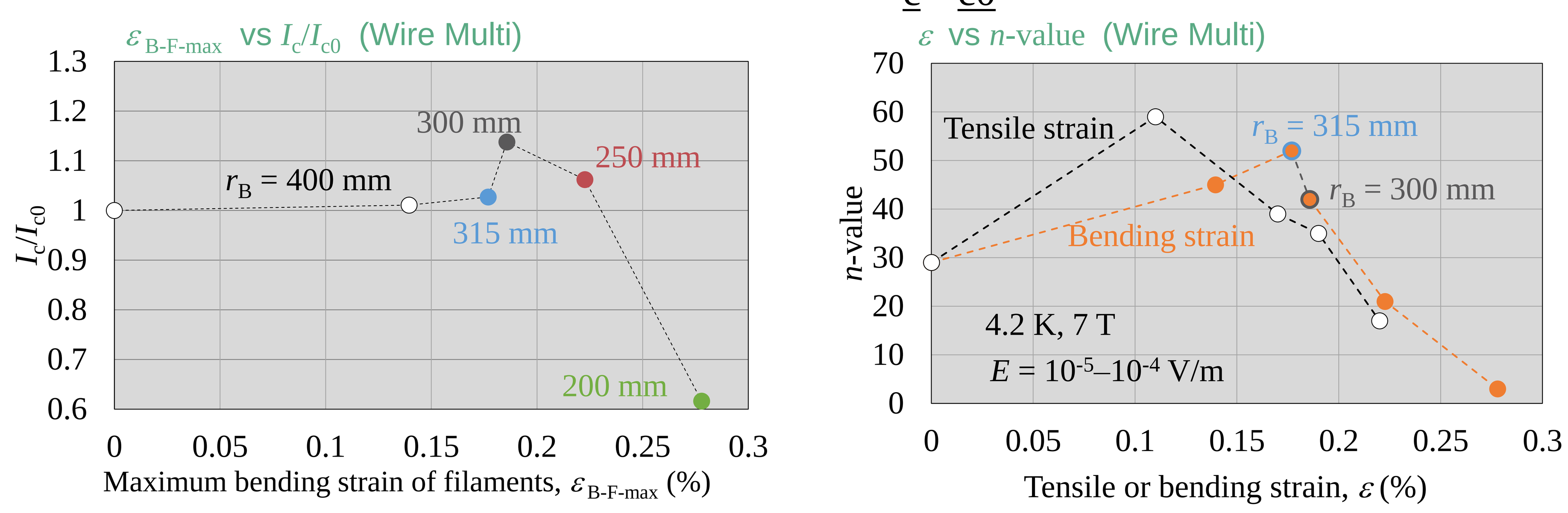
3-4. Critical Tensile Strain at RT Evaluated from I-V Curve

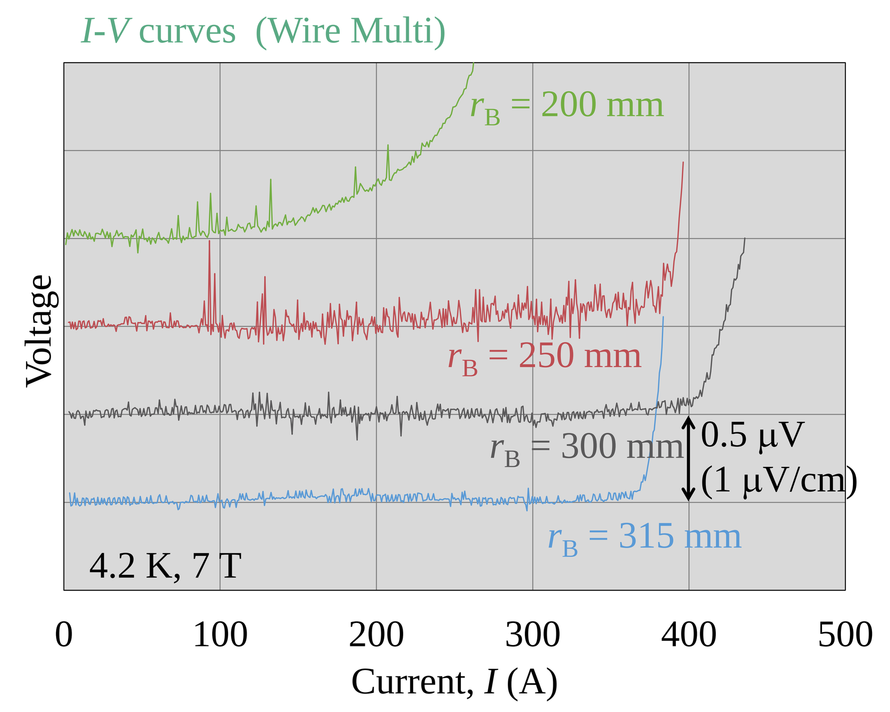


- I-V curve of $\varepsilon_{T\text{-}max}$=0.19% was very noisy.
- It can be estimated that a small part of MgB_2 filaments of $\varepsilon_{T\text{-}max}$ = 0.19% was damaged by tensile stress.
- It can be also thought that the noisy I-V curve was caused by the current distribution from some partly damaged filaments to some undamaged filaments.

The critical tensile strain at RT of Wire Multi was evaluated to be 0.17%–0.19%.

3-5. Critical Bending Strain from I_c/I_{c0} and I-V Curve

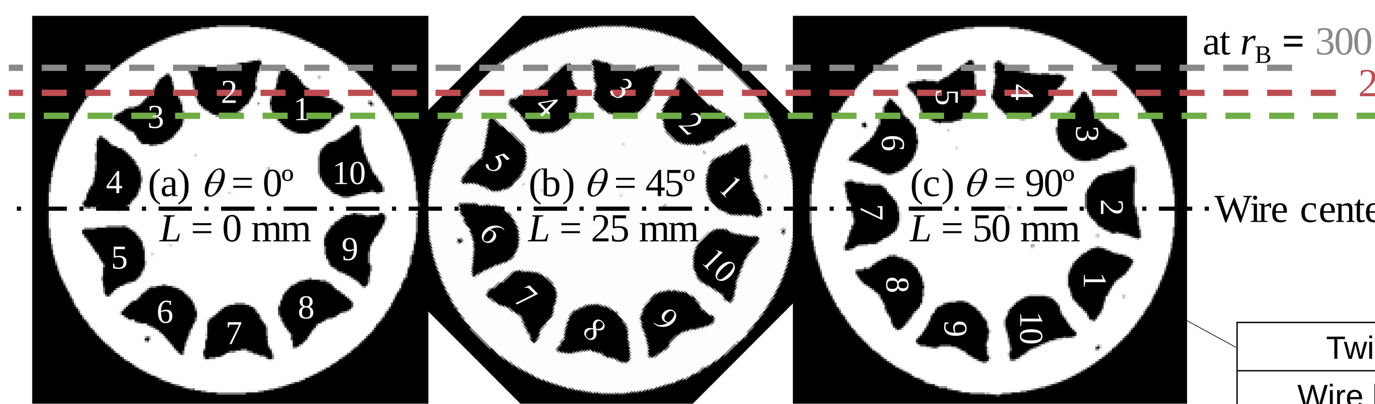




- From I_c/I_{c0}, the critical bending radius seems to be 200–250 mm, but…
- r_B = 250 mm
  I-V curve was noisy like over tensioned wire.
- r_B = 300 mm
  I-V curve was not so noisy.
  n-value begun to decrease.
- r_B = 315 mm
  I-V curve seemed to be perfect.

The critical bending strain of Wire Multi at RT was evaluated to be 0.18%–0.19%.

3-6. Confirmation of Threshold Line of Bending Strain



Twist pitch	200 mm
Wire length on I_c measurement	50 mm

- Threshold line was calculated with critical strain = 0.19%.
  The distribution of these lines agrees experimental results.
  e.g. r_B = 300 mm was close value as critical radius.
  Five filaments were damaged deeply in r_B = 200 mm.

4. Conclusions

(1) The Young's module of MgB_2 filament using mechanical milled powder was higher than that of ball milled powder as expected.
(2) The critical tensile strain at room temperature and the critical bending strain of Wire Multi were agreed well each other and evaluated to be 0.18%-0.19%.
(3) To find the threshold of I_c degradation, we should pay attention to not only the I_c/I_{c0} value but also the shape (noise and n-value) of I-V curve.
(4) The stressed filament has a possibility of being partly damaged even if $I_c > I_{c0}$, and we can find it from noisy I-V curve.

5. References

[1] P. Kováč, *SuST* (2015) 6200607
[2] P. Kováč, *SuST* (2013) 105028
[3] G. Nishijima *SuST* (2012) 054012
[4] C. Zhou, *SuST* (2014) 075002
[5] P. Kováč, *SuST* (2009) 075026
[6] M. Kodama, *SuST* (2017) 044006
[7] H. Tanaka, *IEEE Trans. Appl. Supercond.* (2016) 4600904