Performance study of a new epoxy resin IR-3 in HTS-based high-field magnet application

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Abstrct: REBCO (Rare-earth-based barium copper oxide) conductors are appropriate materials for high-field magnet applications. Vacuum impregnation using epoxy resin is a technique widely used for stable operation of superconducting coils. However, epoxy-impregnated REBCO coils often experience critical current degradation problems. Finding a suitable impregnating material for REBCO coils is important for their application in high-field superconducting magnets. A new toughness epoxy, IR-3, was developed recently. An in-depth understanding of IR-3 on the performance of REBCO coils is critically necessary for its application. Thus, this paper explores the effects of IR-3 impregnation on the performance of REBCO coils at 77 K and 4.2 K. The test results are compared to similar coils impregnated with CTD-101 K and MY750. Meanwhile, the radial stresses at 77 K in self-field and 4.2 K under 10 T were simulated. All epoxy impregnated REBCO coils showed no decay in critical current after thermal cycles at 77 K. When charged at 4.2 K in external fields of 5 T and 10 T, the IR-3 impregnated REBCO coils avoided performance degradation problems and had superior electrical stabilities. Combing the excellent performance at low temperatures, IR-3 is a promising candidate material for impregnating high-field REBCO coils.

Experimental section

Fig.1 Coil assembly.

Table 1. Parameters of the coils.

Parameters	Coil 1	Coil 2	Coil 3	Coil 4	Coil 5	Coil 6
Coil I_c @ 77 K, [A]	103.9	106.9	106.6	106.2	107.2	107.1
Insulation	Kapton					
Winding structure	Double pancake					
Inner diameter [mm]	60	60	60	50	50	50
Outer diameter [mm]	70	70	70	60	60	60
Conductor length [cm]	690	640	640	535	550	550
Turns of single pancake	17	16	16	15	16	16
Impregnation method	IR-3	CTD-101K	MY750	IR-3	CTD-101K	MY750

Table 2. Specifications of the epoxy systems

Epoxies	Resin system	Ratio by weight	Curing procedures
CTD-101K	DGEBA+ anhydride hardener +accelerator	100 : 90 : 1.5	5h at 110℃+ 16h at 125℃
IR-3	DGEBA+ anhydride hardener +accelerator	82 : 100 : 1	5h at 110℃+ 16h at 125℃
MY-750	DGEBA+aliphatic diamine hardener	100 : 55	6h at 40℃+ 3h at 80℃

The coil performance at 77 K in self-field

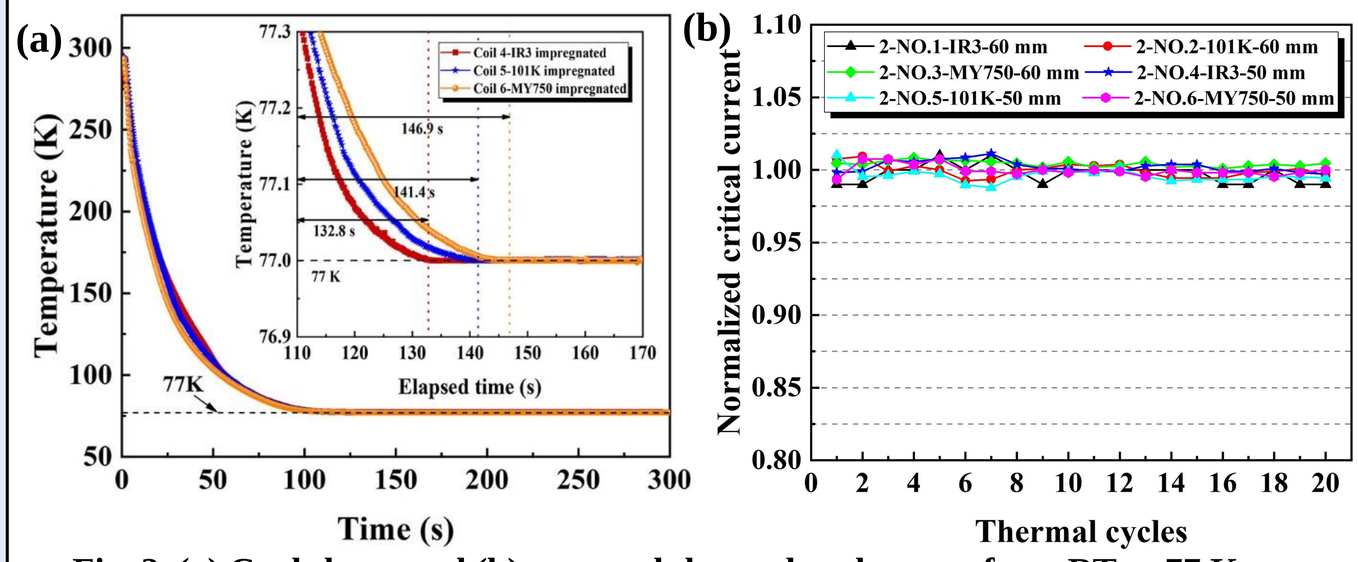

Fig. 2. (a) Cool-down and (b) repeated thermal cycles tests from RT to 77 K 。

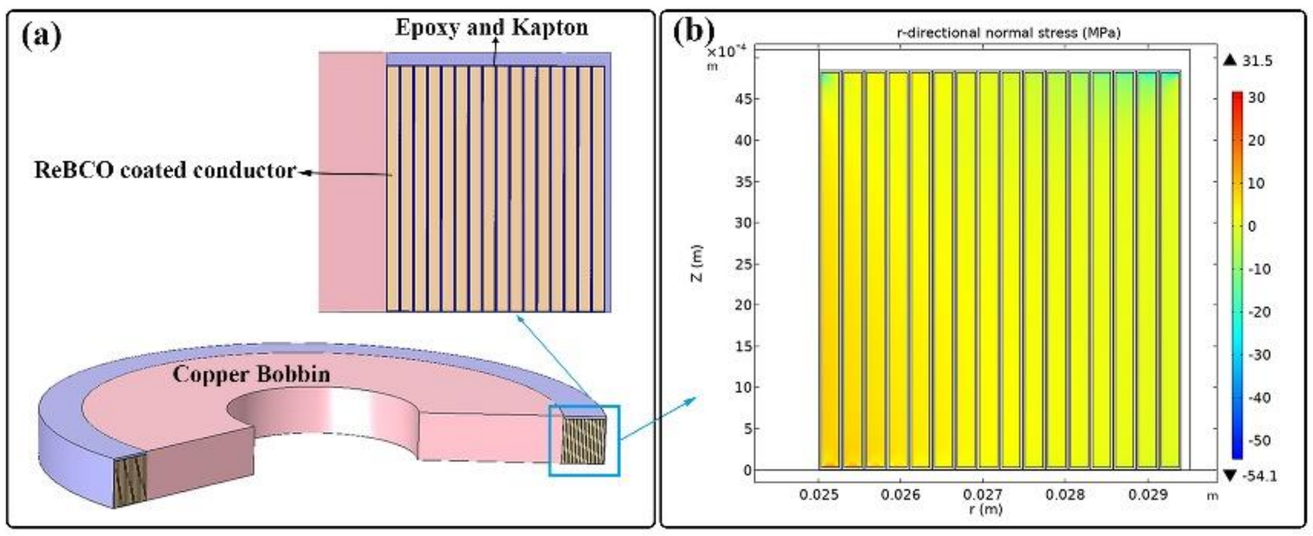

Fig. 3 (a) Modeling of the thermal contraction for the epoxy-impregnated coil and (b) analysis result for the r-directional normal stress.

Table 3. Minimum quench energy

Operating current	Coil 4		Coil 5		Coil 6	
	D=50mm, R=350.6 Ω		D=50mm, R=350.4 Ω		D=50mm, R=350.1 Ω	
	Pulse current (mA)	MQE (J)	Pulse current (mA)	MQE (J)	Pulse current (mA)	MQE (J)
70% I_c	84	7.42	84	7.42	85	7.59
80% I_c	68	4.86	70	5.15	69	5.00
90% I_c	58	3.54	59	3.66	59	3.66

The coil performance at 4.2 K in external fields

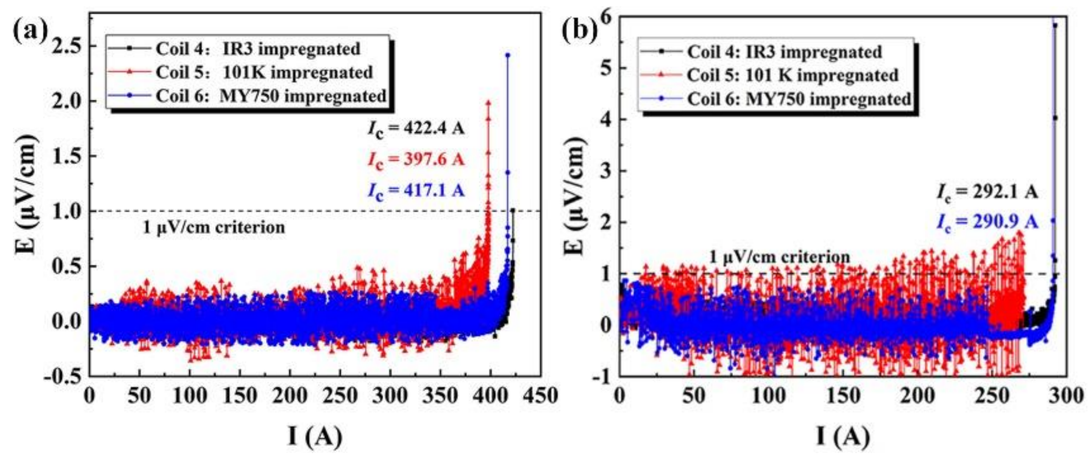

Fig. 4. *V-I* curves of the coils at 4.2 K under (a) 5 T and (b) 10 T.

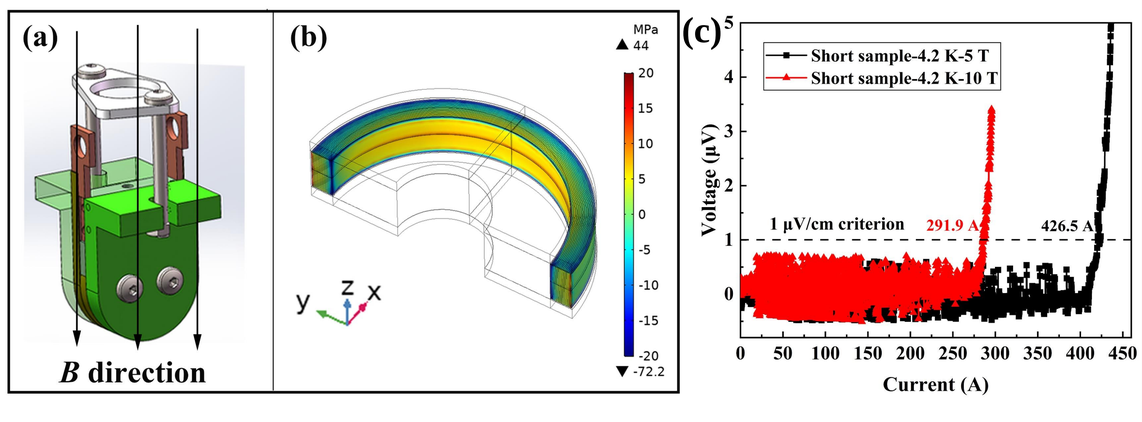

Fig. 5. (a) Schematic illustration of the fixed coil; (b) analysis result for the radial stress at 4.2 K; (c) the *V-I* characteristics of short tape at 4.2 K under 5 T and 10 T..

Conclusion

- At 77 K in self-field, the IR-3, CTD-101K, and MY750 impregnated REBCO coils can avoid performance degradation after repeated cooling tests. All the impregnated coils exhibited almost the same thermal and electrical stabilities. The IR-3 impregnated coil enabled well cooling performance between liquid nitrogen and the coil.
- Under 4.2 K with 5 T and 10 T background fields, the IR-3 impregnated coil showed superior electrical stability and also maintained its current-carrying capability.
- IR-3 exhibits high toughness, long-pot life, good mechanical strength, and acceptable radiation resistances. It has the potential as an impregnating material for HTS coils.