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Evaluation of Joint Resistance and Bending Performance of Various Ultrasonic Weld CC Joints

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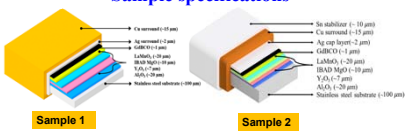
Introduction

- In practical applications, the superconducting coils and magnets impose to use joints to connect the unit lengths of 2G CC tapes and to constitute the termination of winding units such as in the cases of pancakes and double pancakes coils.
- Relevant joining technique that recently emerged in superconducting tape joints is ultrasonic welding. The localized high frequency ultrasonic vibration and pressure generated frictional heat and achieve metallurgical bond at contacting interfaces without melting the base metal.
- In this study, to further enhance the capability of the UW method to Cu stabilized REBCO CC tape joints, lap- and bridge-joints intended to be embedded in the coils using intermediate CC tapes were considered. The Taguchi Method, as design of experiments in optimizing the welding process parameters, was adopted to minimize the number of experiments.
- Joint resistance, R_j and critical current, I_c measurements of UW CC joints were measured at 77 K. Bending performance of UW CC bridge joints as a practical evaluation for magnet and coil applications were carried out and discussed.

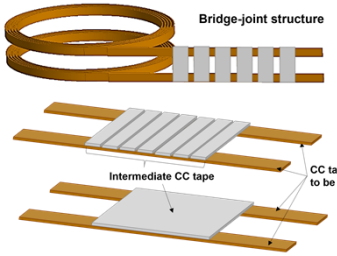
Experimental procedure

Sample specifications

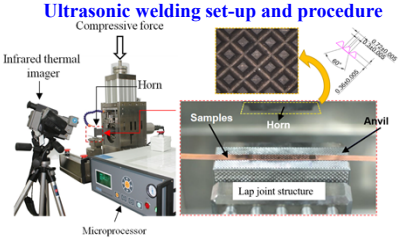


Specification of CC samples		
	IBAD/GdBCO CC	
Fabrication process	RCE-DR	
Structure	Ag/GdBCO/$LaMnO_3$/ Homo-epi MgO/IBAD MgO/ Y_2O_3/AlO_3/Stainless steel/Cu stabilized	
GdBCO film (*t*)	~ 1 μm	
Substrate, (*t*)	Stainless steel, ~100 μm	
Stabilizer, (*t*)	Cu surround, ~15 μm	Sn-Cu stabilized
Dimension, t x w *(mm)*	0.130 mm x 4.05 mm	0.140 mm x 4.05 m m
Critical current (I_c)	~ 220 A	~270 A
Manufacturer	SuNAM Co.	

Joint configuration

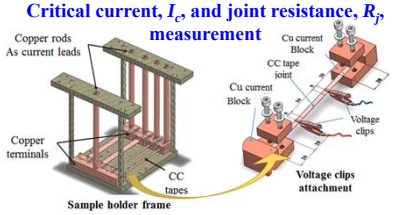


Ultrasonic welding set-up and procedure



❑Ultrasonic welder (KORMAX, Korea: KM-2035): frequency of 20 kHz

Critical current, I_c, and joint resistance, R_j, measurement



- ❑ **Lap-joint:** overlapping CC tapes on top of one another. GdBCO film sides facing each other, face-to-face structure
- ❑ **Bridge-joint:** indirect joint using an intermediate material
- ❑ **4-mm and 12-mm bridges:** Suitable if the joint is required to extend or replace the CC tapes in the coil winding, like in the case of double pancake coils

Double bending test

$$\varepsilon_b = \frac{t}{2r+t} \times 100\%$$

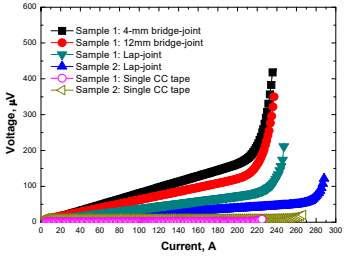
Where: ε_b = bending strain (+/-)
r = bending radius
t = thickness of CC tapes at the joint region

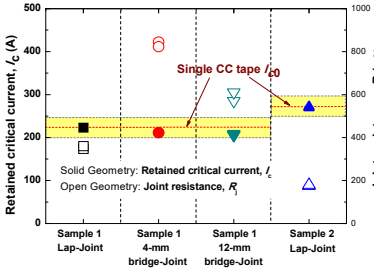
Shin, H.S., Dizon, J. R. C., Bonifacio, R. F., and Park J. S., 200 7, "Influence of bending strain on ic degradation behavior i n MCCI coated conductor tapes processed using RABiTS/M OD," KIASC Journal, vol 6, no 2, pp. 11-14.

- ❑The welder can generate power up to 3.5 kW varying the vibration amplitude at fixed frequency of 20 kHz
- ❑ Multiple I_c measurement fixture was used:
  - ✓ Voltage taps were clipped instead of soldering for an easier attachment
  - ✓ I_c was measured using four-probe method at 77 K (LN_2) with a voltage criterion of 1 *μV/cm*
  - ✓ The R_j was derived from the initial part slope of the V-I curve

Results and Discussion

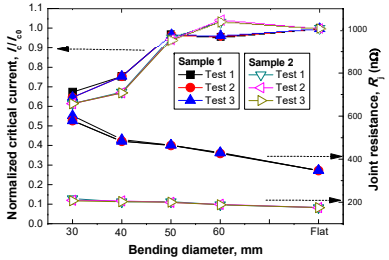
Electromechanical properties of UW CC joints





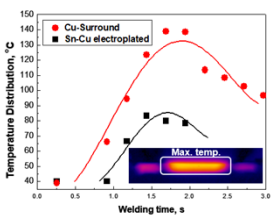
- ❑ All UW CC joints retained I_c (from single CC tape) without I_c degradation during UW process
- ❑ R_j for Sample 1 UW lap-joint is 340 nΩ and is about twice of Sample 2, R_j = 170 nΩ
- ❑ R_j for Sample 1 bridge joint is 820 nΩ and 600 nΩ for 4 mm and 12 mm bridges, respectively

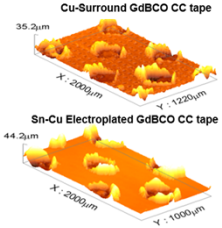
I_c/I_{c0} and R_j of UW CC lap-joints after double bending tests



- ❑ No substantial I_c degradation: up to 50 mm (0.26% bending strain)
- ❑ Abrupt I_c degradation (~70% of I_{c0}) at 40 mm bending diameter (0.62% bending strain)
- ❑ Sample 2: showed bending tolerance at the smaller diameters, increasing in a less sensitive way down to a 30-mm bending diameter

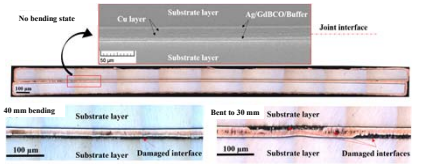
Temperature history distribution and surfaces images of UW CC joints





- ❑ **Results optimized by Taguchi method:** good indicators of weld quality: ~130 J and 288 W for Sample 1 and ~80 J and ~170 W for Sample 2
- ❑ **Max temp of ~140°C for Sample 1 and ~85°C for Sample 2:** recorded temp are not enough to alter the weld quality nor damage the CC tapes
- ❑ **Horn tip penetration:** ~7.5*μm* deep to Cu-stabilizer of Sample 1, while ~10*μm* to Sn-stabilizer of Sample 2 (Vickers hardness value difference)

Cross-sectional views of Sample 1 at UW CC lap-joint interfaces



- ❑ I_c degradation also affects the increase of R_j as the bending diameter decreases
- ❑ 50-60 mm bending dia w/out I_c degradation is consider safe as required in various CC tapes utility devices
- ❑ Incomplete bonding and damages along the joint interfaces, even in the unbend UW CC joints

- ❑ High R_j for bridge-joints were perhaps due to complex current transfer path and R from voids at the joint interface
- ❑ After bending, damage interface was only visible along the Ag/GdBCO/Buffer layer at 40 mm bending dia
- ❑ 30 mm, multiple locations of damages were observed at the interface

Summary

- ❑ The retained I_c of CC joints did not show any degradation after the UW process.
- ❑ A joint resistance value ranging from ~100 to ~200 nΩ could be obtained for a lap-joint structure using the UW method. The double bending test of UW CC joints demonstrated a large tolerance to smaller bending diameter up to 50 mm without any I_c degradation, which particularly within the minimum 100 mm required bending diameter in various CC device applications.
- ❑ The results were considered suitable for practical 2G CC device applications. To further improve the joint quality, hybrid UW variants and other joint configurations in CC coil winding application involving intermediate material, such as butt, inclined, etc., are still needed.

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