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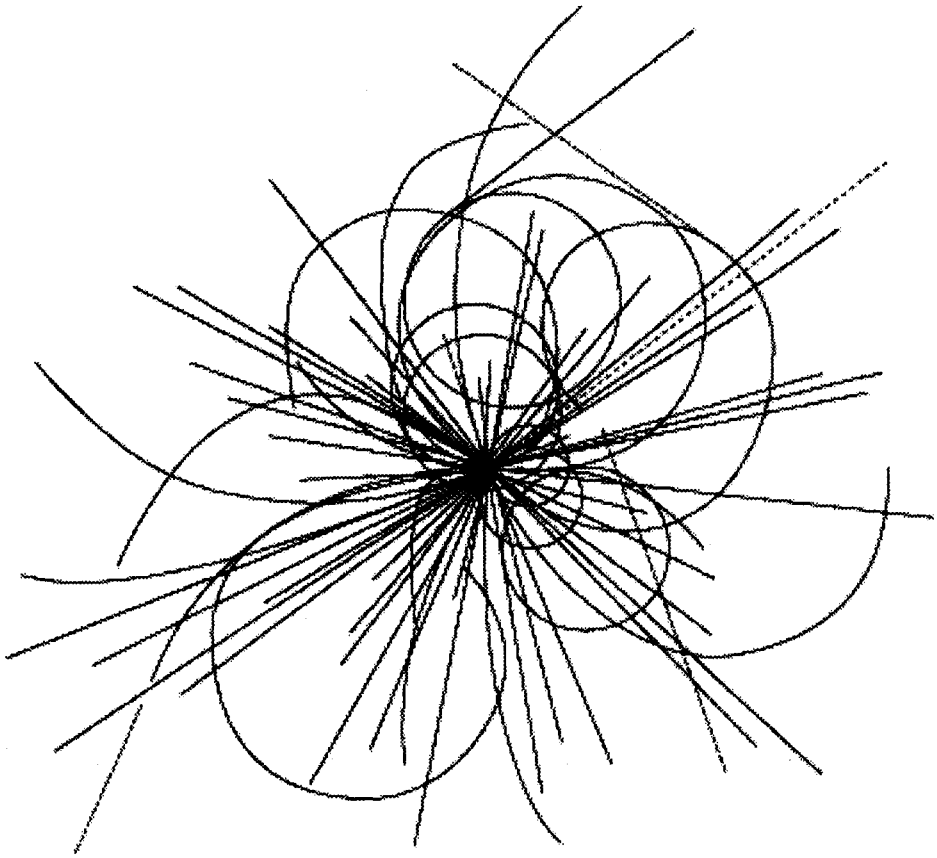

Superconducting Super Collider Laboratory

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A Study of the Effect of Cable Insulation on Coil Properties*

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A STUDY OF THE EFFECT OF CABLE INSULATION ON COIL PROPERTIES

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INTRODUCTION

Stacks of insulated superconducting cable were cured and tested for mechanical properties. Four different polyimide films were investigated in all polyimide insulation schemes. The effect of bottom layer material, top layer material and wrapping scheme on stack size, modulus, and compressive creep are reported.

TEST METHOD

Ten pieces of manually insulated superconducting cable five inches long were stacked with staggered keystone angles and cured for one hour at 150°C. The central 3 inches of the stack were subjected to pressure. The deflection, temperature, and pressure were measured and recorded once a minute during cure. Three stacks of each combination were cured and tested. The stacks were used to model a coil for the purpose of testing insulation schemes.

For the study of film type, bottom layer films used were Kapton H, Apical NP, and Upilex R and top layer films were Kapton LT, Apical NP, and Upilex R. The bottom and top layers were 50% overlap and there was adhesive only on the outside surface of the top layer. In addition, wrapping configuration was studied. For this part of the study, film type was held constant with Kapton H on the bottom layer and Kapton LT on the top. The 50% overlap top layer was compared to a butt wrap top layer and adhesive on both sides of the top layer was compared to adhesive on one side of the top layer. The modified 3P adhesive system was used throughout because it was the only adhesive available on all film types. The same batch of cable was used for all stacks. Fiberglass systems were not investigated due to a shortage of cable.

The modulus and compressive creep were measured with an MTS servohydraulic test machine. Deflection was measured on each side of the stack with extensometers. Modulus data were taken at a load rate of 1 ksi/sec. The modulus was taken to be the slope of the stress strain curve between 8 ksi and 12 ksi. The height at 10 ksi was found by subtracting the deflection of the stack at 10 ksi as measured in the modulus test from the stack height at 0 ksi. Compressive creep data were taken for four hours at 12 ksi and were taken at least

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24 hours after the modulus measurements to allow for recovery of the stacks. The coefficient of the best fit logarithmic curve was used as the basis of comparison. Results presented in Tables 1 and 2 are the average values for these trials.

RESULTS

Statistical analysis was performed using analysis of variance (ANOVA). After the existence of a statistically significant difference was found with ANOVA, post hoc tests using pair-wise comparison were used to determine which configuration(s) were statistically different.

The wrap configuration had a significant effect on stack height. For both the 0 ksi and 10 ksi stack height measurements, the butt wrapped top layer stacks were, as expected, smaller than the stacks with 50% overlap top layers and the two sided adhesive stacks were only slightly larger than their one sided adhesive counterparts. The two sided adhesive stacks had significantly higher moduli than the one sided glue stacks. There did not appear to be a difference in modulus between the butt wrapped and 50% overlap configurations. Compressive creep was significantly affected by both the wrapping and the adhesive layers. Creep was higher in the 50% overlap than the butt wrapped configurations and in the one sided glue than the two sided glue configurations. The data can be seen in Figure 1.

Both top and bottom layer materials had a significant affect on the stack height at both 0 ksi and 10 ksi. For the 0 ksi height, the stacks with a bottom layer of Upilex R were significantly smaller than the others with no difference between Apical NP and Kapton H. At 10 ksi, the stacks with bottom layer Apical NP were significantly larger than the other stacks, with no difference between Upilex R and Kapton H. At both 0 ksi and 10 ksi, the stacks with top layer Kapton LT were significantly smaller than the others with no difference between Apical NP and Upilex R. Perhaps the Kapton LT was smaller than the nominal 1 mil and that accounts for the top layer effect. Figures 2 and 3 show this data.

The stack modulus depended only on the bottom layer with Upilex R having a significantly higher modulus than the others and no difference between Apical NP and Kapton H, as can be seen in Figure 3. The creep coefficient depended only on top layer material, as can be seen in Figure 2. Stacks with Apical NP as a top layer material suffered significantly less creep than others and no difference between Kapton LT and Upilex R. This is surprising because Kapton LT is widely believed to reduce creep.

CONCLUSIONS

The optimum coil would have the lowest possible creep rate, the most consistent stack height under load, and the highest modulus. It would be recommended that a butt wrap be used on the top layer with glue on both sides, and that Apical NP be used as the top layer material. Because the bottom layer effect on size and modulus were both due to Upilex R, which is no longer available in the United States, further study may be needed to determine an optimum bottom layer material. Determination of optimum glue type and cure cycle will also require further research.

Table 1. Wrap configuration data.

adhesive	wrapping	height (in) @ 0 ksi	height (in) @10 ksi	modulus (ksi)	creep coef. ($x10^{-4}$)
1 side	butt	0.636	0.621	794.4	-5.623
1 side	50%	0.659	0.638	804.2	-5.906
2 side	butt	0.637	0.624	839.1	-5.212
2 side	50%	0.661	0.648	851.2	-5.644

Table 2. Film type data.

bottom layer	top layer	height (in) @ 0ksi	height (in) @10ksi	modulus (ksi)	creep coef. ($x10^{-4}$)
Kapton H	Kapton LT	0.659	0.638	804.2	-5.906
Kapton H	Apical NP	0.657	0.642	777.5	-4.816
Kapton H	Upilex R	0.657	0.641	795.6	-5.556
Apical NP	Kapton LT	0.655	0.639	776.1	-5.063
Apical NP	Apical NP	0.661	0.643	869.3	-4.814
Apical NP	Upilex R	0.660	0.643	823.7	-4.906
Upilex R	Kapton LT	0.652	0.638	881.0	-5.954
Upilex R	Apical NP	0.657	0.643	920.8	-4.291
Upilex R	Upilex R	0.655	0.641	911.5	-5.195

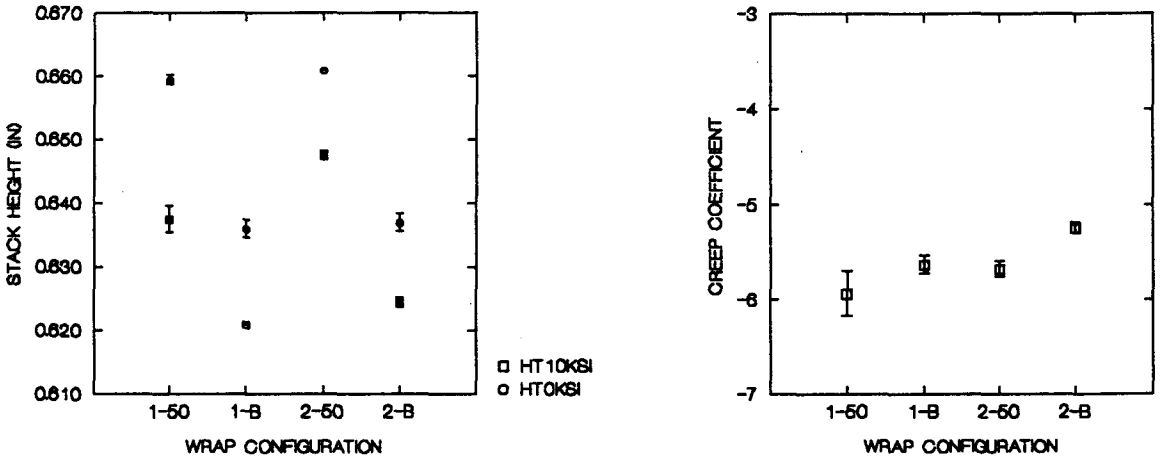

Figure 1. Effect of wrap configuration on stack height and creep coefficient.

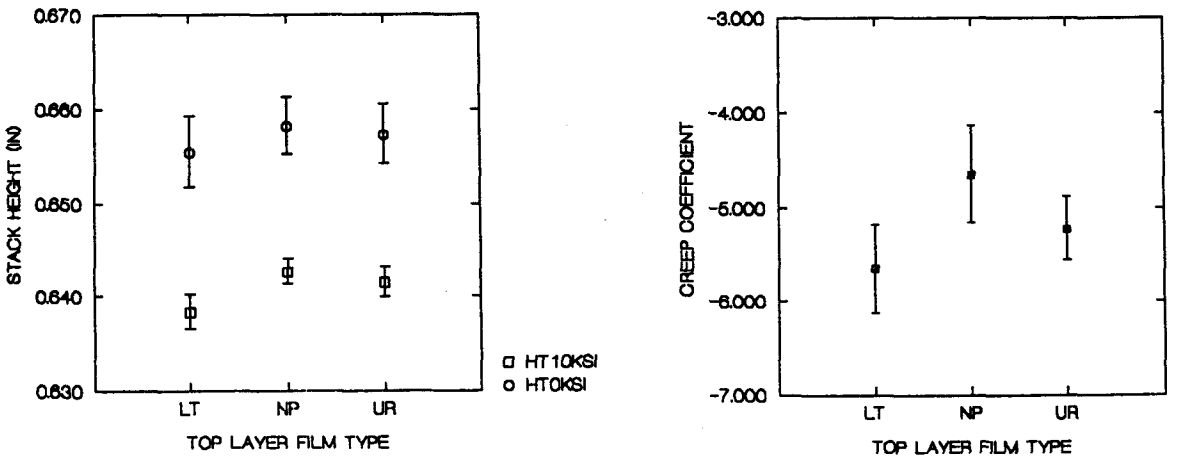

Figure 2. Effect of top layer materials on stack height and creep coefficient.

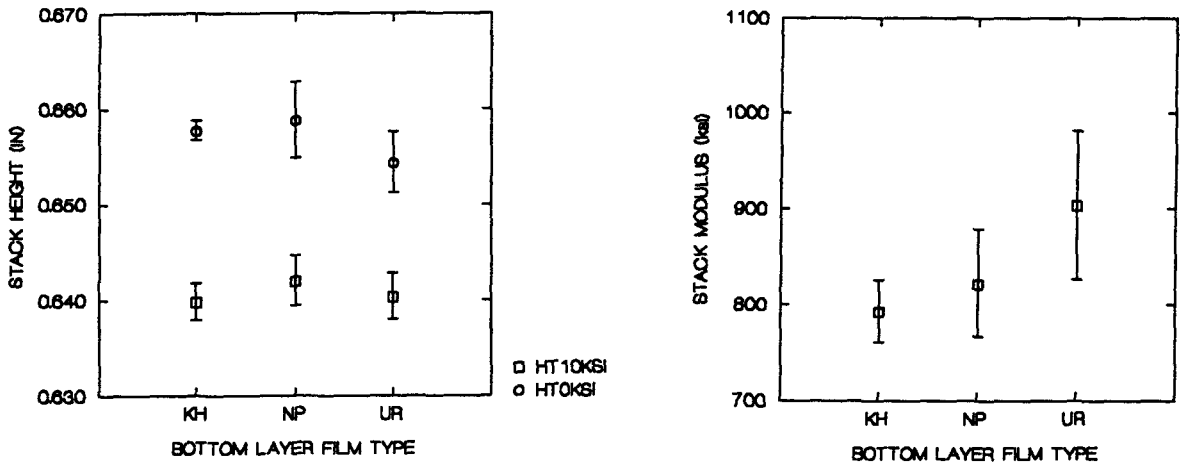

Figure 3. Effect of bottom layer materials on stack height and modulus.