Phil Heitzenroeder

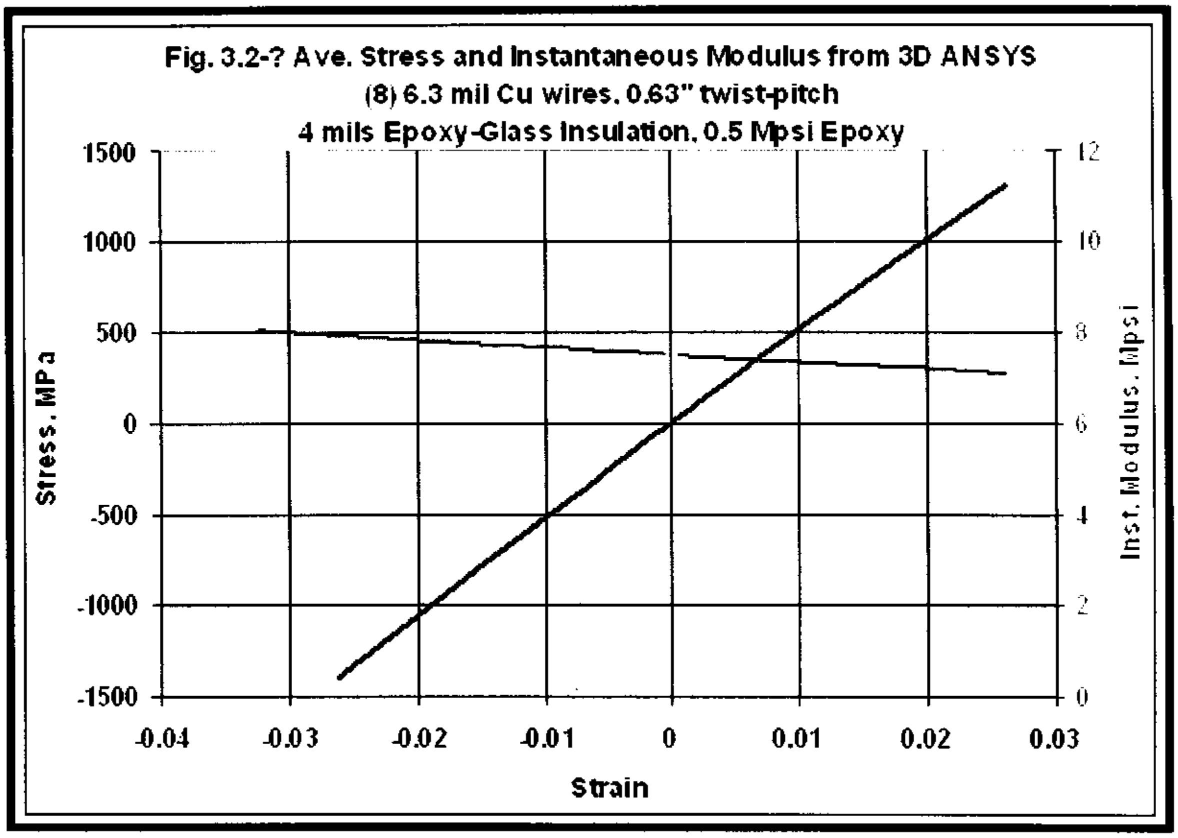
From: Phil Heitzenroeder
Sent: Tuesday, February 10, 2004 8:49 AM
To: Jim Chrzanowski (jchrzanowski@pppl.gov)
Subject: Info on cable properties from Len

Phil and others,

During the Wednesday conference call, you asked what the effect would be if the epoxy modulus was changed from 10 GPa (1.45 Mpsi) to 0.5 Mpsi. Although the effort was rather simple, I have been distracted by company, family commitments and a holiday. Sorry for the late reply, but I have finally pulled it together in this email. (Let me know if you want it formalized in a project memo.)

I made two ANSYS runs of my 8-strand cable model to answer this question; one in tension, and the other in compression. I also applied the rule of mixtures. Again, the model is pretty consistent with the hand calculation, and higher than we see in the test data. The model indicates a modulus of 7.5 Mpsi, while the hand calculation results in 7.7 Mpsi. The plot below shows the stress-strain curve (in black) and the local derivative representing the modulus (in blue). Recall that the 10 GPa epoxy results in a cable modulus of about 8 Mpsi.

This indicates that the epoxy modulus has a small impact on the composite cable modulus. It, of course, has a huge impact on the mechanical performance of the cable... since it holds everything together and does not allow any gross motion of the strands. But, the modulus is only a small part of the composite, and so any change in the modulus (even this reduction by a factor of three) has a relatively small impact on the overall average.



I also asked for and received some micrographs of the cable cross-section from Brad Nelson. I was curious about the strand-to-strand spacing and thoroughness of epoxy impregnation. Below are two of the micrographs Brad sent to me. The most interesting thing to notice is that a significant number of the strands are pressed into contact with their neighbors. These contact regions are easily seen in the 50 µm close-up image.

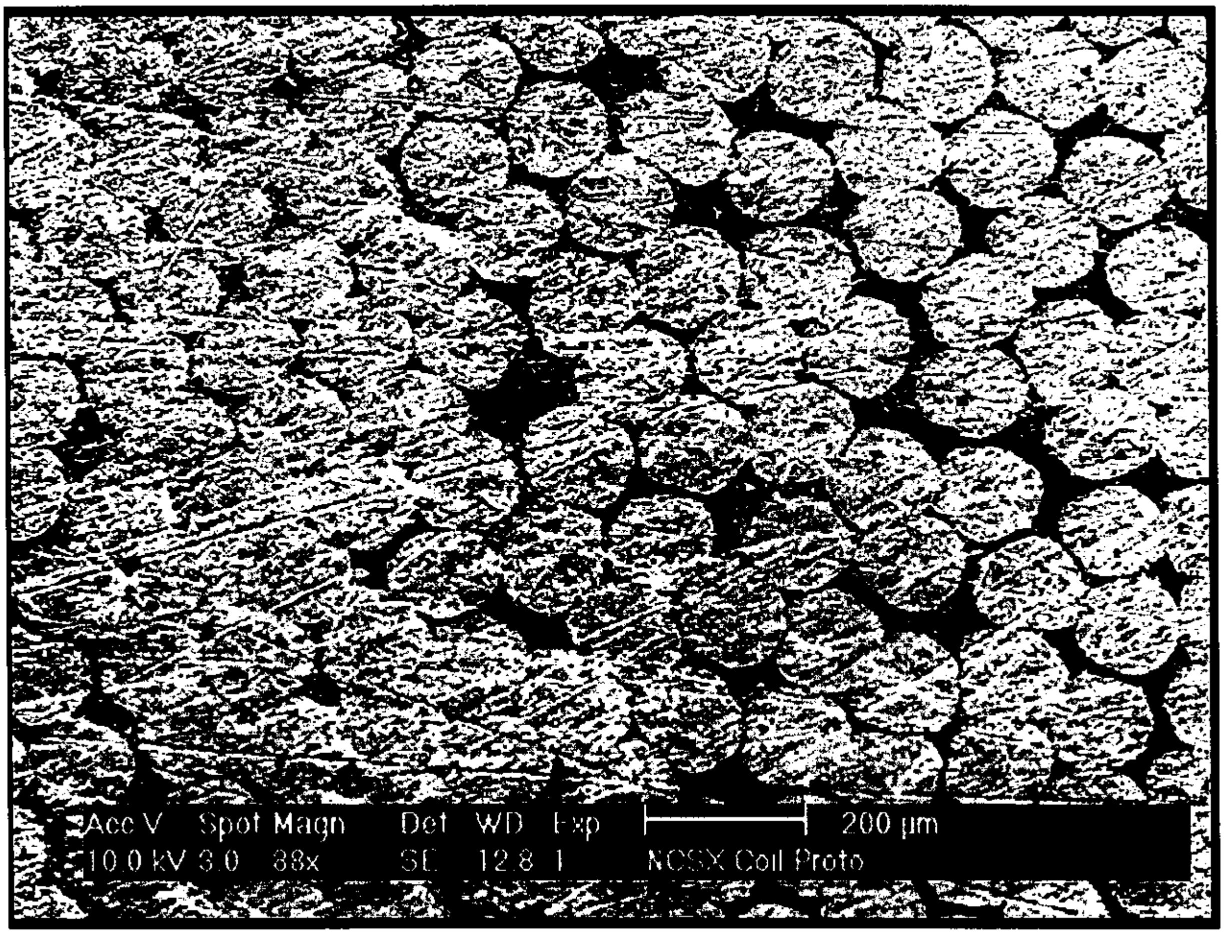
It strikes me that the strands are neither metallurgically nor epoxy-bonded at these contact surfaces. Now, the cross-section will look different at another axial position, and the unbonded strand surfaces may become bonded some distance away from the strand-to-strand contact region. But, this sets up a situation in which the impregnated cable is not a monolith, but rather a complex composite with millions of unbonded contacting surfaces of various dimensions and shapes.

Clearly, this type of structure will behave softer than our idealized monolith, as these tiny contact surfaces shear and open with applied loads. I can also imagine how an axial compressive load would be softer than an axial tensile load. Compressive loads will tend to spread apart the cable cross-section, thereby opening and shearing the tiny unbonded surfaces. Tensile loads will tend to tighten the cable cross-section, thereby closing and shearing the unbonded surfaces. Both of these actions will propagate millions of "crack fronts." The shearing comes from an almost certain non-uniformity in the load paths. The behavior of these micro-contact surfaces must be seen as a

softening effect relative to the behavior of an idealized monolithic composite.

My feeling is that microcracks are responsible for the softer-than-expected composite modulus. But I have not yet thought of a simple model to help demonstrate this theory.

Any thoughts?



Regards,

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