DEFORMATION BEHAVIOR OF Nb₃Sn TYPE SUPERCONDUCTORS

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This report discusses the pre-strain, deformation behavior and possible strengthening methods in Nb₃Sn type superconductors. In calculation of the pre-strain, we take into account the influence of the temperatures on elastic modulus, yield strength and microstructure on each component. For example, our experimental results demonstrate that the pre-strains accumulated at high temperatures in Cu component are largely relieved due to the recovery of both microstructure and mechanical properties. Therefore only the pre-strains produced in cooling from 473K to 4K are taken into account in our calculations. When all components are in elastic state, the thermal expansion strain of the composite wire is calculated by the following formula

\[ \varepsilon_c(T) = \frac{\sum \varepsilon_i(T) \cdot E_i(T) \cdot V_i}{\sum E_i(T) \cdot V_i} \quad [1] \]

where \( \varepsilon_c \) and \( \varepsilon_i \) are the true strain of the composite and component i, respectively; \( E(T)_i \) is the elastic modulus; whereas \( V_i \) is the volume fraction of component i. If the deformation in component \( k \) reaches its yield strain \( \varepsilon_{k-y} \), the strain hardening rate \( \theta_k(T) \) governs its deformation behavior, then the value of \( \varepsilon_c \) can be calculated by:

\[ \varepsilon_c(T) = \frac{\sum \varepsilon_{k-y} \cdot E_k(T) \cdot V_k - \sum \varepsilon_i \cdot E_i(T) \cdot V_i - \sum (\varepsilon_{k-y} + \varepsilon_k) \cdot \theta_k(T)}{\sum \varepsilon_c \cdot E_i(T) \cdot V_i + \sum \varepsilon_c \cdot \theta_k(T)} \quad [2] \]

The strain-hardening rate of Cu decreases from 2.5GPa to about 0.5GPa at 4K, when plastic stress increases from 0 to 300MPa. Therefore, when one uses [2] to calculate the pre-strain, the strain hardening rate variation has to be considered.

In order to let Cu stabilizer carry more load, one has to either increase the flow stress or strain hardening rates. Reduction of the grain sizes increases the flow stress effectively but reduces the strain-hardening rate slightly in this composite. The effect of grain size of Cu stabilizer on the strength of Nb₃Sn type conductor is showed in Fig.1. The results show that grain sizes influence not only the flow stresses, but also the shape of the stress strain curves.

![Fig. 1](image1.png)

![Fig. 2](image2.png)

Fig. 1. Calculated stress-strain curves of Nb₃Sn composite conductors tested at 4 K. The figure shows that grain sizes influence not only the flow stresses, but also the shape of the stress strain curves. In this example, the Cu stabilizer, Cu-Sn matrix and Nb₃Sn have volume fractions of 50, 30 and 20%, respectively. The thin and thick solid curves show the stress strain curve of the composites with the grain sizes of 100 and 10 µm, respectively in a Cu stabilizer.

Fig. 2. Calculated stress-strain curves of Nb₃Sn composite conductors tested at 4 K. The figure shows that hard particles have very high strengthening effects to the conductor.

Nb₃Sn composites can also be strengthened by other approaches. Two most important ones are solid solution and particle strengthening. The stress increment due to the addition of hard particles depends mainly on the strength of Cu-Sn or Cu matrix material and the average distance between particles. Fig.2 demonstrates that the particle-strengthening is more effective than solid solution strengthening in Nb₃Sn type superconductor composites. Therefore, our simple model provides a useful guidance in development of new high strength Nb₃Sn type superconductor composites for next generation magnet.