STUDY OF REINFORCEMENT MATERIALS FOR HIGH FIELD MAGNETS

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The National High Magnetic Field Magnetic Laboratory (NHMFL) builds various high field magnets. Those magnets require new reinforcement materials that have high strength and toughness at cryogenic temperatures. For the materials used for the cable-in-conduit conductor (CICC) concept for either 45 T hybrid magnet or series connected magnets or other future high field magnets, the materials need to meet an additional requirements to accommodate the manufacturing and heat-treatment processes for the superconductor as well as its strain-sensitive performance during the operation.

We have characterized various candidate alloys that have the potential to be used for the next generation magnets using CICC concept and Haynes 242 is proved to be competitive. The material is a Ni-based alloy and has a composition of 65Ni-25Mo-8Cr-2.5Co-2Fe-0.8Mn-0.8Si-0.5Al0.5Cu-0.03C-0.006B(in wt%). The material has significant higher Young's modulus than SS316LN, which is currently used as reinforcement materials for 45 T magnet. At 4.2 K, the materials have yield and tensile strengths of 0.86 and 1.68 GPa, respectively. After aging using the conditions compatible to superconductor processing, the materials have yield and tensile strengths of 1.34 and 1.97 GPa respectively at 4.2 K. The aging condition used is 700 °C for 100 h. It is known that various phases of Ni-Mo were formed in the f.c.c. matrix as precipitates depending on aging temperature and aging time [1]. The age hardening was due to the fact of formation of very fine precipitates in the matrix, as shown in a transmission electron microscopy (TEM) image. The high density refined precipitates provide barriers for dislocation motion and strengthened the material. Fig.1a is a bright field TEM image showing dislocations in the annealed sample, while Fig.1b, dark field TEM image shows the ellipsoidal disc shaped precipitates in aged material.

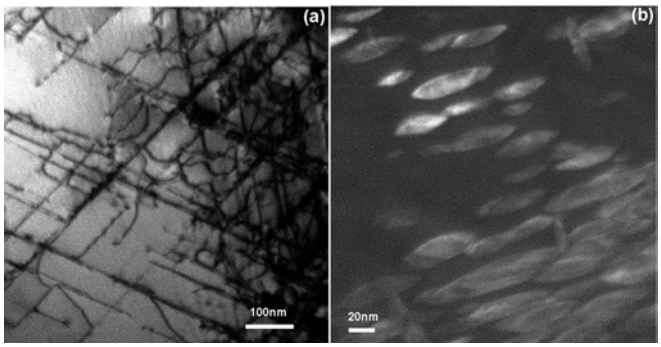

Fig.1 (a) Bright field image shows only dislocations present in the annealed sample; (b) Dark Field image showing the precipitates in f.c.c matrix;

At 4.2 K, the elongation and reduction-in-area at fracture are 26% and 21%, respectively. A typical fracture surface is shown in Fig.2. The surface is very rough with many microvoids and dimples, indicating no catastrophic brittle failure at 4.2 K.

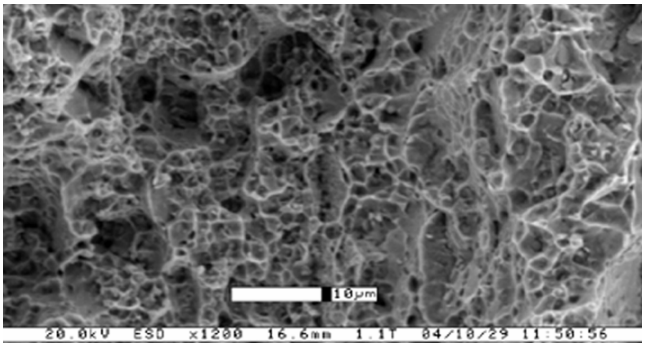

Fig.2 SEM image showing the ductile facture surface of the aged sample fractured at 4.2 K.

Therefore, this material is promising for cryogenic application even after it is heat-treated using the temperature used for superconductors. However, further research is required to measure the fracture toughness and fatigue properties, and to study the failure mechanisms at cryogenic temperatures.

Acknowledgements

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References

[1] Ohgami, *et al*., Journal of Electron Microscopy, **33**, 94-94 (1984); Kumar, *et al*., Acta mater. **44**, 4865-4880 (1996).