High Modulus Reinforcement Alloys

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Introduction

Materials used as reinforcement for conductors in high-field magnets require both a high capacity for load bearing and a high resistance to deformation under stress. In other words, they need both high tensile strength and high modulus. We investigated a number of nickel-based and nickel–cobalt-based alloys designed for high-temperature applications, and we evaluated their potential for use as reinforcement materials in high field magnets.

Alloy Selection

Most nickel-based alloys have higher Young's modulus than the stainless steels that are currently in use as reinforcement materials in high-field magnets. Several nickel alloys (e.g. MP35N, Elgiloy and Haynes 242) have high Young's modulus and strength. We subjected these materials to thermo-mechanical processing that strengthens alloys by forming very fine particles within them. Our initial work focused on changes that occurred during deformation at either cryogenic or room temperature. Both the matrix and the strengthening component area had more resistance to plastic deformation at cryogenic temperatures. In some cases, we further enhanced the strength of the alloy by doping it with other elements. In all cases, these alloys permitted more efficient performance of conductors by sharing more of the load than would be possible with stainless steel reinforcement materials. This report outlines the properties of nickel alloys and establishes their compatibility with some of the conductors now commonly used in high-field magnets.

Properties and Microstructure

Of the two alloys we studied, MP35N and Elgiloy, the modulus is higher in MP35N, which has additional alloying elements of molybdenum. Thus, we chose this as the main subject of our study. End products made from MP35N can have varying moduli. In products that have been fully cold-worked and age-hardened, the Young's modulus has risen as far as 220 GPa or above, significantly higher than any other alloys we studied, including stainless steels [1]. At 77 K, the modulus of these products increased further by 6%. Reducing the temperature to 5 K increased Young's modulus even more, but at a slower rate (Fig. 1). Meanwhile, the shear modulus of MP35N also increased as the temperature decreased. The percentage increment of this increase was slightly higher for shear modulus than for Young's modulus (Fig. 1). This indicates that during cryogenic deformation, the alloy is more resistant to shear than to pull [1]. Both moduli were strengthened by nano-platelets formed during deformation and aging (Fig. 2)

Acknowledgements

The National High Magnetic Field Laboratory is supported by the National Science Foundation through NSF/DMR-1157490/1644779 and the State of Florida.

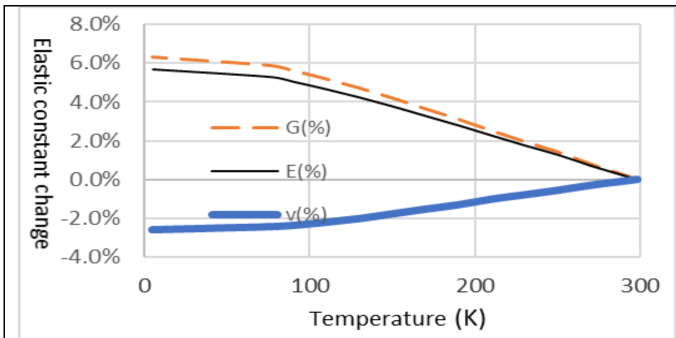

Fig. 1 Percentage change of elastic constant with temperature of MP35N. The dashed line represents the shear modulus (G).The solid thin line indicates the Young's modulus (E). The thick solid line represents the Poisson ratio (v).

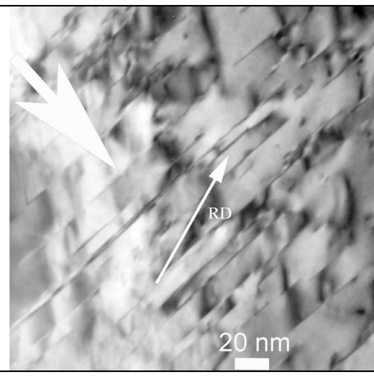

Fig.2 Transmission electron microscopy image (bright field) showing thin platelets (one of them indicated by a fat arrow) to strengthen the materials. This sample had been cold-rolled and aged. The longer arrow indicates the rolling direction.

References

[1] K. Han, V. Toplosky, N. Min, J. Lu, Y. Xin, R. Walsh, High Modulus Reinforcement Alloys, IEEE Transactions on Applied Superconductivity 28(3) (2018) 1-5.