Deformation Processed Al/Al_2Ca Nano-filamentary Composite Conductors

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ABSTRACT

Light, strong, high-conductivity materials are desirable for overhead power transmission and distribution conductors. In this study an Al/Ca (11.5 vol.%) composite with nano-filamentary reinforcement was warm extruded, swaged, and wire drawn to a maximum true strain of 12.7. In an effort to improve the conductor's ability to operate at elevated temperature, the deformation-processed wires were heat-treated at 260˚C to transform the Ca reinforcing filaments to Al_2Ca. The transformation raised tensile strength by as much as 28%, caused little change in ductility, and reduced electrical conductivity by 1 to 3%.

1. INTRODUCTION

A 48% increase in worldwide energy demand is expected by 2040, which will require expansion of electrical power transmission infrastructure [1]. Expanded long-distance transmission grids in China, the United States, and elsewhere are expected to make greater use of high-voltage direct current (HVDC) transmission, the preferred technology for long distances [2]. Conventional aluminum-conductor steel-reinforced (ACSR) cables are not well suited for HVDC transmission due to the presence of the heavy, poorly conducting steel core needed for strength and sag-resistance. Al/Ca composite conductors with monolithic construction produced by powder metallurgy and deformation processing have shown promise as a possible next-generation conductor for this application.

Deformation-processed metal-metal composites (DMMCs) provide an appealing approach for producing lightweight materials with high strength and high conductivity. DMMCs can be produced by powder metallurgy and severe plastic deformation resulting in nano-filamentary reinforcement. Extensive study of this class of materials has shown that they exhibit strength that increases exponentially with true strain while maintaining conductivity close to the rule-of-mixtures prediction [3]. Both materials in the composite must be highly ductile in order to withstand the extensive deformation processing without fracturing. The proposed conductor material utilizes Al as the primary phase and Ca as the secondary reinforcement phase, both starting as elemental powders. They are blended and deformed into sub-micron-thickness filaments with extremely high aspect ratio during wire drawing, resulting in interface strengthening. Al and Ca are ductile fcc metals with high conductivities, similar mechanical properties, and low densities.

The first-generation of Al/Ca conductors proved the strengthening mechanism of the material but was limited by the coarse Ca powder size used [4]. The second-generation material, Al/Ca (20 vol. %), was made with high-purity powders with smaller powder particle sizes, enabling strengths superior to existing cable technologies [5]. One key finding from these studies was the identification of a transformation of the reinforcing Ca phase to Al_2Ca intermetallic at temperatures as low as 175˚C, a temperature sometimes reached by transmission conductors during periods of heavy electrical demand [4, 5].