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Mechanical properties of novel aluminum metal matrix metallic composites: Application to overhead conductors

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ABSTRACT

The mechanical behavior and microstructural evolution of aluminum metal matrix metallic composites fabricated under various process conditions were investigated to understand their process-structure–property relations. The novel techniques for arranging the matrix and reinforcement materials and controlling the processing atmosphere were applied to the extrusion process. The composites were comprised of matrix 1050 and reinforcement 6061 aluminum alloys with varying percent weight compositions and were arranged in a tailorable concentric annular pattern. The composites were shown to substantially increase compressive strength when the atmosphere of composite arrangement was evacuated prior to extrusion. Mechanical response of the composites were compared to the pre-extruded 1050 and 6061 aluminum alloys. The yield strengths of each composite, with varying percent weight compositions, were found to lie between those of matrix and reinforcement alloys, and abided by a simple rule-of-mixtures when considering weight composition. Highly elongated grains were oriented in the as-extruded composites along the extrusion direction and grains near the interface between two constituent alloys showed higher aspect ratio than in the interior region. The present study could lead to the optimum composite design for various industrial applications including all aluminum alloy overhead conductors with high strength and improved electric conductivity.

1. Introduction

For many years, aluminum wire has been developed for manufacturing of Aluminum Conductor Aluminum Reinforcement (ACAR), Aluminum Conductor Steel Reinforcement (ACSR), and All Aluminum Alloy Conductor (AAAC) standard load bearing conductors [1]. Therefore, development and usage is widespread in the power line industry. Because it is more cost-effective, aluminum (Al) has replaced many Copper-Clad Steel (CCR) designs previously used. While the mechanical properties of aluminum are typically better than copper, the conductivity is less. As a result, the vast majority of overhead line conductors made from either copper-based or aluminum-based materials are non-homogeneous which leads to a tradeoff of conductivity and strength [2]. In order to reduce this tradeoff, much research has been performed to increase the strength and retain good conductivity in aluminum by alloy design [2–5]. In addition, some composite methods have also been investigated. The major advantages of Aluminum Metal Composites (AMCs) compared to the unreinforced materials include greater strength, improved stiffness, reduced density, improved high temperature properties, controlled thermal expansion, thermal management, enhanced electrical performance, improved wear resistance, and improved damping [6].

Investigation by Kim et al. [7] showed promise in development of a novel aluminum Metal Matrix Metallic Composite (MMMC) using 1050 and 6061 aluminum alloys that could have properties that satisfy overhead conductor needs. Such composites can also provide superior recyclability as compared to bi-material composites such as CCRs. The recently disclosed manufacturing process of this MMMC was developed by use of 6061 aluminum alloy concentric tubes of different diameters with 1050 aluminum alloy rods sandwiched between the tubes. The aluminum–aluminum composite was then extruded in an aluminum can and wire drawn until the appropriate diameter was achieved. Conceptually, the 1050 aluminum alloy provides good electrical conductivity while the 6061 aluminum alloy provides good strength. By varying the amount of each aluminum alloy, a composite strength and conductance can be tailored for a given wire diameter. This procedure indeed provides novelty in the manufacturing for overhead conductors in the sense that metal composite wires and rods can now be tailored easily

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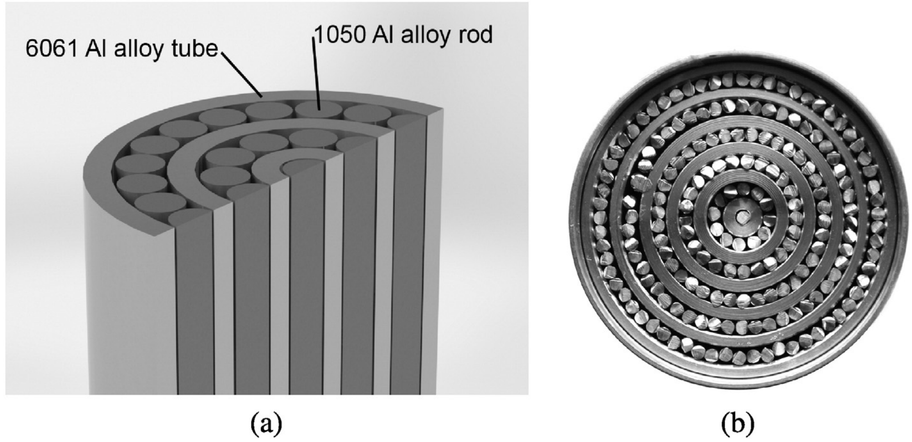

Fig. 1. (a) A schematic illustration of the MMMC constituent materials arranged in a concentric annular pattern and (b) an actual arrangement of the designed composite prior to the primary extrusion process. The diameter of the outer tube is 50 mm.

to fit specific strength, density, and electrical conductivity without intrusion into alloy design.

The chief importance of this novel MMMC is balancing the mechanical and electrical characteristics. For the mechanical properties, strength and weight are typical factors in determining the robustness of the resultant wire [8]. The previous work by some of the present authors [9] has shown that significant damage between the aluminum rods and wires which could contribute to reduced strength and ductility. One hypothesis considered is that the ambient atmosphere contained in the aluminum can is trapped during extrusion and subsequently manifests itself as cracks much like porous castings [10]. Therefore, investigation into reducing and/or eliminating the cracks is important to improve the overall performance of the MMMC.

Since composite properties depend on their constituent materials, variability in the amount of each aluminum alloy in the MMMC affects the relationship between strength and electric conductivity. Furthermore, the mechanical performance of the resultant MMMC is significantly dependent upon the history of deformation provided by the extrusion process [11]. Therefore, investigation into the microstructural evolution after extrusion is also important.

Although the MMMCs possess various advantages over currently used bi-material counterparts, their composite arrangement methodologies and mechanical responses have not been reported. The main objective of the present study is to investigate the mechanical behavior and microstructural evolution of the newly developed 1050/6061 aluminum alloy MMMC under ambient as well as evacuated (i.e., vacuum) extrusion conditions for power line applications. The material database obtained from this experimental effort will be provided to further modeling and simulation research. This systematic study could provide fundamental understandings for process-structure–property phenomena that can lead to the optimum composite design for various industrial applications including all aluminum alloy conductors with high strength and improved electric conductivity.

2. Experimental procedures

The matrix 1050 aluminum alloy rods and the reinforcement 6061 aluminum alloy tubes were used to fabricate the MMMCs. They were arranged in a concentric annular pattern with varying percent weight compositions, namely 20 wt.%, 35 wt.%, and 50 wt.% 6061 aluminum alloy with 1050 aluminum alloy as the remainder. Fig. 1 provides a schematic illustration and an actual arrangement of the designed MMMC prior to the extrusion process.

The pre-extruded MMMCs were tightly enclosed in the 6061 aluminum alloy cans specifically designed for extrusion process. These canned aluminum MMMCs were then directly extruded with an extrusion reduction ratio of 15:1. In order to investigate the effect of atmosphere on the mechanical behavior of the final extruded MMMCs, canned pre-extruded MMMCs were evacuated and their mechanical properties were compared with those obtained from ambient extrusion condition. Detailed geometry of constituent materials and extrusion process parameters and procedures can be found elsewhere [7].

Resultant 13 mm diameter extruded MMMC rods were fabricated and utilized for experimentation and analysis. Specimens were sectioned parallel and perpendicular to the extrusion direction, ground and polished (final step using OPS colloidal silica) for microstructure

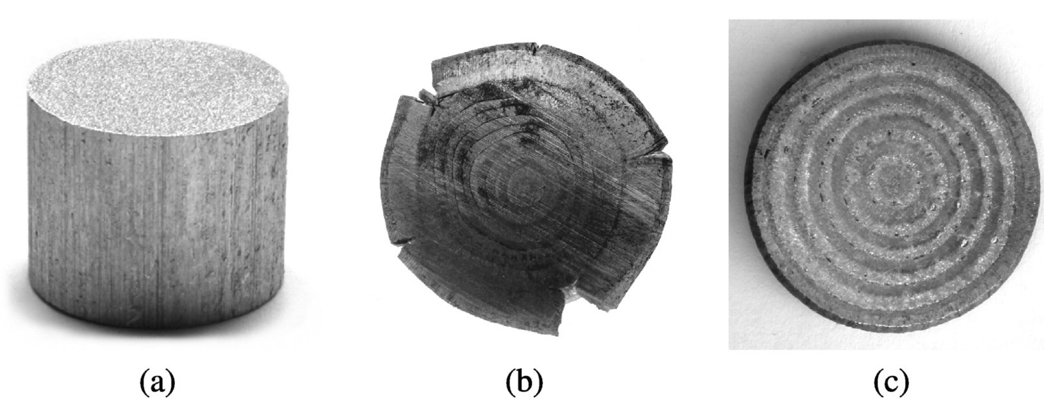

Fig. 2. Compression test specimens; (a) before testing (outside diameter = 12.7 mm), (b) after testing on an ambient extruded sample, and (c) after testing on an evacuated extruded sample.