Building Professional Skills in Mechanical Engineering: Aluminum Battery Cable Development for Electric/Hybrid Electric Vehicles

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Extended Abstract
The paper presents professional experience of a first year graduate student in Mechanical Engineering at Youngstown State University (YSU). YSU is part of a team which in 2011 was awarded an Ohio Third Frontier grant for the development of aluminum cables for electric and hybrid electric vehicles. The grant provided resources for a graduate research assistant interested in working in the development of aluminum cables. The graduate assistant position was assigned to a physics major graduate from Clarion University, Pennsylvania. The challenges for the new graduate student were twofold: to transfer the physics science skills to engineering and to build new professional skills in an engineering discipline. Besides taking classes in Mechanical Engineering the project work required building skills in Materials Science and Engineering. The paper will present the individual experience in building professional skills in Mechanical and Materials Engineering, through the presentation of the experimental results obtained so far by working on the aluminum cable project.

Aluminum cables are much more cost effective and lightweight when compared to standard copper wiring. Without sacrificing conductivity, aluminum wiring can offer up to a 48% weight reduction versus copper wiring [1]. This is particularly important in vehicle wiring, since any reduction in weight will improve fuel economy which will result in reduced carbon dioxide emissions. Although replacing copper wiring with aluminum wiring offers such advantages, it does come with its own set of challenges. One such challenge is creating successful terminal connections. Connecting aluminum cables to terminals by mechanical crimping is not nearly as effective as crimping copper cables to terminals. Also, due to the properties of aluminum, aluminum cables can experience plastic deformation at the crimp site during environmental temperature cycling. While crimping aluminum to terminals may work for smaller cables and wires, to connect larger aluminum cables, such as battery cables in vehicles, another method of connection should be used. A potentially effective connection alternative method is through ultrasonically welding the cables to the terminals.

Ultrasonic welding is a process of joining two overlapping metal pieces by applying pressure and high frequency vibrations to them, causing dynamic shear stresses high enough for plastic deformation to occur and bond the pieces. Though this process is performed differently than conventional welding, the result can be compared to conventional welding techniques but is characterized by low input energy, low weld temperature, and short welding times [2]. Aluminum and aluminum alloys are one of the most easily welded structural metals by this method. Since no electrical current actually passes through the aluminum being welded, the heat of the weld is not high enough to affect the mechanical properties of the welded sample. Also since the heat involved in the weld is not nearly enough to melt the aluminum, there is no formation of a cast

nugget at the weld interface, which results from resistance welding, creating a smoother weld boundary. Ultrasonic welding does have some drawbacks, such as thickness limitations, but for the cables in this project, this limitation should not be a problem.

The purpose of this project is to determine the prerequisite material and surface conditions necessary to obtain a reliable ultrasonic welding between the aluminum battery cable and the terminal. This paper will presents the results of analytical investigation on surface morphology and chemical composition of aluminum battery cables. A set of six aluminum cable samples are to be analyzed, each from a different cable manufacturer, of which the effectiveness between samples is not consistent. The cable surface morphology was investigated with the aid of scanning electron microscopy (SEM). The overall chemical composition of the cables was determined by X-ray energy dispersive spectrometry (XEDS) in SEM, and X-ray diffraction (XRD). The surface chemistry was investigated by Auger spectroscopy. The Auger will reveal the atomic composition through the first hundred or so nanometers of the cables surface.

The aluminum battery cable consist multi-wires bundled together in a braid. The typical surface morphology of a single aluminum wire, separated from a battery cable, is shown in Figure 1. The noticeable differences among wires selected from various cables are that some have more scratches and very small tool fragments resulted from the drawing process. At least one of the wires has distinctly more aluminum oxide agglomeration present on the surface. The cables were analyzed by XRD to determine if there was multiple phases present in noticeable quantities. It was found through this method that all six samples were essentially pure aluminum. The last analytical method used on the cables was Auger spectroscopy. For each sample the graphs of depth versus atomic composition, i.e. depth profile, were obtained and compared. These profiles showed that each cable had varying thicknesses in the carbon and the aluminum oxide layers on the surface.

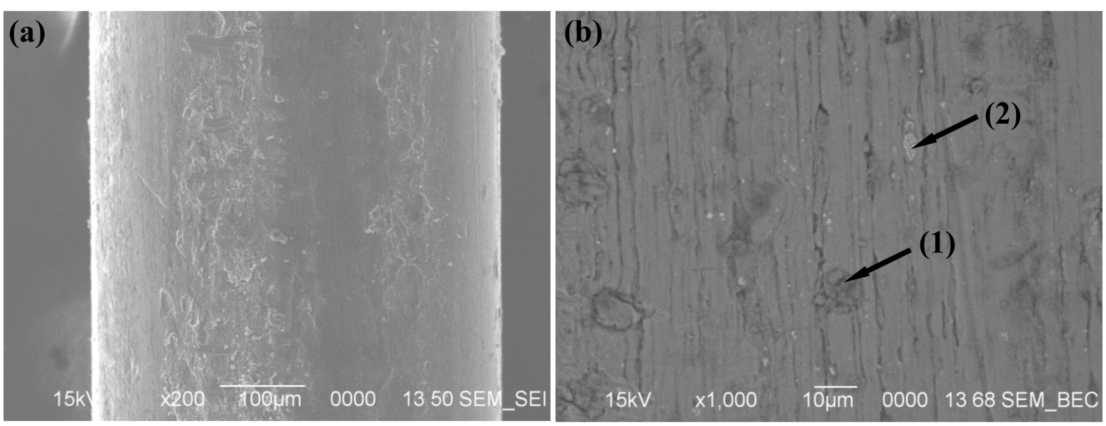

Figure 1. (a) Secondary electron micrograph of an individual aluminum wire separated from a battery cable. (b) Backscattered electron micrograph showing details of surface morphology. Aluminum oxide particles (1) and iron-based inclusions (2) can be readily observed.

The conclusions drawn so far from these results, is that all six cables are, for the most part, the same. The only noticeable difference between them is the thickness of the oxide layer, which was distinctly shown in the Auger spectroscopy investigation results. It is expected that

Proceedings of the 2013 ASEE North-Central Section Conference

aluminum oxide layer will have minimum influence on the weld quality. During the ultrasonic welding process, the vibrations between the two materials being welded breaks up and removes the oxide layer and other films on the surface of the materials [3, 4]. Continuing work on this project will include obtaining samples of each cable after being ultrasonically welded to the terminal and analyzing each of these samples with the methods previously used on the cables, along with other methods, such as tensile strength testing. Another process that will be performed is various cleaning processes on each cable before being welded to the terminal to rule out surface contaminants as a factor in the quality of the weld.

Bibliography

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