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Final Technical Report

LightMat Seedling Project: Enabling the Development of High Strength Magnesium Alloy Sheet for Light-Weighting Applications

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Background: It is well known that a 10% reduction in vehicle weight can result in a 6-8% fuel economy improvement in gasoline/diesel vehicles. Replacing steel and aluminum with magnesium can result in weight savings between 25 and 75% and hence magnesium alloys have been considered for multiple body-in-white components to reduce the weight of the glider. For example, magnesium sheet has been considered for decklid inner panels, rear seatback panels, roof panels, and door inners.

Lightweighting of electric vehicle structures is also critical in that this can extend their range, thereby accelerating their adoption. A specific target for weight reduction in electric vehicles is the battery compartment. A battery system of size 2m x 1.4m can weigh as much as 700 kg and comprise 22-27% of total vehicle weight. In addition to protecting the batteries, the enclosure should have the ability to absorb energy during crashes. It is estimated that 20% of the weight and cost of these battery systems are associated with the containment. While traditionally, these have been fabricated with steel, more recently, there has been an increasing use of aluminum in these battery enclosures. All currently available long-range Battery Electric Vehicles (BEV) that have a range greater than 250 miles use aluminum as the main material for the battery enclosures. Reducing the weight of battery enclosures will continue to be a priority with electric trucks which will require large batteries, thus maximizing payload and minimizing energy consumption. While aluminum suppliers such as Novelis have proposed newer generations of aluminum-based battery enclosures based upon high strength 7075-T6 aluminum alloy sheets, magnesium has not yet been considered for such applications.

As an example of high strength Mg alloys, Mg alloy AXM5303 (Mg-5Al-3Ca-0.3Mn) has achieved an yield strength of 315 MPa, ultimate tensile strength of 451 MPa in laboratory scale heats with elongations to failure of ~4% in the as-extruded condition [1]. Although this alloy has been fabricated and tested in the form of extruded plates, there has not been a significant effort in producing sheets of this or similar material and evaluating properties. The purpose of this project was to evaluate the feasibility of developing advanced manufacturing processes to roll one or more high-strength magnesium alloys into sheet of thickness 1 -2 mm thereby providing a candidate alternative to aluminum alloys for use in battery compartments in BEVs and HEVs.

Project Objectives: The objective of this Lightmat seedling proposal was to perform proof-of-concept rolling of plate to sheet and characterize microstructure and mechanical properties of sheet produced from a new high-strength magnesium alloy which would have the potential for applications in multiple transportation applications.

Experimental Approach: A high-strength aluminum alloy, a variant of the AXM5303 was supplied to ORNL in the form of extruded cut plate of dimensions 14 cm x 14 cm x 10 mm by Terves Inc. These plates were rolled using two different approaches:

1. Convetional Rolling: Plates were preheated to temperatures in the range of 100°C to 450°C followed by conventional rolling using rolls at room temperature. Preheat temperature, and % reduction per pass were varied systematically to evaluate the effect of these processing conditions on the quality of the rolled sheet and mechanical properties
2. Warm Shear Rolling: Plates were preheated to temperatures in the range of 100°C to 450°C followed by rolling using a special Fata-Hunter shear-rolling mill with heated rolls available at ORNL. The rolls can be heated to maximum temperatures of 300-350°C allowing the plates/sheets to be rolled isothermally at this temperature. In addition, this mill is capable of linear rolling speeds of up to 500 ft/min and provides the ability to apply shear to the plates using differential rotation of the two rolls. Rolling trials were performed using an approach described in #1 above but with heated rolls and at selected low and intermediate speeds.

Tensile properties were measured at room temperature for the sheets with little or no obvious defects. Microstructures of selected processed sheets were evaluated by optical microscopy.

Results and Discussion: Several processing conditions from approaches #1 and #2 resulted in good quality rolled Mg alloy sheet. An invention disclosure identifying the most successful processing conditions will be submitted as an output from this work. Figure 1 shows two examples of successfully rolled sheets using rolling sequence # 1 and rolling sequence #2.

(a) (b)

Figure 1. Image of sheet processed using (a) rolling sequence #1 and (b) rolling sequence #2.

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Figure 2 shows a comparison of the mechanical properties of the extruded plate with that of sheet in the as-rolled condition using rolling sequence 2 above, and measured by extracting 4" long specimens. It was observed that the yield strength in the as-extruded condition was about 96 MPa, the ultimate tensile strength was about 211 MPa and the total elongation to failure was about 6.6 %. Mechanical properties of sheet specimens rolled using sequence 2 showed about 224 MPa yield strength, ultimate tensile strength of 281 MPa, and total strain to failure of 7.9 %. Clear improvement in strength and ductility was observed after rolling.

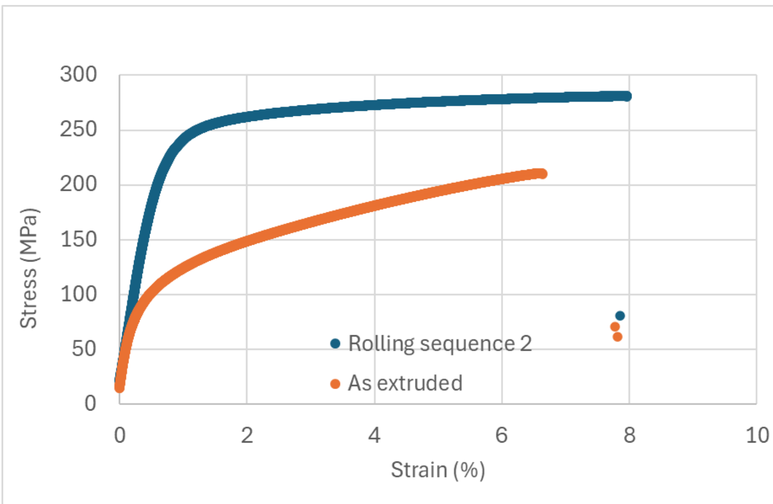

Figure 2. Comparison of the mechanical properties of the high-strength Mg alloy rolled using sequence 2 above with as-extruded properties.

Figure 3 shows an example of the difference in microstructure observed between the plate in the as-extruded condition and after rolling using a different rolling sequence #3. Note that the grains have dynamically recrystallized in the as-rolled grain with a relatively fine-grained microstructure. By carefully selecting temperature and total deformation, a fine grain size can be achieved in rolled sheet, resulting in a good combination of strength and ductility. Further work is required to optimize the processing conditions to achieve ultra-fine grain size.

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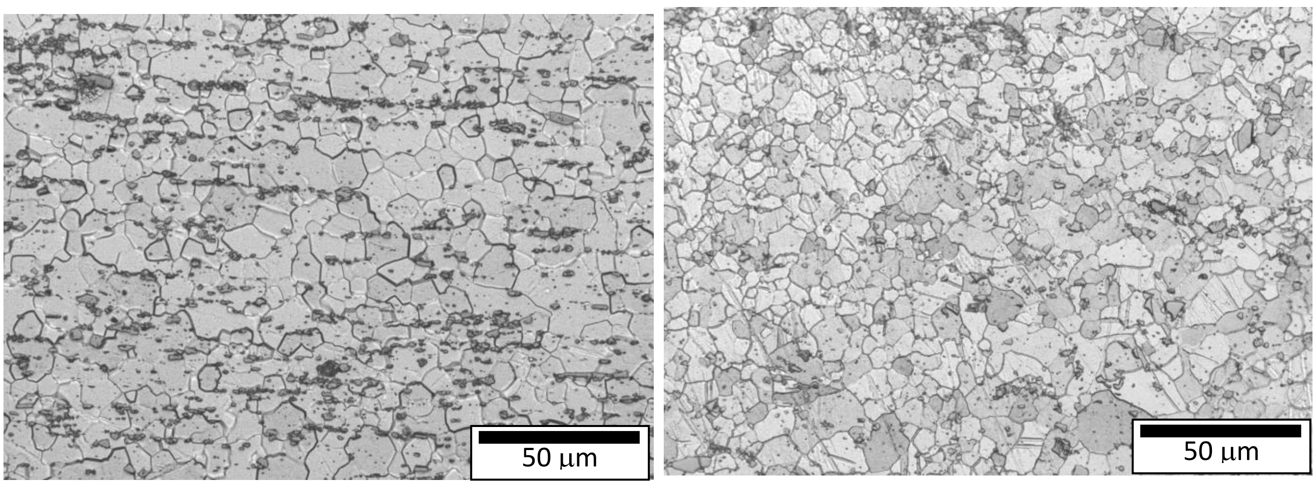

(a) (b)

Figure 3 (a). Cross-sectional Optical microstructure of as-extruded alloy and (b) rolling sequence #3.

Potential impact and Future Work: This project represents the first effort to produce sheet from high strength Mg alloys. The combination of process development and property evaluation shows the potential improvement in specific tensile strengths that can be achieved in these alloys when compared to 6061-T6. 6061-T6 with a tensile strength of 310 MPa and a density of 2700 Kg/m^3 has a specific UTS of 114.8 KN.m/Kg. For the magnesium alloy discussed above, using the ultimate tensile strength of 281 MPa, and a density of ~ 1820 Kg/m^3 results in a specific UTS of 154.4 KN.m/Kg which is 1.34 times that of 6061-T6.

Due to the wide process window that is possible with the warm shear rolling mill, future effort should focus on achieving a partially recrystallized microstructure consisting of very fine recrystallized grains along with unrecrystallized region which is known to provide the best combination of strength and ductility. High strain rate testing would help identify the condition with mechanical properties suitable for use in battery enclosure applications.

References

1. Z. T. Li, X. G. Qiao, C. Xu, S. Kamado, M. Y. Zheng, and A. A. Luo, "Ultra-high strength Mg-Al-Ca-Mn extrusion alloys with various aluminum contents," J. of Alloys and Compounds 792 (2019) 130-141.