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PhD Dissertation

Entitled

Development and Characterization of Sustainable Novel Aluminum Metal Matrix Composites

by

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Abstract

Low crude oil prices have impacted the economy of the Gulf Cooperation Council (GCC) member countries especially the United Arab Emirates (UAE). Hence it is vital to accelerate the diversification of the economy. Among the many potential diversification avenues, manufacturing is a promising area that could add to the GDP. The UAE is fortunate to have a vast wealth of industrial rocks, minerals and metals. Manufacturing of Aluminum-based Metal Matrix Composite (MMC) automotive components is a viable industry in which local companies could be part of the original equipment manufacturer (OEM) to global automotive giants. This work brings out a renewable and cost-effective method for manufacturing AMC's and expanding their applications.

With the emphasis on sustainable manufacturing, this work aims to use Scrap Aluminum Alloy wheels of cars (SAAW) as the matrix. SAAW was easily obtained from the scrap alloy wheels of cars which are abundantly available in the UAE. The reinforcement material, alumina, was sourced from the local oil refineries, where Spent Alumina Catalyst (SAC) is a waste material from crude oil refining. Presently the oil refineries in UAE face problems disposing of the huge quantity of spent catalyst generated during crude oil refining. The main objective of this work is to manufacture MMC's sustainably using Scrap Alumina Alloy Wheel as matrix and industrial wastes as fillers. To achieve this, the following steps where followed.

(1) Production of AMC's using Stir- gravity casting

Four composites were made with different combinations such as LM25+Al_2O_3, SAAW+Al_2O_3, LM25+SAC, and SAAW+SAC using stir-gravity casting. Microstructure and mechanical analyses showed a nonhomogeneous distribution of reinforcements with high amount of porosity. Therefore, this method was not used for optimization and casting of AMCs.

(2) Production of AMC's using Stir- squeeze casting

Similar to the previous casts, four composites of LM25+Al_2O_3, SAAW+Al_2O_3, LM25+SAC, and SAAW+SAC were made through stir- squeeze casting. This method exhibited better strength when compared to gravity cast samples. SAAW+Al_2O_3 exhibited almost uniform distribution of reinforcement particles and superior mechanical properties with lowest porosity (7.3%), highest hardness (69 VHN), minimum abrasive wear loss (0.001g), second highest tensile (129 MPa) and compressive (320 MPa) strengths among the four composites. The results also revealed that, optimizing the stir squeeze casting process parameters, can further contribute to the performance of the recycled AMCs.

(3) Optimization of casting parameters using Taguchi method

Taguchi-Grey relational analysis (GRA) has been successfully utilized for the first time to handle the multi-response objective system for optimizing process parameters in the squeeze casting of AMCs. This method was used to determine the optimized condition with a minimal set of experiments, which is relevant in the stir–squeeze casting process. Taguchi method developed 9 samples (L1-L9) and out of that L5 and L6 exhibited the best mechanical properties. Thus, the optimum levels of process parameters are squeeze pressure of 100MPa, squeeze time of 30s, die preheat temperature of 250°C and stirrer speed of 525 rpm.

(4) Producing the optimized sample (M2)

Taguchi's confirmation test was run based on the obtained mechanical properties and L6 method showed an improvement in the GRG value by 12.5%. Based on the confirmation test,

the optimized sample M2 was produced using squeeze pressure of 100 MPa, squeeze time of 45s, die preheating temperature of 250°C, and stirrer speed of 525 rpm. M2 sample showed the lowest porosity (5.29%) and significantly higher ultimate compression strength (433 MPa) although it exhibited slightly lower hardness and ultimate tensile strength when compared with the L6 and L5 samples, respectively.

(5) Hybrid AMCs

To further enhance the performance of the produced recycled AMCs, hybrid reinforcements were introduced while casting. Five casts (1% graphite+ Al_2O_3, 3% graphite+ Al_2O_3, 4% graphite+ Al_2O_3, 3% SiC+Al_2O_3, 6% SiC+ Al_2O_3) were prepared with SAAW as matrix and alumina, graphite and SiC as fillers with different percentage. AMC with 4% graphite along with alumina showed highest tensile and compressive strength of 250 MPa and 508 MPa respectively, followed by sample with 3% SiC and alumina.

(4) Friction Stir Welding (FSW) to check the weldability.

To estimate the weldability of the developed AMC's, Friction Stir Welding, a more environment friendly welding technique was used. L5, L6, M2, and hybrid AMC samples were successfully welded using a cylindrical tool pin with 4 mm pin depth, tool rotation of 1100 rpm and feed rate of 50 mm/min. Tensile results from the welded zone showed that sample M2, and AMC with 4% graphite exhibited high strength of 185 and 210 MPa respectively. From these results it can be seen that this approach can easily be scaled up for production in large volumes as well as opens avenues for developing AMCs reinforced with other waste materials.

Keywords:

Aluminum Matrix Composites (AMCs), Scrap Aluminum Alloy wheel (SAAW), Spent Alumina Catalyst (SAC), alumina, Friction Stir Welding (FSW), mechanical properties, tribological properties.