THERMAL EVALUATION OF AL-SiC METAL MATRIX COMPOSITE FABRICATED THROUGH LIQUID METALLURGY PROCESS

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ABSTRACT

The importance of the thermal stability of aluminum alloys and composites used in the manufacturing of automobile engine parts cannot be overemphasized. In this study, the thermal analysis of fabricated aluminum matrix composites manufactured by centrifugal casting technique proposed for high-temperature automobile part applications is investigated. The thermogravimetric curve obtained from this study's thermal analysis showed the samples' weight response to temperature increase. At a temperature region below 655°C, the composites' heat flow rate is lower than at the temperature region beyond 655°C. From the DSC curve generated, the sample reinforced with 5 wt.% and 15 μ m of the SiC particle (Sample G), is observed to give the most desired thermal behavior at the temperature region beyond 655°C, having the lowest heat flow rate of 0.004 w/g at a maximum experiment temperature. However, the percentage weight loss of all the fabricated samples obtained from the TGA curve is negligible within the experiment's temperature parameters.

KEYWORDS: Metal Matrix Composites, Thermogravimetric Analysis, Differential Scanning Calorimetry, Silicon Carbide & Heat Flow Rate

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1. INTRODUCTION

The response of engineering materials used in automobile engine applications to temperature changes and increases in heating rate has evoked keen interest from researchers in the recent past. Being one of the most abundant metals in nature and owing to its good properties, aluminum alloys are favored by researchers as the material of choice in the fabrication of automobile engine parts like piston heads, cylinder walls, crankshafts, and engine blocks [1]. The constant movement and rubbing of mechanical parts against each other generate heat, affecting the material's performance during service [2]. Thus, thermal stability and thermal degradation properties are vital in determining composite materials' suitability for high-temperature applications. The choice of aluminum as the preferred engineering metal in automobile applications is justified by the excellent mechanical, physical, and thermal properties it exhibits when reinforced with oxides, carbides, or nitrides of other materials [3, 4]. Silicon carbide (SiC) particles possess an excellent combination of good abrasive and mechanical properties, making them a unique choice of reinforcement in the fabrication of aluminum-based composites.

Researchers have reported in literature how incorporating SiC particles into the matrices of aluminum alloys influences the resultant composites' properties. In a study conducted by Xiaoyu, et al. [5], SiC particles were adopted as the reinforcement of choice in the fabrication of pistons by centrifugal casting technique. Their study concluded that casting parameters such as reinforcement particle concentration, melt temperature, and rotation speed of mold contributed significantly to the cast piston's observed mechanical and thermal properties.

Furthermore, a comparative study of the properties between pistons fabricated by a centrifugal casting technique and those manufactured through gravity casting showed that the former process produces improved hardness and wear resistance properties compared to the latter. A similar outcome was achieved in a study conducted by Arsha, et al. [6] when a functionally graded aluminum piston was fabricated by vertically oriented centrifugal casting technique using Si particles as reinforcement. Characterization of the fabricated piston showed improved properties of hardness and wear resistance at the piston head, where a high concentration of the reinforcing materials is. It is notable that, in addition to the presence of reinforcement in the matrix of composite material, the particle size of the reinforcement, and the weight ratio of the reinforcement within the matrix also play a significant role in the overall properties of the fabricated material [7-11].

The response of engineering materials to temperature changes depends on heat capacity, the thermal stability of the composite's elemental composition, and density. Thermogravimetric analysis (TGA) is a technique that accounts for the change in mass of materials and the heat flow through them as the materials' temperature rises. For an engineering material to perform optimally in predetermined thermal conditions, the material's stability in this boundary condition must be guaranteed. A hybrid aluminum metal matrix composite was analyzed using thermogravimetric analysis by Sangeetha, et al. [12]. They adopted a heating rate of 5 °C/min and a maximum temperature of 700 °C and reported a decrease in the composite's weight as the temperature increases. The DSC analysis conducted at 10 °C/min and a maximum temperature of 300 °C revealed an increased heat flow through the material at a lower temperature. A further increase in temperature to 300 °C brought about a gradual decrease in the heat flow recorded. In another study, thermal decomposition of aluminum precursor fibers was observed by Gao, et al. [13] when it was subjected to a heating rate of 5 °C to a maximum temperature of 700 °C in a thermal analyzer, resulting in a weight loss of 65% of the fiber.

Aluminum composites have been the material of preference by engineering researchers and manufacturers alike in the production of components of automobile engines such as flywheels, pistons, and cylinder walls, owing to properties such as ease of fabrication, lightweight, corrosion resistance, toughness, and the high strength-to-weight ratio [14, 15]. Automobile engine components such as pistons are constantly being subjected to thermal change and abrasive and compressional forces during service, thereby making the thermal, chemical, and mechanical stability of materials used in fabricating such components of great importance.

This paper presents a report on the response of aluminum metal matrix composite fabricated through centrifugal casting to periodic increment in temperature to a maximum of 1000 °C.

2. MATERIALS AND METHOD

In fabricating the functionally graded composite, aluminum ingots with trace amounts of alloying elements were impregnated with silicon carbide particles. The fabrication technique of choice was the centrifugal casting technique due to relative ease of processing and comparative cost advantage for mass part production [16]. The as-received aluminum alloy was charged into the furnace, and melting was achieved at a temperature of 750 °C. Mechanical stirring of the melt was done to create a vortex where SiC particles, preheated in an induction furnace at 300 °C, were introduced. Stirring was continued after impregnating the aluminum matrix to ensure even dispersion of the particles in the melt. The liquid composite was poured into the cavity of the rotating mold of a centrifugal machine. The cast sample was allowed to solidify in the rotating mold. The spatial positions of the individual particles within the matrix of a sample are determined by the amount of the centrifugal force acting on it and the drag they encounter due to the melt's viscosity and density. The impact of the centrifugal force exerted on the reinforcement particles is governed by Stokes' law expressed in Eq. (1).

$$v = \frac{d^2(p_p - p_l)g}{18\mu} \quad (1)$$

Where:

v Particle velocity,

d Particle diameter,

μ Viscosity of liquid metal,

ρ_l Density of liquid metal, and

ρ_p Density of the particle.

Using variations of SiC weight percent and particle sizes, six composite test samples were fabricated and prepared for analysis. A control sample (sample D) with no reinforcement particle was also fabricated. Samples A, B, and C contained 1 wt.%, 3 wt.%, and 5 wt.% of reinforcement with an average particle size of 7 μm while samples E, F, and G had 1 wt.%, 3 wt.%, and 5 wt.% of reinforcement with an average particle size of 15 μm respectively. Sample D is not reinforced with SiC particles. The thermogravimetric analyzer SDT Q600 shown in Figure 1 was used to investigate the fabricated composite samples' behavior under varied temperature and heat change.

Figure 1: Thermogravimetric Analyzer SDT Q600.

The elemental composition of fabricated samples and reinforcement particles obtained from EDS analysis is presented in Tables 1 and 2 respectively, while the parameters adopted for the samples' TGA analysis are shown in Table 3.

Table 1: Elemental Compositions of the Fabricated Samples

	Si (%)	C (%)	O (%)	Fe (%)	Al (%)
Sample A	0.85	5.81	1.28	0.95	Remaining
Sample B	0.93	7.04	1.80	0.81	Remaining
Sample C	1.37	16.98	3.12	0.62	Remaining
Sample D	-	5.83	1.52	0.36	Remaining
Sample E	0.80	5.84	1.30	0.87	Remaining
Sample F	0.87	7.08	1.85	0.69	Remaining
Sample G	1.29	16.85	3.24	0.48	Remaining

Table 2: Elemental Composition of the SiC Particle Reinforcement

	Al	C	O	Fe	Si	Total
Reinforcement (wt.%)	-	42.63	3.01	-	54.36	100

Table 3: TGA Test Parameters

Gas used	Flow Rate	Temperature Range	Heating Rate
Argon	100 ml/min	25 °C to 1000 °C	10 °C/min

3. RESULTS AND DISCUSSIONS

In the authors' prior work, the effect of the addition of varied particulate size and weight percent of SiC_p reinforcement on mechanical and wear properties of the Al-SiC_p composites was discussed extensively [8, 17, 18]. This study seeks to highlight the response of the fabricated composites' thermal changes when subjected to elevated temperature. Although most engineering and automobile applications aluminum composites are intended for temperature regions below 400 °C[19], this study seeks to determine the behavior of the fabricated composites at a much higher temperature region.

3.1 Thermogravimetric Analysis of Fabricated FGM Samples

The thermogravimetric analysis of the cast samples shown in Figure 2 represents the materials' weight response to temperature increase from 25 °C to 1000 °C. It is evident that the fabricated aluminum composites exhibited negligible multistage weight loss over the given temperature range. This is attributed to the relative thermal stability of aluminum alloy within the temperature region in which the test was carried out. However, the extent of weight loss is different for each sample, as shown in Figure 3. At a temperature region of about 655 °C (where aluminum starts to melt), it is observed that sample C, which contained 5 wt.% of reinforcement with particle size 7 µm had the least amount of weight loss of 0.37 % compared to the other samples. Samples A (with SiC reinforcement of 1 wt.%, 7 µm) and sample D (with SiC reinforcement of 0 %) had the most weight loss of 1 % recorded by the materials.

Figure 2: TGA Graph of the Fabricated Al-SiC Composites.

Figure 3: Expanded TGA Graph of the Fabricated Al-SiC_p Composites.

3.2 Differential Scanning Calorimetric Analysis of Fabricated FGM Samples

The differential scanning calorimetric analysis examines the heat flow through the samples as the temperature increases. The DSC curves of the fabricated composite samples were obtained at a heating rate of 10 °C/min in an inert Argon atmosphere is shown in Figure 4.

Figure 4: DSC Curves Showing Heat Flow in Fabricated Al-SiC Composites.

A slow increase in the heating rate is observed for the samples at a lower temperature region. Further increase in the temperature towards melting temperature brought about a slight decrease in the heat flow through the materials. Similar behavior was reported in work done by Sangeetha, et al. [12] when a hybrid aluminum metal matrix composite was subjected to thermal analysis. As the temperature continues to rise, a distinct endothermic peak can be observed for all the

samples at 655 °C, which corresponds to the aluminum alloy's melting temperature region. Beyond 655 °C to 1000°C, the samples' heat flow rate is observed to increase sharply. Sample G with 15µm and 5 wt.% of the SiC_p reinforcements displayed the lowest heat flow rate of 0.004 w/g at 1000 °C. This low heat flow rate could be due to the amount and particle size of the reinforcement in the sample's matrix.

4. CONCLUSIONS

In this study, a thermogravimetric analysis of aluminum metal matrix composites fabricated through centrifugal casting was carried out. The results of thermal analysis of the materials obtained from this study inform the conclusions, which are as follows:

- The overall percentage weight loss resulting from increased temperature to 1000 °C is negligible as the maximum process temperature is significantly lower than the composites' boiling temperature and that of its individual components.
- The particle size and weight percent of the SiC_p reinforcement in the composite matrixes influence the heat retention capacity and heat flow through them at elevated temperatures.
- A slow increase in the materials' heat flow occurs at the temperature region below the melting temperature. In contrast, a sharp rise in the materials' heat flow occurs at a temperature beyond the melting temperature.
- With a combination of 15µm and 5 wt.% of the SiC_p reinforcements, sample G displayed the best thermal resistant property at an elevated temperature having the lowest heat flow rate of 0.004 w/g at 1000 °C.

Conflict of Interest

The authors have no conflicts of interest to declare.

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