ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 18 (2018) 1645–1650

Available online at www.sciencedirect.com

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journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Effect of process parameters on mechanical properties of hollow glass microsphere reinforced magnesium alloy syntactic foams under vacuum die casting

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ARTICLE INFO

Article history:
Received 20 June 2018
Accepted 30 July 2018
Available online

Keywords:
Syntactic foams
Vacuum casting
Magnesium
HGM
Optimization

ABSTRACT

In the present study, an endeavour has been made to investigate the mechanical properties of hollow glass microspheres reinforced die cast magnesium alloy under vacuum die casting process. The particle size, mass fraction, stirring speed has been considered as input process parameters to analyze the mechanical properties such as hardness, compressive strength, porosity and density of the syntactic foams. Taguchi-Grey relational based multi response optimization has been utilized to compute the optimal process parameters and find the influence of those parameters on performance measures of casting process. From the experimental investigation, the optimal process parameters have been found as particle size (45 microns), mass fraction (20%) and stirring speed (600 rpm) among the chosen process parameters. The highest max–min indicates the particle size has higher influence on determining the mechanical properties of the syntactic foam owing to its importance on determining the porosity. It has been also observed that the density of syntactic foam decreases with increases in the mass percentage of hollow glass microspheres.

1. Introduction

Low density materials with high specific strength are significant for marine industry providing buoyancy for subsea apparatus such as submersible vehicles and oceanographic equipments. The syntactic foam is synthesized by introducing a light weight material as reinforcement in a matrix alloy. Gupta et al. (2010) studied about the need and synthesize of closed cell syntactic foam by dispersing rigid hollow particles in a metal matrix material. Since the hollow microspheres or the gas-containing particles are filled mechanically into the

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https://doi.org/10.1016/j.acme.2018.07.008

matrix alloy, the syntactic foams can be categorized as physical foams [1]. Bunn and Mottram (1993) stated that hollow glass microspheres can reduce the density of the syntactic foam considerably [2]. Tao et al. (2009) experimentally proved that metal matrix syntactic foams can possess excellent mechanical properties such as high specific strength, stiffness and excellent energy absorption capability as compared with traditional metal foams [3]. Schaller et al. (2003) studied that the magnesium foams have higher specific strength and stiffness compared with aluminium foams owing to its lower density as compared with aluminium [4]. However it is highly tedious process to synthesize the magnesium based syntactic foams due to its higher pyrophoric nature. Rohatgi et al. (2009) studied the feasibility of reinforcing the fly ash cenospheres in die cast magnesium alloy to increase the hardness of the syntactic foam [5]. Anbuchezhiyan et al. (2017) synthesized hollow glass microspheres (HGM) reinforced magnesium syntactic foam using stir casting approach. It has been inferred that the fabricated syntactic foam could exhibit better mechanical properties such as compressive strength, hardness, porosity and density [6]. However the wettability of reinforcement particles with matrix alloy is not favorable in conventional casting process. Hence the vacuum die casting method can be adopted to nullify this drawback as well as to reduce matrix porosity. Li et al. (2016) found that vacuum die casting process could significantly improve the mechanical properties of the components by reducing the gas pores [7]. Wen et al. (2012) proved that the vacuum die casting process can increase the corrosion resistance of AM60B magnesium alloy [8]. Patel et al. (2012) demonstrated that vacuum die cast based AM60B magnesium alloy could exhibit superior fatigue resistance [9].

It is very important to analyze the effects of the individual process parameters on performance measures in any process for improving the product quality. The optimization of input parameters involved in any manufacturing process can enhance the performance measures in such process. Tham et al. (1999) studied the influence of processing parameters on synthesis of Al–SiC particle reinforced metal matrix composites by the disintegrated melt deposition technique. The processing parameters include stirring speed, stirring time and total flight distance to analyze the porosity level [10]. Daoud et al. (2006), investigated the influence of various processing parameters on synthesizing ZC63 Magnesium alloy-fly ash microballoon foam using stir casting approach. The melt temperature, type of the stirrer, pouring temperature and mould type have been chosen as input process parameters to analyze the distribution of the fly ash microballoons in the Magnesium matrix alloys [11]. Mo et al. (2014) fabricated the magnesium alloy ZAX12405 by squeeze casting method. The effects of processing parameters including applied pressure, pouring temperature and dwell time on microstructure and mechanical properties of ZAX12405 alloy have been investigated through single response optimization [12].

If any process needs more than one better performance measures, conventional single response optimization is not helpful. Hence multi response optimization techniques have to be employed. The synthesized magnesium syntactic foam needs to satisfy multiple desirable properties such as lower density, higher hardness and compressive strength. Hence it is necessary to adopt multi response optimization approach while synthesizing the syntactic foam using vacuum die casting method. Das et al. (2016) optimized the processing parameters such as pouring temperature, reaction time and stirring speed in liquid melt-stirring process using an efficient grey based differential evolution algorithm in order to achieve better mechanical properties such as micro hardness, toughness and ultimate tensile strength [13]. Muthuramalingam and Mohan (2014) made an attempted to apply multi response optimization approach for deriving optimal process parameters involved in electrical discharge machining process [14]. It has been found that Taguchi-grey relational approach can give better optimal process parameters with higher accuracy compared with other approaches.

From the literatures, it has been observed that only little research attention has been given to magnesium based syntactic foams. It has been inferred that many research works have been focused on effect of process parameters on mechanical properties while synthesizing syntactic foam. It has been noticed that multi response optimization approach has not been applied on synthesis of magnesium matrix syntactic foams (MMSF). Hence the present experimental investigation has been carried out. The present study deals about adaptation of Taguchi-Grey relational based optimization approach on synthesizing AZ91D magnesium alloy matrix reinforced with hollow glass microspheres (HGM) under vacuum die casting method to enhance the mechanical properties.

2. Experimental methodology

In the present study, AZ91D/HGM syntactic foams under dissimilar mass fraction have been synthesized using vacuum die casting method.

2.1. *Synthesis of magnesium syntactic foam using vacuum die casting process*

The melting furnace has been preheated to 450 °C subsequently 1 kg of AZ91D magnesium alloy along with dissimilar mass fraction percentage such as 10%, 15% and 20% of HGM. The particles have been taken into the vortex with average size of 45 μm, 55 μm and 65 μm as shown in Fig. 1. A mixture of SF_6 and argon at a flow rate 40 l per minute has been used to prevent oxidation and combustion of magnesium during all process. The temperature has been maintained at 800 °C for 5 min to completely melt the metal. Then the stirring has been done at 450 rpm, 500 rpm and 600 rpm for 15 min to ensure homogeneous distribution of reinforcement in the matrix alloy. An enhanced vacuum die-casting method has been developed by adding a vacuum device along with the bottom of the mould as shown in Fig. 2. It has created a vacuum inside the mould cavity during casting. The die has been coated with sulphur powder to prevent oxidation. The molten MMSF have been allowed to cool inside the die at ambient conditions. The micro structure of synthesized HGM reinforced magnesium matrix syntactic foam is shown in Fig. 3.

2.2. *Measurement of performance measures*

The hardness values of the syntactic foam have been found using Vickers micro hardness tester with the applied load of