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Introduction to magnesium alloy processing technology and development of low-cost stir casting process for magnesium alloy and its composites

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Abstract

This paper presents the processing of magnesium alloys and its composite through different stir casting technologies. Design and development of stir casting technology that is suitable for processing of magnesium alloys has been done in this study. The low-cost stir casting processing of magnesium alloy and its composite with flux and without flux has been explained. The magnesium alloy and its composite have been fabricated by both the stir casting process. The micro structural characterization and mechanical properties of the developed composites has been evaluated. The optical emission spectroscopy of the developed alloy and factography of the developed alloy as well as composite was also examined.

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1. Introduction

Design and development of lightweight and energy efficient material are one of the major challenges for the 21st-century designer. Magnesium has the potential to replace steel, aluminum alloy, and plastic-based materials. Initially, due to the high price, there were limited applications of magnesium alloy. But recently, the interest in magnesium alloys has increased because of gradually decreasing cost of magnesium alloys. Magnesium alloys has better solidification characteristics over other cast metals such as copper and aluminum alloys [1]. Casting is one of the dominant manufacturing processes for the magnesium-alloy components representing 98% of structural application of magnesium [2]. Fabrication of magnesium alloy and its composite is the great challenge for engineers and scientist because of the high affinity of magnesium towards oxygen. There are various synthesis techniques developed for the casting of magnesium-based alloys and composites. Gravity sand and permanent mold processes are used to produce high-performance aerospace and defense components [3]. Melting and casting of magnesium alloys in the vacuum-assisted inert atmosphere is one of the best suitable and environment-friendly processes.

1.1. Melting and melt protection

Molten magnesium does not react with iron like molten aluminum, which has a very high affinity with iron; therefore, magnesium-alloys can be melted and held in a crucible made of steel. If the magnesium alloy contains aluminum as an alloying element then it may react with the ferrous crucible, so to avoid this paste of boron nitride is used to provide a coating on steel crucible. The use of metallic crucibles allows the crucible to be supported from the top by means of a flange, leaving the space below the crucible [3]. Fig. 1 shows the metallic crucible with boron nitride paste inside.

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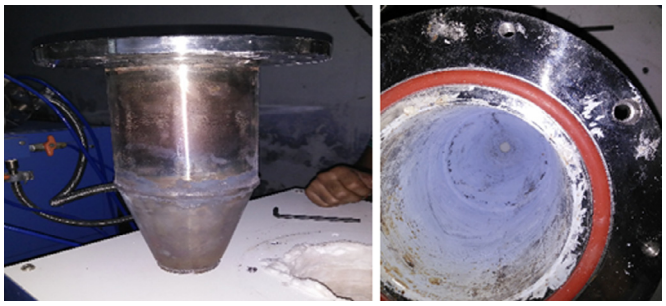

Fig. 1. Metallic crucible with flange.

Molten magnesium is prone to oxidation and burn, unless due care is taken to protect its surface against oxidation Aluminium alloy forms a continuous impermeable oxide on the molten bath that restricts further oxidation but in case of magnesium alloys, they form a loose permeable oxide coating on the molten metal surface. This loose oxide coating allows oxygen to pass through and support burning. Protection of the molten alloy using either a flux or a protective gas cover excluding the oxygen is required. There are basically two methods for melt protection of magnesium alloys as described in next two subsections.

1.2. Flux protection process

Protection of molten magnesium with the help of flux was used before the development of gaseous protection. A small quantity of flux (20% KCl, 50% $MgCl_2$, 15% MgO, 15% CaF_2 wt%) is placed at the bottom of the crucible and preheated to dull red hot [4]. Some more amount of flux is slightly sprinkled during melting, holding and casting [3]. After the invention of the fluxless process (protective gas and inert gas environment) for magnesium melting and casting, application of flux protection process has been limited to gravity casting methods or some special casting with high melting point [3].

1.3. Flux less protection process

With the addition of flux, there was possibility in magnesium alloy to lose their ductility. Therefore, a fluxless process using SF6 has been developed by the researchers in 1970s. A process with the vacuum-assisted inert atmosphere for melting, holding and casting of magnesium alloy and its composite has been developed.

1) *Protection using SF_6*: Development of Flux less melting using air/SF_6, air/CO_2/SF_6 or CO_2/SF_6 as the protective gas mixture was a great invention in melting, holding and casting of magnesium alloys [5,6]. SF_6 is one of the extremely effective oxidation inhibitors for magnesium alloys. The formation of MF_2 during oxidation of magnesium tend to block the pore in the natural oxide MgO and make it more protective [7]

$$2Mg(l) + O_2(g) \rightarrow 2MgO(s)$$

$$2Mg(l) + O_2(g) + SF_6(g) \rightarrow 2MgF_2(s) + SO_2F_2(g)$$

$$2MgO(s) + SF_6(g) \rightarrow 2MgF_2 + SO_2F_2$$

The fluxless production process of magnesium by using SF_6 (nontoxic) as a protective environment is accepted by all the leading manufacturer of the ingot producer and die casting sections of the foundry industry. In the flux-less process, the chance inclusion due to flux is eliminated.

However, SF_6 has very high global warming potential around 24,000 times more than of CO_2, because of very long retention in the atmosphere (3200 years), which means that emission of 1 kg SF_6 is equivalent to 26.5 MT of CO_2 [7]

2) *Protection using inert atmosphere*: A process with the vacuum-assisted inert atmosphere for melting, holding and casting of magnesium alloy and its composite has been developed to cater the disadvantage of using SF_6, which has high global warming potential. The safest way to protect magnesium alloy melt is creation of vacuum followed by impingement of inert gas in a controlled amount. This study is focused on the stir casting process by using vacuum pump followed by impingement of controlled atmosphere of argon gas.

On account of safety, prevention of accident and accidental precaution the weight of the vehicle has been increased by approximately 20% since last two decades. As the weight of a vehicle increases, the fuel consumption also increases in the same proportion of the weight of the vehicle. So there is huge pressure on the design engineer to search newer lightweight material.

Using magnesium alloys is one of the solutions for reducing the weight of the vehicle and most importantly it is recyclable. Some polymer material may also be used as low-weight material, but the cost of polymer material is very high and their thermal properties are highly negotiable. For designing and casting of magnesium alloy based metal matrix composite, there are several variables on the basis of which a new composite can be manufactured. The most important variables are:

- Selection of processing methods.
- Selection of magnesium alloys.
- Selection of reinforcement by characteristics.
- Selection of reinforcement by size.
- Variation of the volume fraction of reinforcement.

The liquid metal casting is one of the best and economical processing method for processing magnesium alloys and its composites. Depending on the use and application, most suitable alloy can be selected from available series of alloy or a new alloy may be created by adding a different alloying element in base magnesium. The reinforcements are also available in different types and sizes. The size and volume fraction of reinforcement plays an important role in the processing of metal matrix composites.

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