RECENT ADVANCEMENTS IN CREEP RESISTANT MAGNESIUM ALLOYS AND COMPOSITES: A REVIEW

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Abstract

Magnesium due to its lightweight gain tremendous interest of automobile industries from the past few decades. To achieve weight reduction without degrading its mechanical properties is a major challenge for engineers and researchers. Till now a lot of work has been done on various magnesium alloys but conventional magnesium alloys (AZ and AM series) are unable to replace aluminium alloys in powertrain applications due to high creep resistant of aluminium alloys. So there is a need of some modifications in magnesium for its utilization in power train applications. Modified magnesium alloys and MMCs (metal matrix composites) are two main alternatives to make a way for magnesium into powertrain application. This article reviews recent developments in the magnesium alloys and magnesium composites for powertrain or high-temperature applications.

Keywords: Magnesium alloys, Creep resistance, MMCs, Power train applications

1. Introduction

Magnesium due to its lightweight gain tremendous interest in automobile industries from the past few decades. The credit goes to the light weight of magnesium which is 1/3rd of aluminium, 3/4th of zinc, 4/5th lighter than steel. Apart from weight Magnesium have other advantages like high strength-to-weight ratio, good castability, high die casting rates, excellent machinability, etc. which encourages the use of magnesium in the automobile industry [1]. 18% averaged growth rate per annum for magnesium components in automobiles has been observed since 1990 [2]. Three biggest automobile companies Ford, General Motors and DaimlerChrysler are inspired to use 100 Kg more magnesium components than present by 2020 [3].

At present AZ and AM series of magnesium alloys are used in the automobile industry for instrument panels, steering wheel armatures, steering column supports, seats, valve covers, and transfer cases. To further increase the quota of magnesium components in automobiles there is a need to develop creep resistant magnesium components to use in powertrain applications where operating temperature is up to 200˚C (e.g. engine block, transmission cases, etc.), but till now this is a major drawback for magnesium due to poor creep behaviour and corrosion resistance of conventional magnesium alloys (AZ and AM series) [1].

Some researchers tried to improve the creep resistance of conventional magnesium alloys by using modifying alloying elements and they witnessed an improvement [4-6]. Apart from modifying base alloy, there is another alternative way to promote the use of magnesium in powertrain applications that is by the development of creep resistant Magnesium MMCs. MMCs are a blend of ductility & toughness of metal matrix with high strength & modulus of hard ceramic particle reinforcements, leading to improved behaviour in shear & compression and improved high-temperature performance capabilities [7]. Flexibility in choice of type, size, and shape of reinforcement available make it possible up to some extent to tailor the properties according to the requirement [8]. This article reviews the recent developments in magnesium alloys and magnesium composites for powertrain or high-temperature applications.

2. Literature review

Ferkel et al. [9] analyse the creep behaviour of nanosize SiC reinforced Mg composites fabricated by the extrusion process at constant stresses for 200˚C and 300˚C. It was observed that creep resistance of both mixed and ball milled extruded composites showed improved creep behaviour but improvement is more significant in ball milled composite. TEM & EDS studied showed grain boundaries decorated by SiC nanoparticles. He concludes that grain boundary pinning by SiC suppress grain sliding in both type of composites is responsible for creep enhancement but in ball milled composites SiC particles are also dispersed in the matrix which hindered migration of dislocations thus requires higher stresses to creep rupture than mixed composite.

Sklenicka et al. [10] witnessed a considerable decrease in creep plasticity in 20% Al_2O_3- AZ91 magnesium composite. This enhancement in creep strength was reasoned by efficacious load transfer between matrix & fibers. Better fiber-matrix bonding during high temperature creep exposure was confirmed by TEM study. Reaction between Mg & Al_2O_3 cause Al enrichment near alumina fiber which results in increased precipitation of the $Mg_{17}(Al, Zn)_{12}$ phase which was promoted by heterogeneous nucleation.

Mondal et al. [11-12] compare the creep rates of AE42-20% saffil short fibres reinforced composites with hybrid composites of saffil short fibres & cheap SiC with different levels of compositions in both longitudinal & transverse direction and conclude that creep rates of both single and hybrid composites are comparable. Mg_2Si formed due to the interfacial reaction between Mg and SiC was attributed for comparable creep resistance of hybrid composites. It was also observed that creep rates are higher in the transverse direction than longitudinal direction.

C. Suman et al. [13] examine the creep rate of both monolithic AZ91D alloy and AZ91D-15% SiC composite at 149˚C for 35 MPa & 39 MPa respectively. It was observed that the creep rate of MMC is the only 1/3rd of the monolithic AZ91D alloy.

Labib et al. [14] studied impression creep of Mg-SiC composites fabricated by powder metallurgical route with different levels of SiC (10µm) concentration (5, 7.5, 10 & 15 vol %). Impression creep behaviour was recorded at temperature from 423-473 K at stress ranges from 150-250 MPa for a dwell time of 4200 s. Improved creep resistance is observed in all the composites but composite with 10 vol% exhibit least creep rates (better creep resistance) among all. No change is observed in grain size with the addition of SiC which suggested no particle simulated nucleation grain boundaries has no or insignificant strengthening effect. The effective load transfer from matrix to reinforcements and discrepancy between thermal behaviour of matrix and reinforcement expected to be responsible for resultant creep resistantce. Observed values of stress exponent & activation energy (7.5 & 90 KJ mol^{-1}) are close to 92 KJ mol^{-1} which suggests dislocation climb controlled by dislocation pipe diffusion is operating creep mechanism for both Mg and composite materials.

Kumar et al. [15] investigated the creep of AS41 alloy and nano-Al_2O_3 particle reinforced (2 & 5 wt %) AS41 alloy matrix composite fabricated by stir casting equipped with ultrasonic vibrations at a temperature range of 448 to 523 K at three stress levels (109.2MPa, 124.8MPa, 140.4MPa). Creep resistance for 5 wt % nano composite was highest, which was credited to Orowan strengthening caused by a uniform distribution of nano particles and finer Mg_2Si precipitates due to strong ultrasonic vibrations. Calculated activation energies for nano composites suggests pipe diffusion governed dislocation climb as operating creep mechanism for nano composites.

Arunachaleswaran et al [16] studied creep performance of AE42 matrix hybrid composites squeeze cast from preforms with the composition shown in Table 1 at constant temperatures (220, 240 and 270 ◦C) and constant loads (100, 120 and 140 MPa). Composite with 10 vol% Saffilf ® and 15 vol% SiCp shows superior creep performance than other ones. Presence of MgO and Mg_2Si as a product of interfacial reaction product may be responsible for improved creep behaviour. The acceleration of creep could be observed at temperatures above 240 ◦C, which is mainly due to the dynamic formation of -Mg17Al12 due to the possible breakdown of $Al_{11}RE_3$ phase.

Table 1. Reinforcement Percentage

Composite	Preform	Alumina fibers (Saffilf ®) (vol %)	SiC particles (SiCp) (vol %)
10/10	A	10	10
10/15	B	10	15
15/5	C	15	5

Majhi et al. [17] proved that addition of Ca or Bi or both Ca and Bi in AZ91 alloy suppress the formation of β-$Mg_{17}Al_{12}$ phase (& break it into small pieces) & refine the size of α-Mg grains and further formation of thermally stable continuous phase Al_2Ca and Mg_3Bi_2 (Bi3Ca5 with combined addition), which results in improved creep resistance in modified AZ91 alloy. It was observed that the single addition of calcium is more pronounced than single Ca addition due to the more thermal stability of Al_2Ca phase than Mg_3Bi_2. Modified alloy with 2.0Ca and 0.5Bi (wt %) exhibit superior creep resistance which was attributed to the more thermal stability of Al_2Ca and Bi3Ca5 phase. Khatkar et al. [18] stated that addition of SiC in AZ91D alloy improves the mechanical and tribological properties of alloy by a formation of β-$Mg_{17}Al_{12}$ phase

Alan et al. [19] developed a modified ACX alloy based on Mg-Al-Ca system, by using commercially available AM50A as the base. Pure calcium (99% purity), Al-10% Sr master alloy, and AS41 were used for the addition of Ca, Sr, and Si respectively. Resultant creep behaviour of the modified alloy is superior to AE42, which is a touchstone of creep resistant magnesium alloys. Intermetallic phase $(Mg, Al)_2Ca$ has Hexagonal structure forms interface coherence with magnesium matrix. Pinning effect at grain boundaries caused by thermally stable $(Mg, Al)_2Ca$ phase cause improvised creep behaviour.

Results and Discussion

From the above discussion on recent advancements on magnesium alloys it has been observed that some work has been done on the modification of magnesium alloys by using single addition of RE elements and alkaline earth metals and improvised results are obtained. Magnesium alloys with RE elements shows benchmark results as Creep resistant magnesium alloys as compare to conventional magnesium alloys but high cost and less stability of RE elements restricts its use in automobile powertrain applications.

Some researchers try to follow the route of magnesium composites by reinforcing magnesium matrix with cheap ceramic particles like Al_2O_3 and SiC. Results prove composites a cheap and viable alternative to motivate the use of magnesium in automobile powertrain or high temperature applications.

Attempts have been made to improve the creep resistance of magnesium and its alloys such as AZ91D, AM60, AM50A, AE42, and AS41 by reinforcing different hard ceramics material like SiC, Al_2O_3, nano- Al_2O_3 and saffil short fibres. Moreover, material such as Ca or Bi or both Ca and Bi have also been used as reinforcing materials in various magnesium alloy. Different fabrication technique used for development of composite and hybrid composites includes powder metallurgy, stir casting, squeeze casing and stir casting equipped with ultrasonic vibrations. It has been observed that Mg-SiC composites fabricated by powder metallurgical recorded at temperature from 423-473 K exhibited higher creep resistance due to effective load transfer from matrix to reinforcements and thermal discrepancy between matrix and reinforcement. AS41 alloy and nano-Al_2O_3 particle reinforced (2 & 5 wt %) AS41 alloy matrix composite higher creep resistance was credited to Orowan strengthening caused by a uniform distribution of nano particles and finer Mg_2Si precipitates due to strong ultrasonic vibrations. SiC and short carbon fibers (SCF) hybrid reinforcement improved the creep resistance of AZ91 magnesium alloy while this hybrid reinforcement did not showed any beneficial effect on creep behavior of QE42 magnesium alloy. The creep behaviour of nanosize SiC reinforced Mg composites (both mixed and ball milled extruded) show improve creep behaviour but improvement is more significant in ball milled composite

Conclusion and Future scope

Several aspects must be prevailed in order to strengthen the power train and other engineering applications of magnesium alloys and composites such as fabrication techniques, influence of different reinforcements and their combinations, effect of hybrid reinforcements on the creep behavior and its corresponding applications. Following key conclusions are drawn from the previous research work:

1. The addition of Ca or Bi or both Ca and Bi in AZ91 alloy results in formation of thermally stable continuous phase Al_2Ca and Mg_3Bi_2 , which results in improved creep resistance in modified AZ91 alloy.

2. Presence of MgO and Mg_2Si as a product of interfacial reaction product is responsible for improved creep behaviour. Composite with 10 vol% Saffilf ® and 15 vol% SiCp shows the superior creep performance.

3. The creep of AS41 alloy and nano-Al_2O_3 particle reinforced (2 & 5 wt %) AS41 alloy matrix composite higher creep resistance was credited to Orowan strengthening caused by a uniform distribution of nano particles and finer Mg_2Si precipitates due to strong ultrasonic vibrations

4. Improvement in creep resistance of Mg-SiC composites fabricated by powder metallurgical was recorded at temperature from 423-473 K due to effective load transfer from matrix to reinforcements and discrepancy in thermal behaviour of matrix and reinforcement.

5. Creep rates of AE42-20% saffil short fibres reinforced composites and hybrid composites of saffil short fibres & cheap SiC with different levels of compositions are comparable. However; creep rates are higher in the transverse direction than longitudinal direction.

6. The creep behaviour of nanosize SiC reinforced Mg composites (both mixed and ball milled extruded) show improve creep behaviour but improvement is more significant in ball milled composite

7. A considerable increase in creep resistance of 20% Al_2O_3- AZ91 magnesium composite was observed by efficacious load transfer between matrix & fibers.

8. SiC and short carbon fibers (SCF) hybrid reinforcement improved the creep resistance of AZ91 magnesium alloy while this hybrid reinforcement did not showed any beneficial effect on creep behavior of QE42 magnesium alloy.

9. Work can be done on the combined addition of RE elements and alkaline earth metals (e.g. Ca and Sr) to make up for the cost of RE elements.

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