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Aging Characteristics of Short Glass Fiber Reinforced ZA-27 Alloy Composite Materials

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Aging characteristics of short glass fiber reinforced ZA-27 alloy composite materials have been evaluated in the present study. The liquid metallurgy technique was used to fabricate the composites, in which preheated short glass fibers were introduced into the ZA-27 alloy melt above its liquidus temperature. The aging temperature employed was 125 °C for 6, 12, 18, and 24 h. The aged alloy (no fibers) reached the peak hardness after 18 h, while the composites (regardless of filler content) reached the same hardness in 12 h. It is hypothesized that the aging treatment of a composite improves the strength of the interface between the short fibers and the matrix. This is confirmed by the tensile fractograph analysis, which indicates that at a given aging temperature, the composites aged for 18 h exhibit short fibers that remain attached to the metal matrix, while those aged for 6 h undergo debonding.

Keywords aging, composites, hardness, short glass fibers, ZA-27

1. Introduction

Metal matrix composites (MMCs) have several advantages over the base alloys that are very important for their use as structural materials. The most obvious advantages are their high modulus, improved strength, and enhanced strength to weight ratio (Ref 1). The discontinuously reinforced MMCs have attracted quite a lot of attention both in the industrial sector and the academic community. Zinc-aluminum (ZA) alloys, which have a relatively high strength compared to zinc or aluminum alloys with a lower melting temperature, have found considerable industrial use (Ref 2). The ZA-27 alloy, which belongs to the family of ZA alloys, is used in bearing and bushing applications as a replacement for bronze bearings because of their lower cost and equivalent or superior performance.

It is well established that the addition of discontinuous ceramic reinforcement to metal matrices results in the composites exhibiting different aging kinetics compared to unreinforced alloys, and an acceleration in the aging kinetics of the composite materials has been observed frequently (Ref 3, 4). It has been shown that several factors affect the age-hardening characteristics of the composites, which in turn depend largely upon the characteristics of the reinforcement used. It is also important to consider the chemical properties of the reinforcement and the matrix and any possible reactions that occur between these two components of the composite (Ref 5). Such chemical reactions can change the composition of the matrix alloy and consequently influence the aging behavior of the composites (Ref 6).

It is also well established that the addition of discontinuous ceramic reinforcement to alloy matrices results in the composites exhibiting different aging kinetics compared to the unreinforced alloys. Extensive experimental results on aging of long fiber reinforced composites and whisker reinforced composites are available (Ref 7). However, limited open literature reports are available on the aging response of short fiber reinforced composites, although increasing attention is being focused. Hence, this attempt to study the aging characteristics of short glass fiber reinforced ZA-27 alloy composites is of significance, because it enhances the readily available database of the aging behavior of short fiber reinforced MMCs.

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2. Experimental Procedure

In the present work, ZA-27 alloy had a chemical composition of 25 to 28 wt% Al, 2 to 2.5 wt% Cu, 0.01 to 0.02 wt% Mg, and a balance of zinc, in accordance with ASTM B 669-82 ingot specification and was used as the matrix alloy. The microstructure presented in Fig. 1 shows the structure of the alloy used. E-glass, which accounts for more than half the glass-fiber reinforcements used, was used in the present case as the reinforcement. The diameter of the fibers was 4 to 6 μm and the length was 0.4 to 0.6 mm. The percentage of glass fibers was varied from 1 to 5% in steps of 2% by weight. The "compocasting" technique, which is similar to the one used by Hosking et al. (Ref 8), was used to prepare the composite specimens. In this process, the matrix alloy (ZA-27) was first superheated above its melting temperature and stirring was initiated to homogenize the temperature. The temperature was then lowered gradually until the alloy reached a semisolid state. At this temperature (440 °C), the glass fibers were introduced into the slurry. The temperature during the addition of glass fibers was raised gradually, and stirring was continued until interface between the fibers and the matrix promoted wetting. The melt was then superheated above its liquidus temperature of 500 °C and finally poured into the lower die-half of the press and the top die was brought down to solidify the composite by applying high pressure. Uniform distribution of the fibers in the matrix alloy was achieved, which is evident from the SEM micrograph presented in Fig. 2.

The composites as well as the unreinforced alloy were aged at 125 °C for 6, 12, 18, and 24 h and subsequently air-cooled. The hardness tests were conducted in accordance with ASTM E 10, and the results reported are an average of eight measurements. There was very little scatter in the results obtained, and each reading did not deviate by more than 2% from the respective mean value.

3. Results and Discussion

The results of the hardness tests of aged alloys, as well as the composites containing 0, 1, 3, and 5% short glass fibers by weight, are represented graphically and are as shown in Fig. 3. It has been reported previously (Ref 9) that the addition of short glass fibers brings about a considerable increase in hardness of the composite. The increase in hardness is to be expected, because the glass fibers are very hard and its addition to a base alloy tends to harden it. The glass fibers act as barriers to the movement of dislocations within the matrix and exhibit greater resistance to indentation of the hardness tester thereby bringing about an increase in hardness of the reinforced materials. Each aged composite as well as the alloy shows a significant increase in hardness with increasing aging time. The difference in hardness between the aged alloy and the aged composites is not as marked as in the unaged condition. It can be observed that the addition as well as increase in the reinforcement content brings about significant improvement in hardness of the unaged composites, while aging brings about less improvement. The aged alloy reached a peak hardness after 18 h, while the composites reached the same hardness in 12 hours. Various other researchers (Ref 10) have reported such accelerated aging responses of the composites in comparison with the base alloy. The hardness of the aged composites, as well as the alloy, decreases beyond the peak hardness aging time period. However, the decrease was not significant when aged beyond the peak aging time period of 24 h.

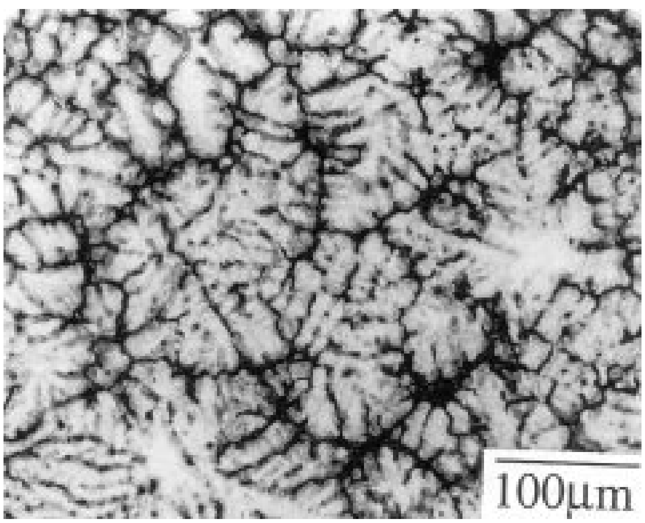

Fig. 1 Microstructure of the ZA-27 alloy

Fig. 2 SEM micrograph showing the uniform distribution of the short glass fibers in the alloy matrix

The trend of the results obtained and the cooling method adopted in the present case are almost on par with the one reported by Song and Baker (Ref 11). In the present case, the aged composites have shown hardness values of 140 HB, which is quite remarkable. This is an improvement over the results reported by Altorfer (Ref 12), who has reported a hardness value of 130 HB for ZA-27 alloy. Another point to be noted is that there is a considerable difference between the hardness values of the nonaged specimens with varying content of the glass fibers, while that between the aged composites is not minimal. In other words, the glass fiber content plays a significant role in determining the hardness of the composites only in the nonaged condition and to a very lesser extent in the aged condition. The difference in hardness between the aged alloy and the aged composites is not very marked indicating that the glass fiber content no longer affects the hardness to a significant extent. This is primarily due to the reason that in the aging process of

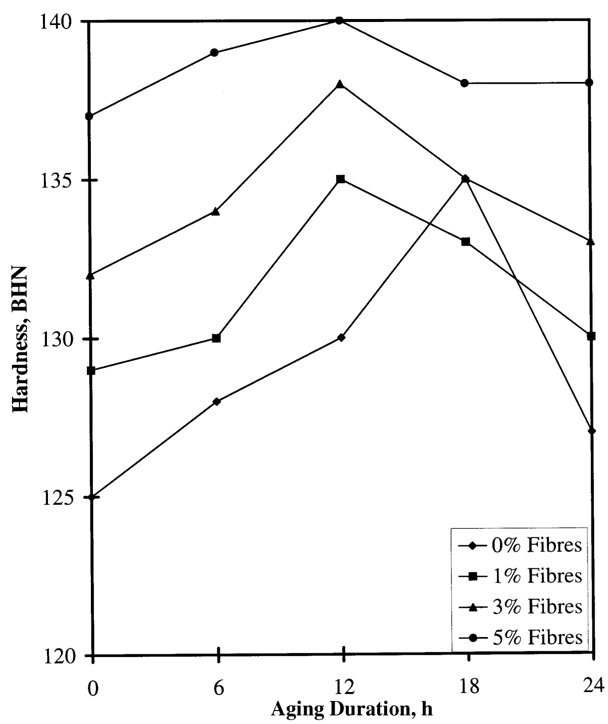

Fig. 3 Graph showing the age hardening curves of the alloy and the composites aged at 125 °C

ZA-27/short glass fiber composites, it is the matrix alloy that is affected rather than the reinforcing fibers. It is evident from the results observed that the aging process in the present case affects mainly the ZA-27 alloy and the glass fibers to a lesser degree. Moreover, the glass fibers do not react with the matrix material, and hence they do not play a significant role in affecting the properties of the matrix material even at high temperatures (Ref 13). The aging response of the alloy can be explained by referring to the zinc-aluminum phase diagram (Ref 14). A study of the phase diagram shows that as ZA-27 zinc alloy is cooled from the melting point to room temperature, it goes through several phases, namely (α + L), β, ($\alpha + \beta$), and finally ($\alpha + \eta$). Cooling in permanent molds may be slow enough to allow the whole casting to reach the equilibrium room temperature phase of ($\alpha + \eta$). In other words, the β phase may still be present in the casting even at room temperature. Subsequent age hardening at about 100 °C for several hours will give the material a chance to reach its equilibrium phase of ($\alpha + \eta$). The conversion from the β (body-centered-cubic) phase to the α (face-centered-cubic) and η (hexagonal-centered-cubic) phases during aging is expected to result in a precipitation-hardening effect. A more detailed explanation of the phase diagram is provided elsewhere (Ref 14).

Aging enables precipitation of different phases of the composite and is found to improve the hardness of the material. The aging response of the composites in general has been attributed by various researchers (Ref 15, 16) to the increased dislocation density in the vicinity of the ceramic reinforcement, which hastens the nucleation and growth of age-hardening precipitates.

The inclusion of the reinforcing short fibers changes the aging response of the matrix mainly due to the presence of high dislocation densities and residual stresses generated close to the interfaces due to the thermal mismatch between the reinforcement and the matrix (Ref 17). Christman and Suresh (Ref 18) have also reported that the increase in dislocation density due to the reinforcement may lead to accelerated aging of the composites. The composites in comparison to the alloy have more nucleation sites available for the precipitates to form in the composites. The dislocations may be generated from the aging operation by the improved bonding between the reinforcing fibers and the matrix. The improved bonding between the matrix and the fibers is observed in the present case too (Fig. 2), which causes improvement in properties. The significant aging response of the composites is also attributed to the decrease in the incubation time required for the nucleation event and an increase in the solute diffusivity and therefore in rate of precipitate growth (Ref 17).

The composites with 5 wt% of glass fibers aged for 6, 12, and 18 h were fractured in a room temperature tensile deformation mode in order to study the effect of aging temperatures on the composites. The fractographs of the fractured specimens aged for 6, 12, and 18 h are presented in Fig. 4(a), (b), and (c), respectively. It can be observed from the Fig. 4(c) that the short fibers remain intact even after tensile fracture in case of composites aged for longer time periods. Large number of short fibers have undergone debonding, as is evident in Fig. 4(a), when subjected to only 6 h of aging time. Figure 4(b), which represents the composite aged for 12 h, shows an intermediate character.

Hence, it can be assumed that one of the most significant features of aging treatment of composites is the improvement in strength of the interface between the fibers and the matrix. Other researchers too (Ref 19) have reported that properties like ductility of composites increase considerably during tensile testing with increase in temperature.

4. Conclusions

The aging process was found to enhance the hardness of the ZA-27/short glass fiber composites. A significant feature of aging treatment of composites is the improvement in strength of

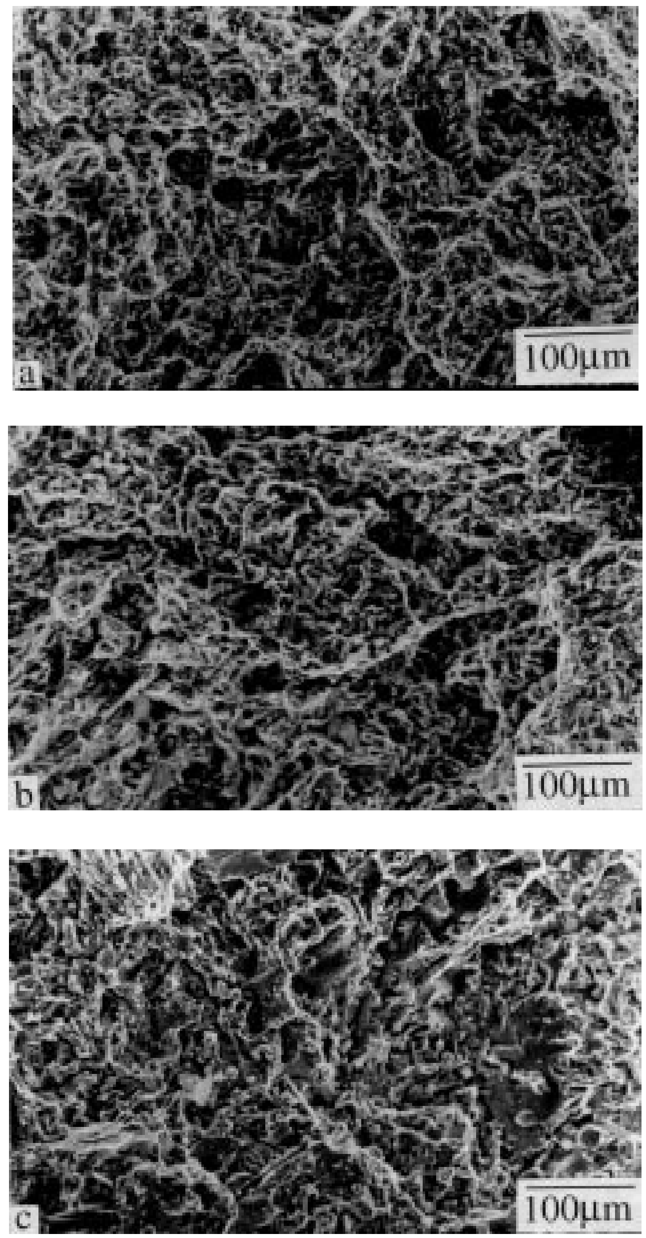

Fig. 4 Fractographs of the tensile fractured composite specimens aged at 125 °C for (a) 6, (b) 12, and (c) 18 h

the interface between the fibers and the matrix. The addition of the glass fibers to the ZA-27 alloy accelerates its aging response, which is basically due to the high dislocation density generated from the thermal mismatch between the reinforcement and the matrix. The effect of the glass fiber addition in enhancing the hardness is marked in the case of unaged composites, while it is of less significance in the aged condition.

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