EFFECT OF SOLUTIONISING AND AGEING ON HARDNESS OF AL2024-BERYL PARTICULATE COMPOSITE

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ABSTRACT

In the present investigation, Al2024–Beryl particulate composites were fabricated by liquid metallurgy route by varying the weight percentage of beryl particulates from 0 wt% to 10 wt% in steps of 2 wt%. The cast matrix alloy and its composites have been subjected to solutionizing treatment at a temperature of 495°C for 2 hrs followed by quenching in different media such as air, water and ice. The quenched samples are then subjected to both natural and artificial ageing. Microstructural studies have been carried out to understand the nature of structure. The density values obtained using rule of mixtures and the experimental values obtained for Al2024 alloy and its composites were compared. The Brinell hardness test was conducted on both matrix Al2024 and Al2024–Beryl particulate composites before and after heat treatment. The density of the composite material decreases as the reinforcement content increases in the matrix material. However, under identical heat treatment conditions Al2024–Beryl particulate composites exhibited better hardness when compared with Al2024 matrix alloy.

***KEYWORDS**: AMMC's, Solutionizing, Artificial Ageing, Density, BHN.*

1.0 INTRODUCTION

Aluminium and aluminium alloys are widely used in automobile, aerospace and mineral processing applications, because of their excellent properties like low density and high thermal conductivity. To increase the mechanical and tribological properties, hard reinforcement phase such as hard ceramic particulates, fibers or whiskers are uniformly distributed in the soft matrix phase. As a result of reinforcement phase, the modulus and strength of the composites were increased while the ductility of the matrix material was decreased [N. R. Prabhu Swamy *et.al.*, 2010]. Metal matrix composites (MMCs) are gaining wide spread popularity in several technological fields owing to its improved mechanical properties when compared with conventional alloys [Surappa M. K, 2003]. Among the several categories of MMCs, Al based composites are finding wide spread acceptance especially in applications where weight and strength are of prime concern. Presently, Al alloy based metal matrix composites are being used as candidate materials in several applications such as pistons, pushrods, cylinder liners and brake dics etc. [Hoskings F.M, *et.al.*, 1982]. In recent years, aluminium alloys are gaining much popularity as a matrix material to prepare MMCs owing to its excellent mechanical properties and good corrosion resistance [Pramila Bai B.N *et.al.*, 1992 and Ramesh C. S *et.al.*, 2005]. In addition, Al2024 & Al6061 alloy is heat treatable and as a result further increase in strength can be expected [Appendino P *et.al.*, 1991]. The density of the Al_2O_3/ SiC particle reinforced Al6061 and other aluminum alloys enhance the density of the base alloy when they are added to the base alloy to form the composite. Moreover, the theoretical density values match with the measured density values of these composites [M.R. Rosenberger *et.al.*, 2005, L.J. Yang, 2003, A.R. Riahi *et.al.*, 2001, Szu Ying Yu *et.al.*, 1997, S.Wilson *et.al.*, 1996, A.B.Gurcan *et.al.*, 1995 and C.garcia Cordovilla *et.al.*, 1996]. Further, Miyajima *et.al.*, [2003] reported that the density of Al2024-SiC particle composites is greater than that of Al2024-SiC whisker reinforced composites for the same amount of volume fraction. The increase in density can be reasoned to the fact that the ceramic particles possess higher density. The particulate reinforcements such as SiC, Al2O3 and aluminide [F.M. Husking *et.al.*, 1982 and Debdas Roy *et.al.*, 2005] are generally preferred to impart higher hardness. J.M. Wu *et.al.*, [2000] and Deuis *et.al.*, [1996] attributed this increase in hardness to the decreased particle size and increased specific surface of the reinforcement for a given volume fraction. The aluminium based composites exhibit excellent heat and wear resistance due to the superior hardness and heat resistance characteristics of the particles that are dispersed in the matrix [Mortensen A et al., Alpas A.T *et.al.*, 1992, Kulkarni M.D *et.al.*, 1996, Kim C.K *et.al.*, 1984 and Dermirci A.H *et.al.*, 1988]. C. Subramanian [1992] incorporated Silicon in Al-alloys and concluded that the higher wt.% of Si improves the hardness of the composites increased particle size improves the load carrying capability of the composites [M. Chen *et.al.*, 2007]. The heat-treated alloy and composite exhibits better hardness [S. Sawla *et.al.*, 2004, W.Q. Song *et.al.*, 1995 and S. Das *et.al.*, 2008], however, the over-aged condition may tend to reduce the hardness significantly [Wang A et.al., 1991]. The heat-treated alloy and composite showed better strength and hardness that resulted in fewer properties for crack nucleation and showed enhancement in wear resistance [S. Sawla *et.al.*, 2004]. In the present work, the Al2024 alloy & Al2024/Beryl metal matrix composites were fabricated by liquid metallurgy route by varying reinforcement from 0 wt.% to 10 wt.% in steps of 2. The effect of quenching media and the ageing duration on the hardness of Al2024 alloy and its composites were characterized.

2.0 MATERIALS

The matrix alloy selected for the development of composite material is Al-Cu-Mg alloy and designated by the aluminium association as Al2024-T6. The chemical composition of the matrix material is given in the table 1. Beryl, which is naturally occurring and chemically having beryllium–alumina–silicate [$Be_3Al_2(SiO_3)_6$] was used as the reinforcement material. The sizes of particles used were of 45-65 μm. They have a density of 2760 kg/m3, having hardness of 7.5 to 8.5 on Mho's scale and it has hexagonal crystal structure. The chemical composition of beryl particles used for development of the composite is mentioned in the table 2.

TABLE 1
Composition of Al 2024-T6 alloy (wt. %)

Al	Cu	Fe	Mg	Mn	Si	Ti	Ni	Zn	Cr	Pb	Sn
91.9	4.63	0.35	1.4	0.6	0.41	0.05	0.01	0.2	0.38	0.04	0.03

TABLE 2
Composition of Reinforcement material (wt. %)

SiO_2	Al_2O_3	BeO	Fe_2O_3	CaO	MgO
68.01	16.74	12.01	1.91	0.86	0.08

3.0 PREPARATION OF THE COMPOSITES

The Aluminium 2024-T6 / Beryl metal matrix composites were fabricated by liquid metallurgy route with varying weight percentage of reinforcement particles from 0 wt% to 10 wt% in steps of 2. This method is the most economical to fabricate composites materials. The matrix material was first superheated to above its melting temperature and preheated beryl particulates were added into molten metal. The molten metal was stirred for duration of 8 min using a mechanical stirrer and speed of the stirrer was maintained at 300 rpm. The melt at 750°C was poured into the pre-heated cast iron molds. The castings were tested to know the common casting defects using ultrasonic flaw detector. The cast composites and the base Al2024 alloy were subjected to solutionizing treatment at a temperature of 495°C for a duration of 2 hrs and then quenched in three different quenching media viz. air, water and ice. Artificial ageing was carried out at 199°C for duration of 4–12 hrs in steps of 2 hrs.

4.0 TESTING OF COMPOSITES

The metallographic, density and hardness tests were carried out on both unheat treated and heat treated samples as per ASTM standards. Density is the physical property that reflects the characteristics of composites. The machined and polished composite specimens (10 mm diameter and 10 mm height) were considered for density measurement using the Archimedian method at room temperature 28°C. The beaker with water was initially kept on the electronic balance (accuracy of 0.1 mg) set to read zero. The initially weighed specimen (say W1 mg) was freely suspended and fully immersed in the beaker. The final weight (W2 mg) shown by the balance represents the volume of the displaced water is equivalent to the volume of the specimen. The ratio of W1 to W2 represents the density of the specimen. [M.D. Bermudez *et.al*., 2001 amd S.C. Sharma, 2003]

$$\rho_c = \text{Mass of the specimen / Volume of the displaced water} \quad (1)$$

The theoretical density values were determined by rule of mixture [B.K. Prasad, 2007] as shown in equation [2].

$$\rho_c = (\rho_r V_r + \rho_m V_m) \quad (2)$$

Where,

V_r is the volume fraction of reinforcement in cc
V_m is the volume fraction of matrix in cc
ϱ_c is the density of the composite in g/cc
ϱ_r is the density of the composite in g/cc
ϱ_m is the density of the matrix in g/cc
(m stands for matrix and r for reinforcement material)

The Brinell hardness tests were carried out as per ASTM-E10-93 standard. The hardness test conducted as per HB 500 and tester which have a ball indenter of 10 mm diameter. The tests were conducted on five locations on the sample to counter the possibility of indenter resting on hard particle, which may result in anomalous value.

5.0 RESULTS AND DISCUSSIONS

5.1 Microstructure analysis

The samples for the microscopic examination were prepared by standard metallographic procedures etched with killer's agent and examined under optical microscope. The optical micrograph of Al2024 alloy, Al2024/4wt.% and Al2024/6wt.% beryl particulate composites respectively. The micrographs clearly indicate the evidence of minimal porosity in both Al2024 alloy and its Al2024/Beryl composites. Micrograph indicates the nearly uniform distribution of the reinforcement particles in the composite.

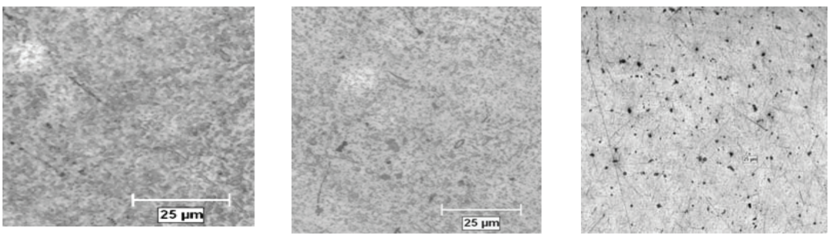

FIGURE 1 Micrograph of Al2024 alloy, Al2024/4 wt.% and Al2024/6 wt.% beryl composites.

5.2 Density

The theoretical density was determined by the rule of mixture and the experimental density values were obtained by Archimedes principle for both as-cast and its composites. The figure 2 shows the effect of weight percentage of reinforcement on theoretical and experimental densities. The density of the composite material decreases as the reinforcement content increases in the matrix material [7, 8]. From the figure 2, it can be seen that experimental and theoretical density values are in line with each other and confirms the stability of the liquid metallurgy technique for successful development of the composite material.

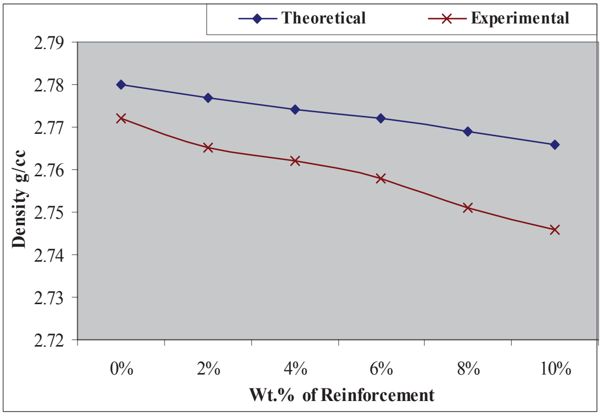

FIGURE 2 Effect of reinforcement on theoretical and experimental density

5.3 Hardness

Hardness is described as resistance to surface indentation of the material. The variation of hardness of matrix and its composite materials are shown in the Figure 3. This graph explains the effect of particulate reinforcement on the Brinell hardness (HB 500). The hardness of the Al2024/10wt.% of beryl composite increased by around 37% as compared to Al2024 matrix alloy. It is observed that with increased content of beryl in the matrix alloy, there was a significant improvement in the hardness of the composites. This trend is similar to the result of other researchers [1, 17, 19-29]. This increase in hardness is expected since beryl particulates being very hard ceramic material which contributes positively to the hardness of the composite.

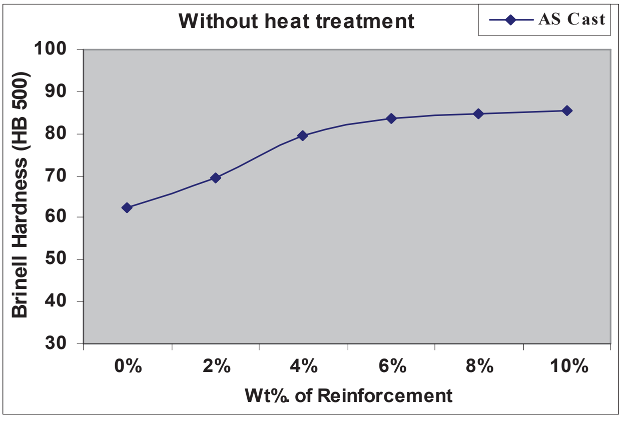

FIGURE 3 Variation of Brinell hardness of Al2024/beryl composites with increase of beryl content before heat treatment

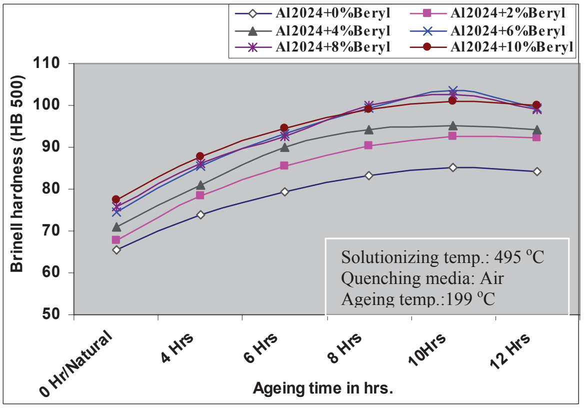

FIGURE 4 Variation of Brinell hardness with increase in ageing time for Al2024 and Al2024/beryl composites for air quenched and different hear treatment condition

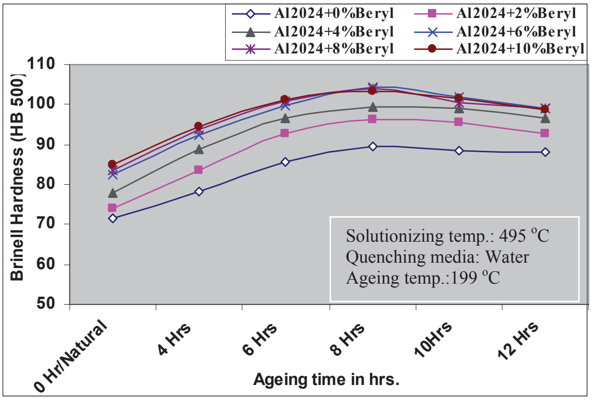

FIGURE 5 Variation of Brinell hardness with increase in ageing time for Al2024 and Al2024/beryl composites for water quenched and different hear treatment condition

The variation of Brinell hardness under heat treatment conditions are shown in figure 4-6. Heat treatment has a significant influence on the hardness of the matrix alloy as well as its composites. For a solutionizing temperature of 495°C, solutionizing duration of 2 hrs, ageing temperature of 199°C, quenching media and ageing duration significantly alters the hardness of both the matrix alloy and its composites. The maximum hardness was observed for both the matrix alloy and the composites for ageing duration of 8 hrs when the quenching media was ice and water, while the maximum hardness for the matrix alloy and its composites was achieved only after 10 hrs of ageing on air quenching.

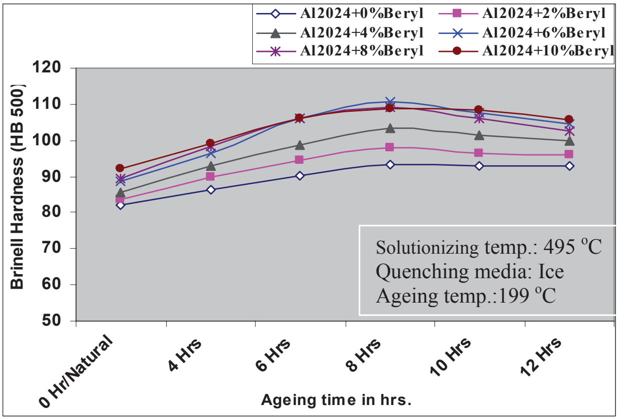

FIGURE 6 Variation of Brinell hardness with increase in ageing time for Al2024 and Al2024/beryl composites for ice quenched and different hear treatment condition

In all the quenching media and under all ageing times composites exhibits higher hardness when compared with the matrix alloy. After solutionized with ice quenching and aged for a duration of 8 hrs at a temperature of 199°C results in obtaining maximum hardness of the matrix alloy and its composites. Ice quenching and ageing for 8 hrs, the matrix Al2024 alloy exhibited a maximum improvement in hardness of around 49%, while Al2024–10 wt.% of Beryl composites exhibited a maximum improvement in hardness of around 32%. On water quenching and ageing for 8 hrs, the matrix Al2024 alloy exhibited a maximum improvement of hardness of around 43%, while Al2024–10wt.% of beryl composites exhibited a maximum improvement in hardness of around 21%. On air quenching and ageing for 10 hrs, the matrix Al2024 alloy exhibited a maximum improvement in hardness of around 36%, while Al2024–10 wt.% of beryl composites exhibited a maximum improvement in hardness of around 19%.

6.0 CONCLUSIONS

Based on the results of this study, the following conclusions are arrived.

- The Aluminium 2024-T6 / Beryl particulate reinforced composites were successfully developed using liquid metallurgy route. (stir casting technique)
- The microstructural study clearly reveals the nearly uniform distribution of reinforcement particulates in the Al 2024 matrix alloy.
- The density of the composite material decreases as

the reinforcement content increases in the matrix material and confirms the stability of the liquid metallurgy technique for successful development of the composite material.

- The Brinell hardness of the composites increased significantly with increased content of Beryl particles. Heat treatment has a significant effect on Brinell hardness of Al2024 matrix alloy and its composites. Ice quenching followed by artificial ageing for 8 hrs resulted in maximum hardness of matrix alloy and its composites.

7.0 REFERENCES

A.R. Riahi and A.T. Alpas. 2001. Wear. 251. pp.1396–1407.

A.B.Gurcan and T.N.Baker. 1995. Wear.188. pp.185-191.

Alpas AT and Zhang J. 1992. Wear. 155. pp.83–104.

Appendino P, Badini C, Marino F and Tomari A. 1991. Journal of Mater. Sci. & Eng. A135. 275.

B.K. Prasad. 2007. Wear .262. pp. 262–273.

C.garcia Cordovilla, J.Narciso and E.Louis. 1996. Wear. 192. pp.170-177.

C. Subramanian. 1992. Wear.155. pp. 193–205.

Debdas Roy, Bikramjit Basu and Amitava Basu Mallick. 2005. Intermetallics. 13. pp.733–740.

Dermirci A.H & Gulec S. 1988. Metall. 42 (10). pp. 977-980.

F. M. Husking, F. Folgar Portillo, R. Wunderlin and R. Mehrabian. 1982. Journal of Mater. Sci. 17. pp. 477-498.

Hoskings F M, Portillo F F, Wunderlin R and Mehrabian R 1982 J. Mater. Sci. 17, 477 .

J.M. Wu and Z.Z. Li. 2000. Wear. 244. pp.147–153.

Kim C.K and Park S.Y. 1984. Journal of Korean Inst. Met. Mater. 22. pp.185–92.

Kulkarni M.D, Robi PS, Prasad R.C and Ramakrishnan P. 1996. Mater Trans. JIM; 37. pp.223–229.

L.J. Yang. 2003. Wear. 255. pp. 579–592.

M.R. Rosenberger, C.E. Schvezov and E. Forlerer. 2005. Wear. 259. pp. 590–601.

M.D. Bermudez, G. Martinez-Nicolas, F.J. Carrion, I. Martinez-Mateo, J.A. Rodriguez and E.J. Herrera. 2001. Wear. 248. pp. 178–186.

Mortensen A and Wong T. 1990. Metall Trans A; Vol 21 A: pp 2257–63.

N. R. Prabhu Swamy, C. S. Ramesh and T. Chandrashekar, 2010, Bull. Mater. Sci., Vol. 33, No.1, pp. 49–54.

Pramila Bai B. N, Ramasesh B. S and Surappa M. K. 1992. Wear. pp.157-295.

R.L. Deuis, C. Subramaniun and J.M. Yellup. 1996. Wear. 201. pp. 132–144.

Ramesh C. S, Anwar Khan A. R, Ravikumar N and Savanprabhu, 2005, Int. J. Wear, 259, pp. 602.

S.Wilson and A.T.Alpas. 1996. Wear. 196. pp. 270-278.

S. Sawla and S. Das. 2004. Wear. 257. pp. 555–561.

S. Das, D.P. Mondal, S. Sawla and N. Ramakrishnan. 2008. Wear. 264. pp. 47–59.

S.C. Sharma.2004. Journal of Materials Engineering and performance. Vol. 12 (3). Pp. 324-330.

Surappa M. K. 2003. Materials research: Current scenario and future projections. Pp. 301–318.

Szu Ying Yu, Hitoshi Ishii, Keiichiro Tohgo, Young Tae Cho and Dongfeng Diao. 1997. Wear. 213. pp. 21-28.

T. Miyajima and Y. Iwai. 2003. Wear. 255. pp. 606–616.

T. Perry and A.T. Alpas. 2007. Wear. 263. pp. 552–561.

W.Q.Song, P.Krauklis, A.P.Mouritz and S.Bandyopadhyay. 1995. Wear. 185. pp. 125-130.

Wang .A and H.J. Rack. 1991. Wear. 146. pp. 337-345.