Journal of Engineering Science and Technology
Vol. 9, No. 4 (2014) 455 - 462

EFFECT OF AGING ON MECHANICAL AND WEAR PROPERTIES OF BERYL PARTICULATE REINFORCED METAL MATRIX COMPOSITES

H. N. REDDAPPA[1,*], K. R. SURESH[2], H. B. NIRANJAN[3], K. G. SATYANARAYANA[4]

[1]Research Scholar, Dept. of IE&M, Bangalore Institute of Technology, Bangalore, India
[2]Principal/Director, Bangalore Institute of Technology, Bangalore, India
[3]Prof. & Head, Dept. of Mech. Engg., Sambhram Institute of Technology, Bangalore, India
[4]Honorary Professor, Poornaprjna Institute for Scientific Research, Bangalore, India
*Corresponding Author: reddyhn.phd@gmail.com

Abstract

This paper describes the study of effect of aging on mechanical and wear properties of 'hot rolled' Al6061-10% wt. of beryl particulate reinforced composites produced by stir casting have been examined. The result shows that hardness and tensile strength of '90% hot rolled and aged' composites were increased by 10.28% and 3.78% as compared to 'hot rolled' composites respectively. The 'hot rolled and aged' composite shows significant decrease in specific wear rate when compared to that of 'hot rolled' composites.

Keywords: Hot rolling, Heat treatment, Al6061, Beryl.

1. Introduction

Aluminum based Metal Matrix Composites (AMMC's) have been attracting a lot of attention in the fields of automotive, aerospace engineering and structural applications, because of their desirable combination of properties including specific strength, specific stiffness, wear resistance, excellent corrosion resistance and high elastic modulus [1-3]. The composites have been fabricated by many manufacturing processes. In general, most metal matrix composites are produced by casting and powder metallurgy techniques [4]. The casting method is simple and economical due to the possibility of utilizing the conventional casting equipment without any limitation in size and shape of components [5]. However, composites prepared by this method do exhibit certain limitations such as non uniform distribution and poor wettability of ceramic particles with the molten metal leading to the absence of sound interface between matrix and reinforcement.

Abbreviations

AMMC	Aluminum Metal Matrix Composites
ASTM	American Society for Testing and Materials
BHN	Brinell Hardness Number
MMC	Metal Matrix Composites

Formation of interfacial products and incomplete adhesion leads to generation of inherent casting defects [6,7]. It has been reported that the above mentioned problems can be effectively addressed by preheating the ceramic particles before addition in to the molten metal [8].

Further, it has been reported that conventional secondary metal working processes such as extrusion, forging and rolling modifies the microstructural parameters of the composites and improves the mechanical and wear behaviour of the composite materials [9,10]. It is also reported that hot deformed aluminum based composites do exhibit excellent strength coupled with high ductility when compared with primarily processed techniques such as casting, spray deposition, etc. [11].

Among all the available secondary processing techniques, rolling is the most preferred because it can offer large plastic deformation without the failure of formed parts [12]. Added to this, it is possible to achieve rapid production of near-net-shaped components without incurring any damage [13]. Further, improvements in the mechanical properties and wear resistance of aluminum matrix composites can be achieved by adopting suitable heat treatment. Some researchers have concluded that mechanically deformed and heat treated composites yields the maximum improvement in wear resistance as compared with the 'as-cast' composite [14]. Hence, the aim of the present work is to prepare Al6061-10% wt. beryl particulate composites by using low cost stir casting technique and evaluation of mechanical and wear properties in 'hot rolled' and 'hot rolled and aged' conditions.

2. Experimental Details

Beryl particles [15], which are naturally occurring in the form of mineral and having the formula ($Be_3Al_2(SiO_3)_6$) were used as the reinforcing agent, while Al6061 alloy has been used as the matrix. For the preparation of the composite, liquid metallurgy route was adopted as described in earlier studies [16, 17]. Hot rolling method has been used in the present study. The cast specimens (20 mm× 40 mm × 200 mm) were homogenized at 450°C for 1hour and then hot rolled in a rolling machine (Model: BHULER & CO. GmbH VRW 105/32-100 2007, GERMENY) at the same temperature in several passes to obtain a reductions (0.25 mm/pass) of 30%, 50%, 70% and 90%. The tensile specimens were prepared as per ASTM E8-04 specifications and tests were conducted along the rolling direction using Tensometer (Make: Tensometer Ltd., England) with an initial strain rate of 1 mm/min. Brinell hardness measurements were made as per ASTM E10-10 [18] specifications. Sliding wear tests were conducted as per ASTM-G99-95 [19] standard using a pin-on-disc wear testing apparatus (MODEL: TR20-LE, DUCOM make). Information for soak times required for wrought products of various section thicknesses is given in Table 1 and typical heat treatment for aluminum alloys is shown in Table 2.

Table 1. Soak Times and Maximum Quench Delays for Solution Treatment of Aluminum Composites [20].

Thickness, mm	Soak time, minutes		Maximum quench delay, s
	Min.	Max.	
1	30	40	10
3	40	55	15
5	52	63	15
7	65	75	15
10	65	75	15

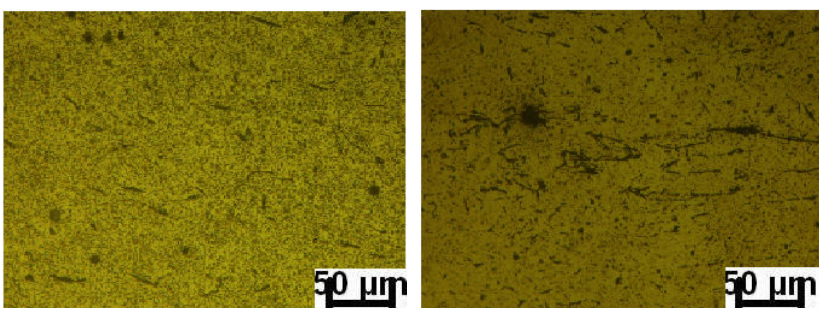
Table 2. Typical Heat Treatment for Aluminum Composites [20].

Temper	Solution heat treatment		Aging treatment	
	Temperature, °C	Time, hours	Temperature, °C	Time, hours
T6	525-530	14-20	175	20

3. Results and Discussion

3.1. Microstructure

Figure 1 shows the micrographs of 'hot rolled' and 'hot rolled and aged' composites confirming the uniformity in the distribution of beryl particles throughout the matrix alloy. Also it is confirmed that an intermetallic precipitates (Mg_2Si) formed after heat treatment. Most of the precipitates are located along the grain boundaries.



(a) '90% hot rolled" **(b) '90% hot rolled and aged'**

Fig. 1. The Micrographs of (a) '90% Hot Rolled' and (b) '90% Hot Rolled and Aged' Specimens.

3.2. Tensile strength

Figure 2 illustrates the tensile strength values of the Al6061-10 wt. % beryl particulate composites with different reductions produced by hot rolling. It can be seen that tensile strength increases when the reduction quantity is increased. The 'hot rolled and aged' composites have a far higher tensile strength than the 'hot rolled' composite so that the tensile strength of the composite increases to 274.8

MPa after 90% reduction, which is 3.78 times higher than what was obtained for the 'hot rolled' sample (264.8 MPa). These results are related to three main effects of the reduction ratio as follows:

- The uniformity of the beryl particles has an important effect on the strength of the MMC's. As shown in the previous sections, by increasing the reduction ratio, a deagglomeration process takes place in the composites. Deagglomeration phenomenon is attributed to the high deformation ratio applied to the aluminum matrix. Plastic flow of the aluminum matrix causes the beryl particle clusters to break and the beryl particles to get separated from each other, resulting in a more uniform distribution of the particles in the matrix. Particle clustering increases the local stress levels and provides crack nucleation sites and low energy propagation routes through connecting brittle particles. Therefore, it can be concluded that by increasing the reduction ratio, which improves the distribution of beryl particles in the aluminum matrix, a more uniform product with a higher strength is obtained.
- The porosity of the composites has a major effect on the strength of the MMC's. Crack formation is associated with porosity to a larger extent. By increasing the reduction ratio, the porosity content in the composite decreases, thus enhancing the strength further.
- An effective bonding of the beryl and the matrix is another factor that affects the higher strength of the MMC's. By increasing the reduction ratio, the bonding between beryl particles and the matrix becomes stronger due to the greater rolling, which imparts a higher strength to the product.

Further, the untreated composite ('as-cast' and 'hot rolled') has the lowest tensile strength values when compared to hot rolled and aged composites. Upon solution treatment, the tensile strength has been observed to be increased. When the solution treated composites were aged, there was a substantial increment found in tensile strength. The tensile strength of the composite gradually increased with an increase in the extent of rolling. This has been attributed to the fragmentation and dispersion of the Mg_2Si intermetallic particles throughout the matrix [14].

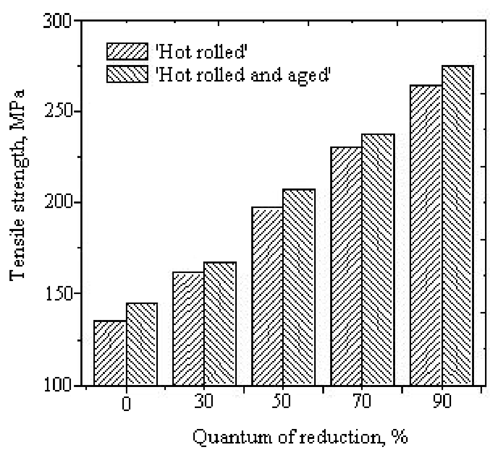


Fig. 2. Tensile Strength of of 'Hot Rolled' and 'Hot Rolled and Aged' Al6061-10% wt. Beryl Particulate Composites.

3.3. Hardness

Figure 3 shows the variations of hardness of 'hot rolled' Al6061-10 wt. % beryl composites in 'hot rolled' and 'hot rolled and aged' conditions. It can be observed that the hardness increases with increase in percentage of reduction. A maximum increase of 110.27 BHN, i.e., 10.28% improvement is noticed in 'hot rolled and aged' Al6061-10 wt. % beryl composites when compared to that of 'hot rolled' composites.

Increased hardness can be attributed to the following reasons.

- Excellent bond between matrix alloy and reinforcement as a result of pre-heating of beryl particles [15].
- The increase in the hardness is to be expected because ceramic reinforcements are very hard and act as a barrier to the movement of dislocations within the matrix and exhibit greater resistance to indentation of the hardness tester [21, 22].

Further with hot rolling hardness was increased because of refinement of grain size. It is also observed that the heat treatment has profound influence on hardness of hot rolled Al6061-10 wt. % beryl composites. All the heat treated and aged samples exhibit higher hardness values when compared with 'hot rolled' composites. Improved hardness in aged samples can be mainly attributed to the formation of intermatallic precipitates namely Mg_2Si from the super saturated solid solution.

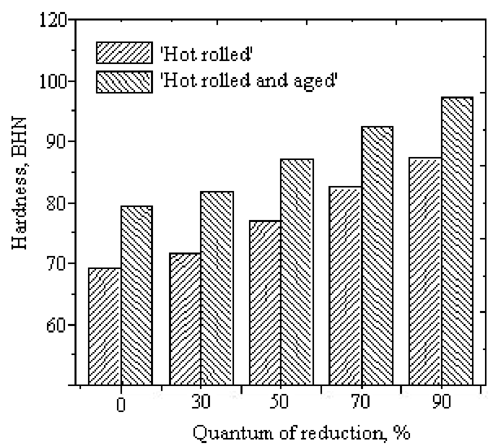


Fig. 3. Hardness of 'Hot Rolled' and 'Hot Rolled and Aged' Al6061-10% wt. Beryl Particulate Composites with Quantum of Reduction.

3.4. Specific wear rate

Figure 4 shows the variation of the specific wear rate of the composites with heat treatment. The untreated composites ('as-cast' and 'hot rolled') composites has the highest specific wear rate when compared to 'hot rolled and aged' which brought a substantial decrease in the specific wear rate. Same trend was observed by Ahmed et al. [14] in their research. As shown in Fig. 4 the 'hot rolled and aged' composites with 90% reduction exhibit lower wear rate of 0.38863×10^{-4} mm^3/N-m, which 1.09 times lower when compared to the 'hot rolled' one (0.42686×10^{-4} mm^3/N-m).

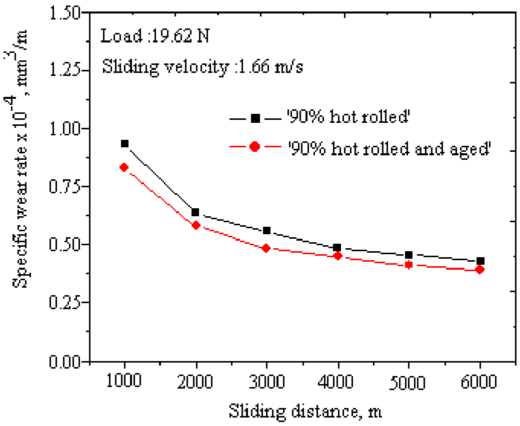
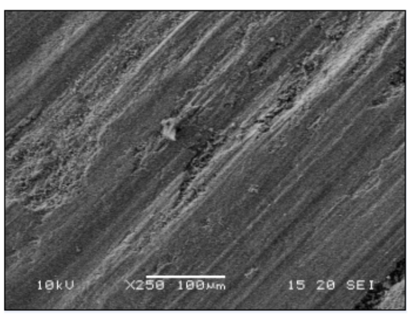
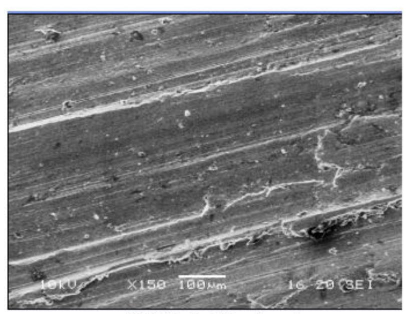


Fig. 4. Specific Wear Rate of 'Hot Rolled' and 'Hot Rolled and Aged' Al6061-10% wt. Beryl Composites.

Figures 5(a) and (b) show the micrographs of the worn composites in the 'hot rolled' and 'hot rolled and aged' conditions. The micrographs show the presence of deep grooves and valleys on the worn surfaces indicating that mainly abrasive wear was in operation in all conditions. The extent of abrasive wear damage was higher in the hot rolled composites, as evidenced by the presence of deeper grooves, as well as by highest wear loss. Dark patches presumably of transfer layer were seen in some cases, particularly in the worn surface of the (hot rolled and aged) composites.



(a) '90% hot rolled'



(b) '90% hot rolled and aged'

Fig. 5. Micrographs of the Worn Composites in (a) 'Hot Rolled' and (b) 'Hot Rolled and Aged' Conditions.

4. Conclusion

Within the preview of the experimentation the following conclusions can be drawn:

- The 'hot rolled' composites exhibits the higher strength, higher hardness and lower wear rate as compared to 'as-cast' composites.

- Hot rolled and aged composite (90% reduction) exhibits a tensile strength of 274.8 MPa showing an improvement of 3.8% when compared to hot rolled composites.
- Hardness of '90% hot rolled and aged' composites increases to 107.28 BHN showing an improvement of 10.28% when compared to hot rolled composites.
- The specific wear rate of the '90% hot rolled and aged' composites is lower as compared to 'hot rolled' composites.

References

1. Satyanarayana, K.G.; Pillai, R.M.; Pai, B.C.; Kestursatya, M.; Rohatgi, P.K.; and Kim, J.K., (2000). Development in cast metal matrix composites over the last three and a half decades. *Proceedings of the Third International Conference, Advances in Composite Materials*, IISc., Bangalore, 753-763.
2. Taha, M.A. (2001). Practicalization of cast metal matrix composites. (MMCCs). *Materials and Design*, 22(6), 431-441.
3. Sahin, Y.; and Murphy S. (1996). The effect of fibre orientation of the dry sliding wear of borsic-reinforced 2014 aluminium alloy. *Journal of Materials Science*, 34(20), 5399-5407.
4. Ray, S. (1993). Review: synthesis of cast metal matrix particulate composites. *Journal of Materials Science*, 28(20), 5397-5413.
5. Valdez, S.; Campillo, B.; Perez, R.; Martinez, L.; and Garcia, A. (2008). Synthesis and microstructural characterization of Al–Mg alloy–SiC particle composite. *Materials Letters*, 62, 2623-2625.
6. Asthana, A.J. (1998). Reinforced cast metals: Part II Evolution of the interface. *Journal of Materials Science*, 33(8), 1959-1980.
7. Ren S.; He, X.; Qu, X.; and Li, Y. (2008). Effect of controlled interfacial reaction on the microstructure and properties of the SiCp/Al composites prepared by pressure less infiltration. *Journal of Alloys and Compounds*, 455(1-2), 424-431.
8. Reddappa, H.N.; Suresh, K.R.; Niranjan, H.B.; and Satyanarayana, K.G. (2012). Effect of rolling on microstructure and wear behavior of hot rolled Al 6061-Beryl composites. *Advanced Materials Research*, 463-464, 444-448.
9. Ramesh C.S.; Keshavamurthy, R.; Channabasppa, B.H.; and Abrar Ahmed, (2009). Microstructure and mechanical properties of Ni-P coated Si_3N_4 reinforced Al6061 composites. *Materials Science and Engineering A*, 502(1-2), 99-102
10. Shi, N.; and Arsenault, R.J. (1994). Plastic flow in SiC/Al composite strengthening and ductility. *Annual Review of Materials Science*, 24, 321-357.
11. Cocen, U.; and Onel, K. (2002). Ductility and strength of extruded aluminum alloy composites. *Composites Science and Technology*, 62(2), 275-282.
12. Kim, Y.H.; Ryou, T.K.; Choi, H.J.; and Hwang, B.B. (2002). An analysis of the forging for 6061 alloy wheel. *Journal of Materials Processing Technology*, 123(2), 270-276.

13. Durrant, G.; and Scott, V.D. (1993). The effect of forging on properties and microstructure of saffil fiber reinforced aluminum. *Composites Science and Technology*, 49(2),153-164.
14. Shafaat Ahmed; Haseeb, A.S.M.A.; and Kurny, A.S.W. (2007). Study of the wear behaviour of Al–4.5% Cu–3.4% Fe in situ composite: Effect of thermal and mechanical processing. *Journal of Materials Processing Technology*, 182(1-3), 327-332.
15. Deer, N.A.; Howie; and Zussman. *Rock Forming Minerals.* Vol. I, Longman, New York, 258.
16. Reddappa, H.N.; Suresh, K.R.; Niranjan, H.B.; and Satyanarayana, K.G. (2012). Effect of quenching media and ageing time on Al6061-Beryl composites. *Applied Mechanics and Materials*, 110-116, 1374-1379.
17. Balasivanandha Prabu, S.; Karunamoorthy, L.; Kathiresan, S.; and Mohan, B. (2006). Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite. *Journal of Materials Processing Technology*, 171(2), 268-273.
18. ASTM International designation ASTM E10-10 Standard Test Method for Brinell Hardness of Metallic Materials.
19. ASTM standard test method for wear testing with a pin-on-disc apparatus. ASTM G99-95. Philadelphia, PA (1995).
20. ASM Handbook (2004). *Heat treating*, Vol. 4, USA.
21. Ganesh, V.V.; Lee, C.K.; and Gupta, M. (2002), Enhancing the tensile modulus and strength of an aluminium. *Materials Science and Engineering A*, 333(1-2), 193-198.
22. Moustafa, Z.F. (1995). Wear and wear mechanisms of Al-22%Si/$A1_2O_3$ Composite. *Wear*, 185(1-2), 189-195.