International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-5, June 2019

Effect of reinforcement and aging time on wear behavior and mechanical properties of Aluminium LM4

Narassima M S, Ilangovan S, Anbuudayasankar S P, Pavithran P

Abstract: ***Aluminium LM4, is widely used in aerospace and automotive industries owing to its light weight and high strength/weight ratio. Further increase in strength might widen the scope of usage of the alloy. Hence, to achieve this, the research investigates on the effects of artificial aging on the wear behavior and mechanical properties of Aluminium LM4 alloys. The LM4 ingots stir cast, homogenized, solution heat treated and aged. The specimen were machined according to the ASTM standards for Tensile, Brinell hardness and Pin-on-Disc wear test. The wear test was conducted for different combinations of applied loads and sliding velocities. It was evident that, the Ultimate Tensile Strength (UTS) and Brinell hardness increased as the aging time increased, before over aging occurred. Wear rates decreased with an increase in hardness. The results revealed that, the wear rates decreased as the aging time and applied load increased. Adverse and undesirable changes in properties were also observed due to over aging.***

Index Terms: Aluminum LM4, Wear behavior, Tribological properties, Heat treatment, Adhesive wear, Mechanical properties

I. INTRODUCTION

Aluminium alloys play an important role in aerospace, automobile, defense and material processing industries with regard to their light weight and high strength/weight ratio [1]. Aluminum-Silicon alloys and aluminium-matrix composites possess superior wear resistance and hence are used for various tribological applications [2, 3]. Aluminium alloys are extensively used as piston material owing to its lightness and good thermal conductivity [4, 5]. In addition to these, presence of silicon content throughout the matrix increases the wear resistance of aluminium alloys [4]. These alloys are also employed in manufacture of automotive engine components such as cylinder blocks, pistons and piston insert rings where good tribological properties are required [6, 3]. However, wear rates are dependent on a number of factors like speed and load apart from the materials used [7]. T.V.S. Reddy et al. [8] observed that the hardness of the stir cast alloys are higher than that of the conventional cast alloys as it results in refinement of the particles and produces spherical shaped aluminium grains. Hence, stir casting was used to prepare LM4 specimens. However, to further improve the mechanical properties, aging treatment would be helpful. Cast specimens underwent heat treatment followed by subsequent machining for performance of various tests such as Tensile, Brinell hardness and Pin-on-Disc test. Heat treatment enhanced the mechanical properties which is effected by rapid cooling by quenching in water [8]. The mechanical and physical properties can be altered by changing the intrinsic and extrinsic factors [9]. There is always a necessity for reducing resources of material and conserving energy which increases the researches on wear of materials. Wear behavior is one of the major facets of aluminium alloy. The wear behavior of a material is governed by the material characteristics and the operating parameters and also observed that the increase in hardness of a material is reflected in improved wear resistance [10]. Hence, this study focuses on improving the hardness and hence the wear behavior of the aluminium alloy by applying heat treatment techniques and also using reinforcements. Zn particles are added as reinforcements in this study into the aluminium matrix. The combined effect of reinforcement addition and heat treatment are studied in this research [11].

II. EXPERIMENTAL PROCEDURE

A. Materials and methods

Aluminium alloy (LM4) was procured in the form of ingots and was cast in the form of cylindrical rods of diameter 16 mm and height 150 mm by Stir casting using Sand moulds [12]. Zn particles were purchased in micron level and were reinforced into the aluminum matrix by similar stir casting technique used for LM4 without reinforcement. Zn were added in 3%, 5% and 7% in order to study the proportionate effect of reinforcement on wear and mechanical properties. The cast specimens were heated to a temperature of 720 °C using an "Oil-Fired Pit-Type" [13]. A graphite crucible as shown in Fig 1 was used for carrying the molten metal from furnace to the sand mould. Zn particles were added and stirring was done vigorously to ensure proper dispersion of reinforcements into the matrix.

Manuscript published on 30 June 2019.
***** Correspondence Author (s)
Narassima M S*, Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India.
Ilangovan S, Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India.
Anbuudayasankar S P, Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India.
Pavithran P, Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India.

Fig 1 Graphite Crucible

B. Heat treatment

Precipitation heat treatment was performed on specimens. This was done with an aim to study the variation in properties with aging time of specimens. A total of 16 unreinforced specimens were heat treated with a soaking temperature of 190 °C. The aging time was varied from 2 to 16 hours in steps of 2 hours i.e., 2 specimens were drawn from the furnace for each aging time [14, 15]. Fig. 2 shows the heat treated LM4 specimens. In addition, Zn reinforced composites were subject to aging for 4, 8, 12 and 16 hours. Each reinforced composition was subject to the above-mentioned aging process.

Fig 2 Heat treated LM4 specimens

C. Tensile test

The test specimens were prepared according to ASTM -E4 standard as shown in Fig 3 and Fig 4. Fig 3 shows the specimen drawing for tensile test and Fig 4 shows the photographic images of the machined specimen.

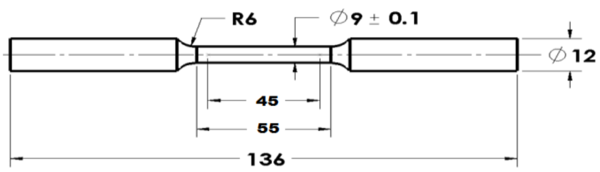

Fig 3 Tensile Test Specimen

Fig 4 Photograph of the machined specimens (Hardness, Tensile test and Wear test)

To observe the variations in tensile strength with the aging time, specimens were made to undergo tensile tests using a computerized universal testing machine as shown in Fig 5 (Make: Tinius Olsen H25KT). The test was conducted with a strain rate of 0.25 mm/min.

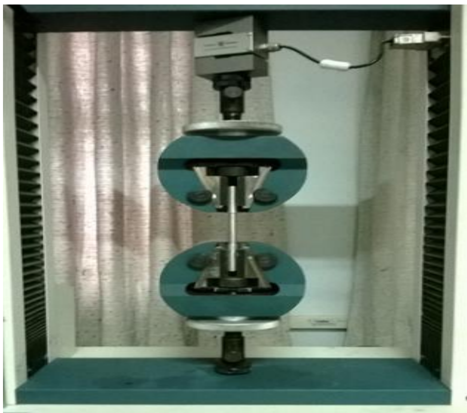

Fig 5 Tensile Apparatus

D. Wear test

Adhesive wear specimens were prepared according to ASTM G99 standards. Cylindrical specimens of diameter 10 mm and height 35 mm were prepared with one end hemispherical. Pin-on-Disc test was conducted using a "Ducom TR-20LE" apparatus (Fig 6). The tests were performed at different loads (10 N, 20 N and 30 N) and sliding velocities (1.5 m/s, 2.5 m/s and 3.5 m/s) by maintaining the sliding track radius as 100mm throughout [6]. Each trial run was for a time period of 10 minutes. Prior to each test run, the disc was ground against the SiC paper in order to remove the accumulated debris from the track [6]. Weight loss of the specimens were measured after each run using a balance having an accuracy of 1mg. The weight loss obtained were converted into wear rates (volume loss per unit time) from the known values, i.e., volume of the specimens and density of the material [2, 6]. The disc material on which the specimen rubbed was made up of hardened steel (EN31). The test data were processed using the software "WINDUCOM-2008".

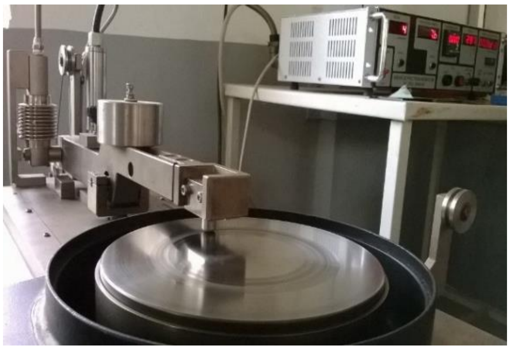

Fig 6 Pin-on-Disc apparatus

E. Hardness test

Specimens for hardness test were prepared as per ASTM -E384 standard. Cylindrical specimens of diameter 16 mm and height 25 mm were prepared. Hardness test was performed using the Brinell hardness testing machine.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

A hardened steel ball of 10 mm diameter was used for indentation. A load of 1000 N was applied for a period of 30 seconds. Using the diameter of indentation and the test parameters, Brinell hardness were calculated using the formula:

$$BHN = \frac{F}{D(D-\sqrt{D^2-d^2})}$$ -------------------- Eq. 1

where
D - indenter diameter (mm),
F - applied load (N),
d - indentation diameter (mm).

III. RESULTS AND DISCUSSION

This section has been broadly sub-divided into two, each one summarizing results of unreinforced and reinforced specimen to avoid misinterpretations and to enhance clarity.

A. Results of unreinforced specimen

Presented below are the results obtained for the various tests performed on heat treated unreinforced specimens. This would demonstrate the response for the heat treatment performed on this alloy.

1) Hardness results

Table 1 displays the results of Brinell hardness tests for the specimens aged from 2 to 16 hours by precipitation heat treatment. The values show that the hardness value increases from 51.87 BHN to 72.41 BHN and then decreases to 56.8 BHN. The maximum hardness value was obtained for the specimen with an aging time of 14 hours. Fig 7 shows the variation of Brinell hardness with aging time. A steady increase in hardness was observed till an aging time of 14 hours due to spinodal decomposition and an ordering reaction. Then, there was a drop in hardness value indicating over aging which might be possibly due to the formation of grain boundary precipitates [16].

Table 1 Results of Brinell hardness test and Tensile test (unreinforced specimens)

Aging time (hr)	Brinell hardness (BHN)	UTS (MPa)
2	51.87	107.6
4	54.26	121.2
6	55.51	130.8
8	58.13	137.1
10	60.94	145.9
12	65.51	139.6
14	72.41	128.4
16	56.8	120.5

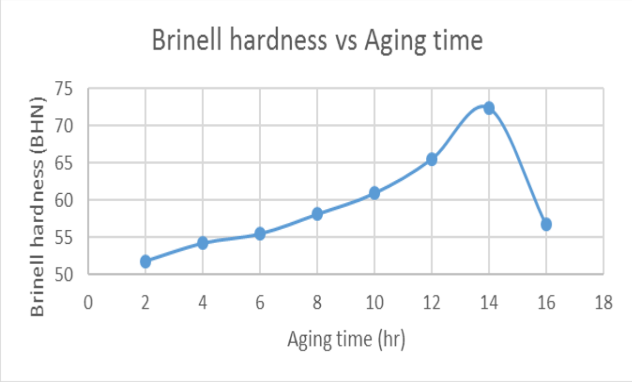

Fig 7 Brinell hardness vs Aging time (unreinforced specimens)

2) Tensile results

Fig 8 indicates the results of tensile test. It is evident that the UTS of the heat treated specimens increase from 107.6 MPa and reach a maximum of 145.9 MPa and then decrease to 120.5 MPa. The decrease in the UTS may be because of the accumulation of precipitates along the grain boundaries which might have resulted in degradation in the strength of the material.

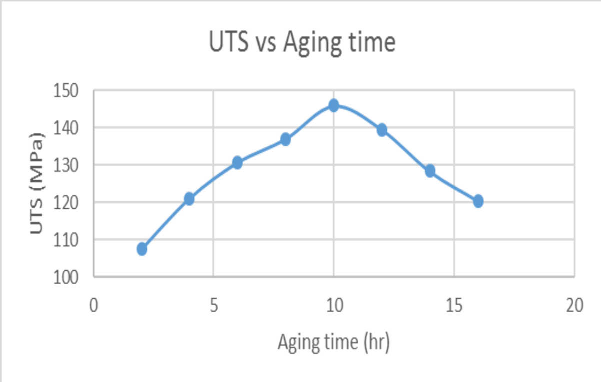

Fig 8 UTS vs Aging time (unreinforced specimens)

3) Pin-on-Disc results

The wear rates obtained from the Pin-on-Disc tests are shown in Table 2. The wear rate values revealed that on an average, wear rates were minimum for specimens with 14 hours aging time. Also, it is observed that the wear rates increased with sliding distance which is in accordance with results observed by Naresh Prasad et al. [17]. Aging ensured homogenous distribution of precipitates that had resulted in increase in hardness and decrease in wear rates [18].

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

Table 2 Results of Pin-on-Disc wear test

Aging time (hr)	Wear rate (mm³/s) x10⁻³								
	Load (10 N)			Load (20 N)			Load (30 N)		
	v=1.5 m/s	v=2.5 m/s	v=3.5 m/s	v=1.5 m/s	v=2.5 m/s	v=3.5 m/s	v=1.5 m/s	v=2.5 m/s	v=3.5 m/s
2	4.779	6.18	8.41	4.714	5.542	7.518	4.459	5.287	5.359
4	4.715	5.48	7.836	4.332	4.97	7.392	3.886	4.777	4.905
6	4.459	5.415	7.581	4.014	4.842	5.988	3.822	4.633	4.777
8	4.014	5.16	6.881	3.759	4.715	5.988	3.759	4.27	4.46
10	3.949	4.905	6.818	3.504	3.97	5.288	3.313	3.715	4.203
12	2.651	3.695	6.051	2.396	3.567	5.16	2.332	3.25	3.714
14	2.484	3.225	4.11	2.103	3.185	4.11	2.103	3.057	3.325
16	4.542	5.695	7.199	3.415	3.759	7.199	3.225	3.759	4.97

Figs 9, 10 and 11 show the variation of wear rates with aging time at different sliding velocities for a constant load. These graphs revealed that the wear rates decrease steadily as the aging time increases. The minimum wear rates were found for the specimen with aging time of 14 hours. Clustering would have resulted in an increase in hardness and hence decrease in wear rates. Reduction in hardness is caused due to the formation of grain boundary precipitates.

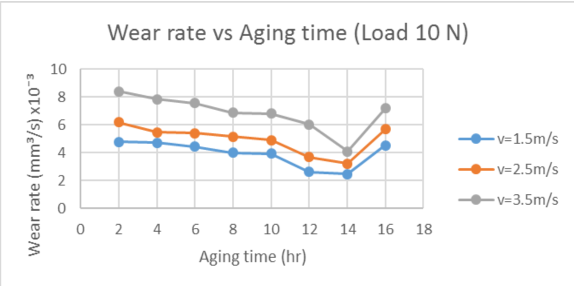

Fig 9 Wear rate vs Aging time (Load 10 N)

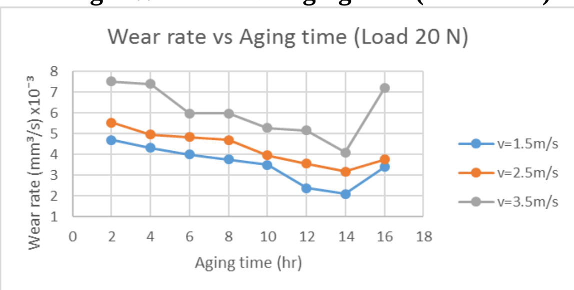

Fig 10: Wear rate vs Aging time (Load 20 N)

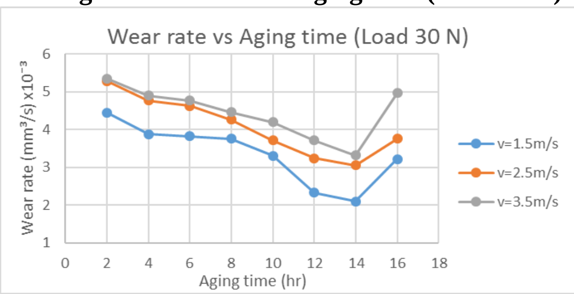

Fig 11 Wear rate vs Aging time (Load 30 N)

Wear rate vs. hardness graphs in Figs 12, 13 and 14 reveal an inverse relationship between the wear rates and hardness of the material. As the hardness values increase, the wear rates decrease for all sliding velocities. It is also seen that the wear rates increase as the sliding velocity increases for all values of hardness which reveals that the increase in sliding distance increases the wear rates.

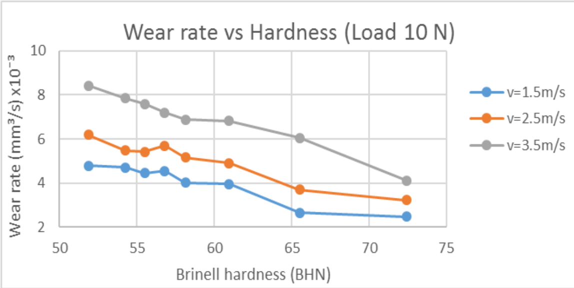

Fig 12 Wear rate vs Hardness (Load 10 N)

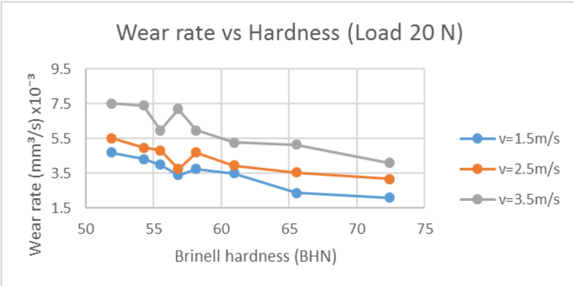

Fig 13: Wear rate vs Hardness (Load 20 N)

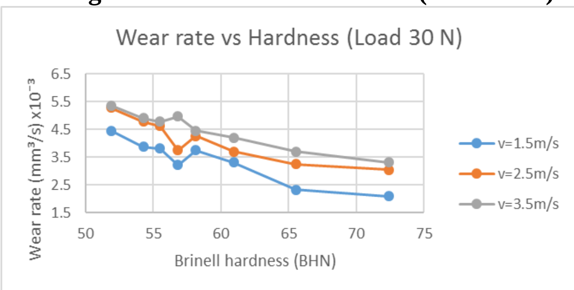

Fig 14: Wear rate vs Hardness (Load 30 N)

Figs 15, 16 and 17 show the variation of wear rates with load for specimens with different aging time at different sliding velocities. The graphs show that wear rates decrease as the applied load increases for all sliding velocities which might be due to the strain hardening effect as more load is applied to the specimen. By analyzing the wear rates for different applied loads, it is seen that the wear rates for specimens with higher hardness values are comparatively lower than the corresponding wear rates for specimens with lesser hardness. i.e., the wear rates decrease with increase in aging time till an aging time of 14 hours.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

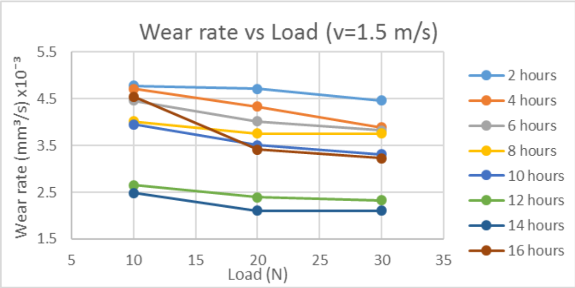

Fig 15 Wear rate vs Load (v=1.5 m/s)

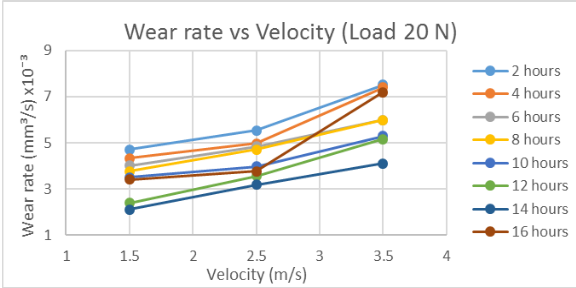

Fig 191 Wear rate vs Velocity (Load 20 N)

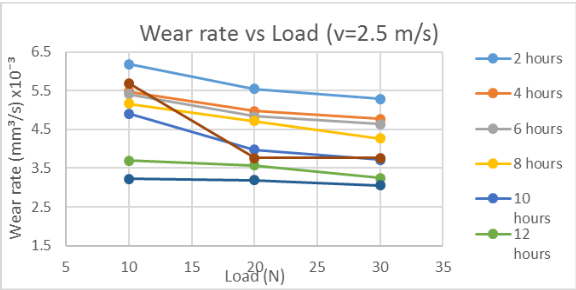

Fig 16 Wear rate vs Load (v=2.5 m/s)

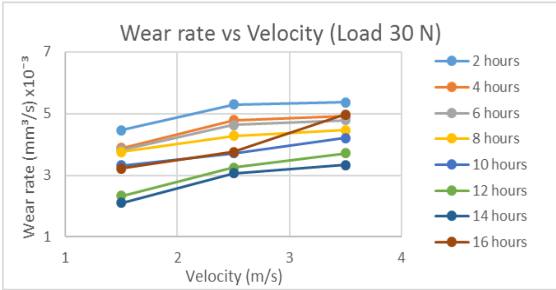

Fig 202 Wear rate vs Velocity (Load 30 N)

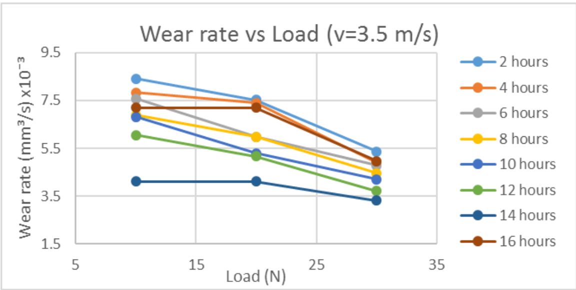

Fig 17 Wear rate vs Load (v=3.5 m/s)

Wear rate vs velocity graphs in Figs 18, 19 and 20 show that wear rates increase as the velocity increases. Since the time period for which the trials were conducted are the same in all the cases, a direct relationship between the sliding distances and the wear rates can be established. Higher velocities have greater sliding distances resulting in higher wear rates. However, wear rate increases with an increase in sliding velocity, it is apparent that the wear rate per unit sliding distance decreases for any particular value of applied load. Also, it is evident that there is a competition between the thermal softening and strain hardening as the sliding speed increases [19, 20].

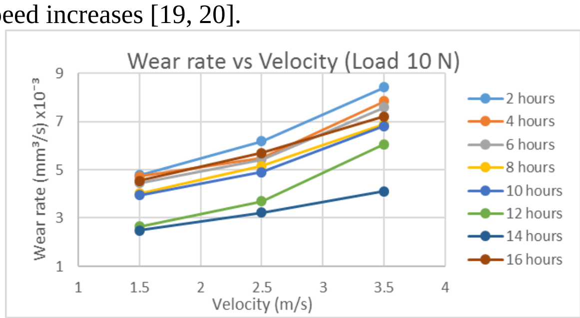

Fig 18 Wear rate vs Velocity (Load 10 N)

A. Results of reinforced specimen

This section presents the results that were obtained by performing various tests on the heat treated reinforced specimens. This is an interpretation of the combined effect of reinforcement and heat treatment.

1) Hardness results

Table 3 Results of Brinell hardness test and Tensile test (reinforced specimens)

Ageing time (hr)	3% Zn	5% Zn	7% Zn
4	51.87	55.51	54.26
8	54.26	58.13	59.51
12	62.41	59.51	62.41
16	59.51	55.51	56.8

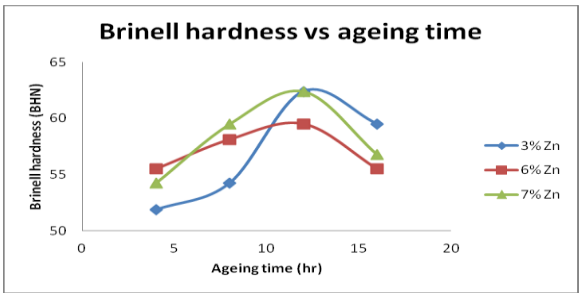

Fig 21 Brinell hardness vs Aging time (reinforced specimens)

It is clear from table 3 and Fig 21 that the peak hardness is seen for the specimens that underwent artificial aging treatment for a duration of 12 hours. Decrease in the hardness for specimens heat treated for 16 hours is an indication of over aging phenomenon.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

2) Tensile results

Table 4 Results of UTS for various compositions (%) of reinforcement at varying aging time (hrs)

Time (hr)	3% Zn	6% Zn	7% Zn
4	123.4	126.7	129.2
8	129.2	134.4	135.1
12	138	138.8	141.3
16	133	132.2	134.1

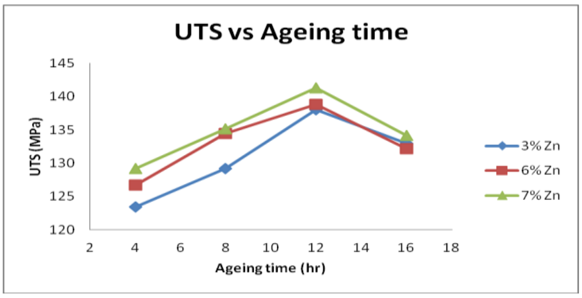

Fig 22 UTS vs Aging time (reinforced specimens)

Fig 22 represents the UTS of the reinforced specimens subjected to artificial aging of varying time durations. It is evident that the UTS reaches a maximum for all different composition specimen those underwent artificial aging for 12 hours.

3) Pin-on-Disc results

Table 5 Results of Pin-on-Disc wear test

Ageing time (hr)	Wear rate (mm³/m) x10⁻³								
	Load (10N)			Load (20N)			Load (30N)		
	3% Zn	6% Zn	7% Zn	3% Zn	6% Zn	7% Zn	3% Zn	6% Zn	7% Zn
4	5.287	5.034	4.524	2.803	2.593	1.803	2.421	2.366	2.246
8	5.289	4.779	4.524	2.739	2.466	2.121	2.293	2.23	2.121
12	4.416	4.224	3.376	1.87	1.591	1.504	1.931	1.775	1.472
16	4.842	4.817	4.842	2.603	2.548	2.548	2.332	2.076	1.873

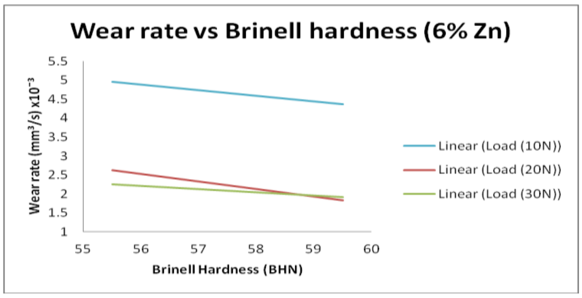

Fig 4 Wear rate vs Hardness for Aluminium LM4 composite with 6% Zn reinforcement

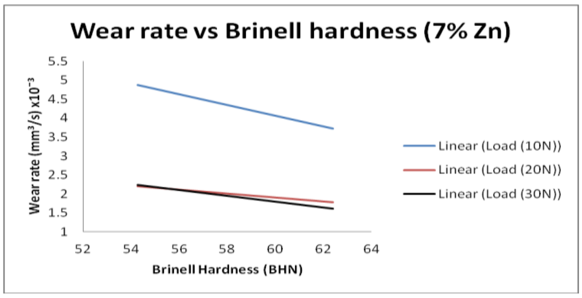

Fig 5 Wear rate vs Hardness for Aluminium LM4 composite with 7% Zn reinforcement

The above graphs show that the wear rate decreases with increase in hardness. Wear rate for any particular value of hardness decreases as the load increases. Strain hardening of specimen may take place due to increase in applied load which may be the reason for decrease in wear rate. Strong oxide layers form on the surface which disintegrate upon application of loads that are sufficient enough to break the bonds formed by the oxide layer. In all the above scenarios, wear rate decreased as the reinforcement percentage increased. This is inline with the results of increasing hardness and UTS with increase in percentage of reinforcement particles.

Table 5 reveals that the wear rates are minimum for the specimens that underwent artificial aging for a duration of 12 hours. Wear rates are seen to increase with an increase in the sliding distance. Also, it is seen that the wear rates decreased with increase in load indicating work hardening at the surface due to the load applied.

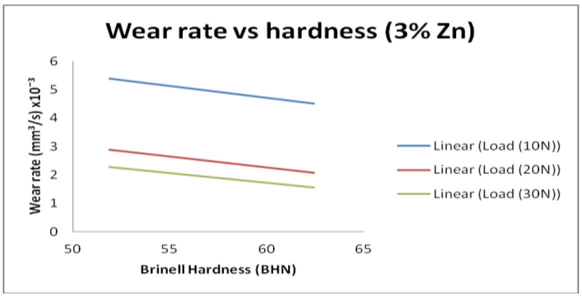

Fig 3 Wear rate vs Hardness for Aluminium LM4 composite with 3% Zn reinforcement

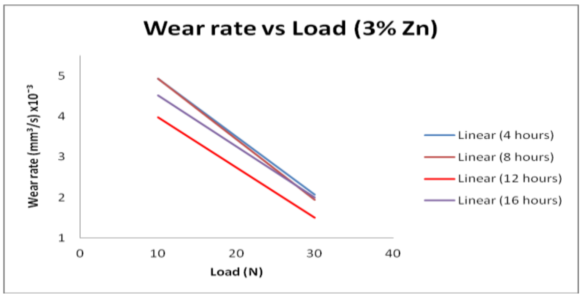

Fig 266 Wear rate vs Load for Aluminium LM4 composite with 3% Zn reinforcement

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication (BEIESP)

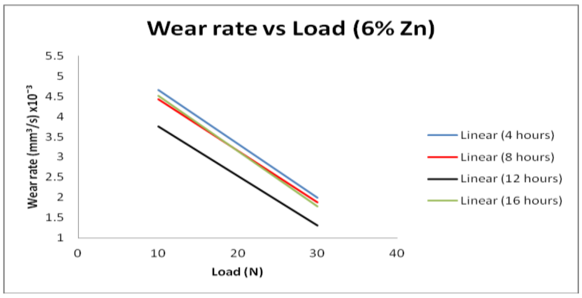

Fig 27 Wear rate vs Load for Aluminium LM4 composite with 6% Zn reinforcement

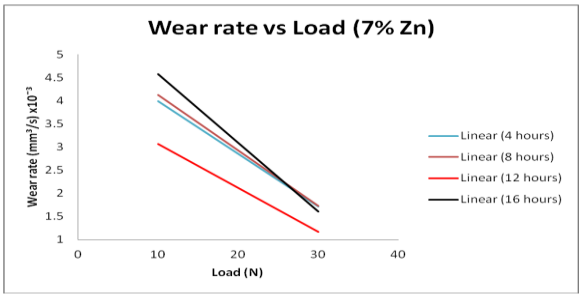

Fig 28 Wear rate vs Load for Aluminium LM4 composite with 7% Zn reinforcement

From the above graphs, we can infer that wear rate decreases with increase in applied load as discussed earlier as a result of work hardening of the specimens. Also the wear rates for any value of applied load increases in accordance with the hardness values of the specimen.

IV. CONCLUSIONS

Aluminium LM4 was procured in the form of ingots, cast, followed by heat treatment (artificial aging) and machining. Tensile, Brinell hardness and Pin-on-Disc wear test were conducted. The hardness increases with increase in aging time, reaches a maximum value of 72.41 BHN for the specimen with an aging time of 14 hours, and decreases to 56.8 BHN for the specimen with an aging time of 16 hours. The tensile strength increases with an increase in aging time. Also, the wear rates increase with increase in sliding speed [21]. The uniform distribution of the micro constituents in the heat treated specimen results in a reduced wear rate which is because of the reduction of cracking tendency. Maximum value of UTS was obtained as 145.9 MPa that decreased to 120.5 MPa. The Coefficient of Friction (COF) remains a constant for all values of Hardness, which indicates that the COF is a material property. Wear rates decrease as the aging time increases in all cases (i.e., for all different velocities). Wear rates decrease as the hardness increases. Also, for any value of hardness, the wear rates increase with increase in velocity. Wear rate decrease as the applied load increases. This is because of the strain hardening effect at higher loads. Wear rates increase as the velocity increases. This shows a direct relationship between the wear rate and the sliding distance. The suggested aging time of LM4 cast specimen considering its hardness, UTS and wear rate was found to be 14 hours from the experimental values. It is evident that the properties are a function of various parameters such as aging time, temperature etc. The hardness of Aluminium increases with increase in ageing time. It reaches a maximum value of 72.41 BHN for an ageing time of 14 hours and then decreases. Hardness values of Annealed specimens are comparatively lesser than the hardness values of other specimen. The maximum hardness values for Aluminium LM4 composites are found to be 62.41, 59.51 and 62.41 for specimens with reinforcement of 3%, 5% and 7% Zinc respectively. Maximum value of UTS is obtained as 145.9 MPa for the Aluminium LM4 specimen with an ageing time of 10 hours. The maximum UTS values of composites are found to be 138,138.8 and 141.3 MPa for specimens with reinforcement of 3%, 5% and 7% Zinc respectively. The maximum UTS value of specimen with 7% of Zn is found to be greater than the corresponding UTS value of Aluminium LM4 alloy with no reinforcement. This shows that reinforcement helps in improving the strength of the alloy. Also, wear behavior and tensile strength depends on the process parameters i.e. load applied and feed in case of tensile testing, load, sliding velocity, sliding distance in case of Pin-on-Disc test. Vast improvements can be made by adding reinforcements to the base alloy to improve the properties.

V. FUTURE SCOPES

Further, extension to the present work can be carried out by casting alloys or composites of Aluminium LM4 using different reinforcements, subjecting to heat treatment, performing the required tests to determine and study the changes in properties. A study can be conducted on high-entropy alloys of Aluminium to analyze the effect of aluminium content on its mechanical properties and wear behavior [22]. Slobodan Mitrovic et al. [23] observed improvement in tribological properties when zinc and aluminium alloys were reinforced with SiC and graphite particles. This can be useful to find better compositions and configurations in which reinforcements can be added to obtain desired properties for various applications. Particles such as red mud, an industrial waste also improved wear behavior and hardness, when reinforced into aluminium matrix [17]. Such findings help to broaden the views about improvement in properties of alloys and composites.

REFERENCES

1.
2. R.N. Rao and S. Das. "Wear coefficient and reliability of sliding wear test procedure for high strength aluminium alloy and composite". Materials and Design 31 (2010) 3227–3233.
3. Y. Iwai, T. Honda, T. Miyajima, Y. Iwasaki, M.K. Surappa, J.F. Xu. "Dry sliding wear behavior of Al2O3 fiber reinforced aluminium composites". Composites Science and Technology 60 (2000) 1781-1789.
4. R. L. Deuis, C. Subramanian & J. M. Yellup. "Dry Sliding Wear of Aluminium composites-A Review". Composites Science and Technology 57 (1997) 415-435.
5. A. D. Sarkar and J. Clarke. "Friction and Wear of Aluminium-Silicon Alloys". Wear, 61(1980) 157 – 167.
6. B. Venkataraman and G. Sundararajan. "Correlation between the characteristics of the mechanically mixed layer and wear behavior of aluminium", Al-7075 alloy and Al-MMCs". Wear 245 (2000) 22–38.
7. C.Y.H. Lim∗, S.C. Lim, M. Gupta. "Wear behavior of SiCp-reinforced magnesium matrix composites". Wear 255 (2003) 629–637.
8. J. F. Archard and W. Hirst. "The Wear of Metals under Unlubricated Conditions". Proc. R. Soc. Lond. A 1956 236, 397-410.

9. T.V.S. Reddy, D.K. Dwivedi ∗, N.K. Jain. "Adhesive wear of stir cast hypereutectic Al–Si–Mg alloy under reciprocating sliding conditions". Wear 266 (2009) 1–5.
10. S.Ilangovan, SaiKrishna Viswanathan, Gopath Niranthar K. "Study of effect of cooling rate on Mechanical and Tribological properties of Cast Al-6.5Cu Aluminium Alloy". IJRET. Volume: 03 Issue: 05 | May-2014.
11. D.K. Dwivedi. "Adhesive wear behavior of cast aluminium–silicon alloys: Overview". Materials and Design 31 (2010), 2517–2531.
12. Ilyas Hussain and Dr. Ilangovan S., "Effect of Variation in Zinc Content and Ageing Treatment on Tribological Properties of Cast Aluminium-Zinc Alloys", International Journal of Pure and Applied Mathematics, vol. 118, no. 11, pp. 563-568, 2018.
13. S.Ilangovan, R.Srikanthan, G. Veda Vyass. "Effects of Aging time on Mechanical properties of Sand Cast Al-4.5Cu Alloy". IJRET. Volume: 03 Issue: 05 | May-2014.
14. S. Ilangovan. "Effects of solidification time on Mechanical properties and Wear behavior of sand cast Aluminium alloy". IJRET, Volume: 03 Issue: 02 | Feb-2014.
15. Aleris Recycling (German Works). 2011, Aleris Switzerland GmbH. Euro Issue 12/11 - 1st release
16. Shairulafizan Bin Muhammad Shamsuddin. "Heat Treatment process of Aluminium Alloy to minimize the precipitate free zones and it effect to wear resistance". May 2006.
17. S.Ilangovan. "Study of microstructure, Hardness and Wear properties of Sand cast Cu-4Ni-6Sn Bronze alloy". Journal of Engineering Science and Technology. Vol. 10, No. 4 (2015) 526 – 532.
18. Naresh Prasad, Harekrushna Sutar, Subash Chandra Mishra, Santosh Kumar Sahoo and Samir Kumar Acharya. "Dry Sliding Wear Behavior of Aluminium Matrix Composite Using Red Mud an Industrial Waste". International Research Journal of Pure & Applied Chemistry 3(1): 59-74, 2013.
19. M. Babić, S. Mitrović and R. Ninković. "Tribological Potential of Zinc-Aluminium Alloys Improvement". Tribology in industry, Volume 31, No. 1&2, 2009.
20. J. Zhang and A. T. Alpas. "Transition between Mild and Severe Wear in Aluminium Alloys". Actu mater. Vol. 45, No. 2, pp. 513-528, 1997.
21. Abdulwahab, M., I. A. Madugu, F. Asuke, O.S.I. Fayomi, F. A. Ayeni. "Effect of thermal ageing treatment on the mechanical properties of antimony-modified A356.0-type Al-Si-Mg alloy". Journal of Materials and Environmental Sciene. Vol. 4, No. 1. PP: 87-92.
22. M. Ruiz-Andrés, A. Conde, J. de Damborenea & I. García. (2013) "Wear behavior of aluminium alloys at slow sliding speeds". Taylor & Francis. May 2015.
23. Jien-Min Wu, Su-Jien Lin, Jien-Wei Yeh, Swe-Kai Chen, Yuan-Sheng Huanga, Hung-Cheng Chen. "Adhesive wear behavior of AlxCoCrCuFeNi high-entropy alloys as a function of aluminum content". Wear 261 (2006) 513–519.
24. Slobodan Mitrovi, Miroslav Babi, Blaža Stojanovi, Nenad Miloradovi. "Tribological Potential of Hybrid Composites based on Zinc and Aluminium alloys reinforced with SiC and graphite particles". 12th International Conference on Tribology – Serbiatrib'11.

AUTHORS PROFILE

Narassima M S is a Research Scholar at Amrita School of Engineering, Coimbatore. He has researched in the area of Supply Chain, Data Analytics, Production Scheduling, Simulation, etc. He also has an industrial experience in the areas of Supply Chain, data analysis, etc. He has worked in areas such as production planning, scheduling, Discrete Event Simulation of real-time systems to improve the operational efficiency of systems, statistical analysis of industrial and organizational problems, healthcare, etc. Presently, he is inching towards engineering viewpoints on energy conservation to minimize the power consumption. He has published his works in international journals and has attended conferences.

Ilangovan S is an Associate Professor in the department of mechanical engineering at Amrita School of Engineering, Coimbatore. The author has completed his Bachelor's Degree in Mechanical Engineering and Master's Degree in Production Engineering. Also he has fourteen years of industrial experience and twenty one years in teaching. Further he has completed Ph.D. in Materials Engineering. He is an active researcher in the area of materials, tribological studies, mechanical behavior of materials, alloying, reinforcements and development of composites, etc.

Anbuudayasankar S P works as Associate Professor in Mechanical Engineering Department at the School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, India. He holds a Bachelor's degree in Mechanical Engineering, a Master's degree in Industrial Engineering, a Management degree in Production. He holds Doctorate in Supply chain and Logistics. His main research interests include optimization, greening the supply chain and location and allocation problems. He has published several papers and book chapters in national and international journals and conferences. He also serves in the editorial board of peer reviewed International Journals.

Pavithran P is a postgraduate student in the department of mechanical engineering in Amrita University. His key research works include optimization techniques and discrete event simulation to improve the performance of industries. He has worked on statistical tools to optimize the process parameters of machining, production planning, priority dispatching of jobs in Jobshop, etc. He has attended international conference in the recent past and was named one of the best presenters.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)