Mechanical characterization of modified and heat-treated ZA-27 alloy

Veerabhadrappa Algur[1], V R Kabadi[2], Deepak C[3], Vasudendra H K[4]

[1]Associate Professor, Department of Mechanical Engineering, Proudhadevaraya Institute of Technology, Hosapete,

[2] Professor, Department of Mechanical Engineering, Cambridge Institute of Technology, North campus, Bengaluru, omvrk

[3]Assistant Professor, Department of Mechanical Engineering, Rao Bahadur Y Mahabaleswarappa Engineering, College, Ballari,

[4]Assistant Professor, Department of Mechanical Engineering, Hangal Kumareshwar polytechnic college, Ballari.

Abstract:
The effect of Mn content on tribological wear behavior of ZA-27 alloy which is used in an Industrial engineering and tribological applications has been studied. 0.2%, 0.5% & 1.0% Mn ZA-27 alloy is selected for the research work. Wear tests have been conducted on as received, annealed quenched alloy and T6 type heat treatment

Mechanical tests were conducted for all the specimens and wear tests have been conducted on all the specimens under constant load of 4kg and sliding speed of 2.5m/s, on pin-on-disc type wear testing machine. To understand the wear results, volumetric wear rate are plotted and discussed. To determine the wear mechanisms of worn-out surface of samples SEM micrographs were examined. T6 type heat treated specimens shows lower volumetric wear rate when compared with the others. ZA-27/0.5%Mn content shows lower volumetric wear rate. Adhesive wear mechanism is observed.

Key words: Adhesive wear, SEM, Volumetric wear rate, XRD, ZA-27 alloy

I. INTRODUCTION

In view of material and mechanical engineering aspects, there are different ferrous and non ferrous metals are being occupied in our nature. There was a time where engineers were used to employ different methods to figure out material characteristics of a metal. As far material science knowledge is concerned in order to enhance the material properties there are several methods commonly encountered, namely Alloying method, Heat Treatment method, Recrystallization and many non conventional methods. So in this respect as far Chemical elements knowledge is concerned several elements are put great emphasis on improving the

Mechanical properties of metal. In this notion, here the principal elements like Zinc and Aluminum play an important role to enhance the properties as Well as increasing the stability of a product. Usually it is need not to say that only major portion of Zinc and Aluminum play an important role to enhance the stability of a product, other ingredients shall also be added to attain required characteristics. So here there are different alloys of Zinc and aluminum can be seen, namely ZA-8, ZA-12, ZA-27 ZA-8 which is having highest creep resistance and it is the strongest and hardest. The major disadvantage of alloy of ZA-8 is difficult to make electroplating process as compared to ZA-12 alloy. ZA-27 would have strongest and easily castable and heat treatable. And it possess resistance towards corrosion, excellent thermal conductivity and high dimensional accuracy and stability the major constituent zinc itself has a tendency to be machined, pressed, stamped and fabricated. So in this connection as far material technology is concerned eventually the ZA-27 alloy is to be considered as the best element among its several alloys for its known characteristics. Interestingly, the ZA-27 can have a tendency to compatible with minor ingredients like Silicon, Magnesium and copper. Wear is the most common problem in an engineering material, Even though wear and friction are of the material properties, where few tribological behaviors are strongly recommended by both physical and mechanical properties. Actually the word tribology had been evolved from the “Greek” word, which means “science of rubbing”. The principal concept of tribology is to control the friction and wear of a respective metal (here ZA-27 alloy). In order to eradicate the problems of wear of a metal a known amount of ingredients are to be added, generally, wear is a gradual loss of material from the attached surface of relative body. While sliding exists touching sense aspects in relative to the attached body could be taken place finally it gives rise to wear particles knocked out by the tips of the members. So in this regard several industrial persons went to produce zinc aluminum products which have been using in bearing application since very long time. Apart from aforementioned ingredients other ingredients were also used to overcome the problems of wear and other metallurgical related problems. Several materials would be known for their excellent characteristics and research fellows who had investigated over those had become successful. In the light of enhancing the properties of a material, the major constituent elements would be changed according to product requirement. So due to technological advancement of Zinc and aluminum alloys they have occupied in various places of engineering sector. So the constituents who could be added like Si, Mn, and Cu, which contributes major advantage to form a new metal which will be free from problems. By this view of there are still investigation is going on ZA-27 alloy, but being an engineer's it's our essential duty to obtain the desirable knowledge of respective materials. After considering all the literature aspects into our account, ours task of this work is to keeping constant all other constituents like Al, Cu, and Si. But only we have to change the wt% of Mn will get a desirable results. And the material of zinc and Aluminum (ZA-27 alloy) would be obtained from gravity die casting technique. By the directions of physical metallurgical engineering, there are different metals or alloys existed in nature. To analyze the metallurgical properties knowledge about solid solution plays an important role in metallurgical sector. Initially many scientist and researcher were not aware of the heat treatment process; later several scientists were made an investigation on ZA-27 based alloy, all scientists were come to know about heat treatment process. Generally in heat treatment process a refractory lined muffle type of furnace to be employed. Heat treatment process is a combination of heating and cooling of a metal or an alloy is called heat treatment process. While performing and conducting experiment on ZA-27 alloy it is need to go for heat treatment process. Usually a muffle type of furnace is to be used for heating a metal or an alloy. So while operating one can satisfy the requirements of muffle furnace that is it is need to maintain the temperature uniformly thought the furnace. And temperature should be controlled for different stages of heat treatment encompassed those are annealing, Normalizing, Hardening, Tempering, Mar tempering and Ageing.

II. EXPERIMENTAL PROCEDURE

A. Material Preparation

The required quantity of product has been obtained from gravity die casting technique. The ZA-27 alloy is to be heated at 740^{0}C. While alloy gets heated at this temperature other required ingredients are to be added to like Cu, Mg, Si, and Mn. So the nominal composition gives a balanced value of ZA-27 alloy. The molten metal has to be brought in a mould after that sufficient time is to be allowed for solidification. Then the material gets required cylindrical shape.

The following table 1 which gives a nominal composition of ZA-27 alloy with other required Ingredients.

Table 1 Nominal chemical composition of experimental alloy

SL.NO	Al	Cu	Mg	Si	Mn
M1	27	2	0.04	3.5	0.2
M2	27	2	0.04	3.5	0.5
M3	27	2	0.04	3.5	1.0

B. Heat treatment

The modified ZA-27 alloys were heated in a muffle furnace to 370^{0}C and held at 5 hours for soaking. Few of samples were quenched in water immediately. Few samples were furnace cooled in a muffle furnace for 20 days. One group of samples were subject to heat treatment of solution at 370^{0}C, soaked for 5 h, then quenched in water and then artificially aged at 160^{0}C for 3h (T6).

C. Measurement of Mechanical characterization

Tensile tests were performed on the ZA-27 alloys for as-cast and heat treated specimens produced in accordance with the specifications of ASTM A-370 standards. The samples for the test were machined to round specimen configuration with 12 mm diameter and 60 mm gauge length. The test was carried out at room temperature using an Instron universal testing machine operated at a strain rate of 1.3 X10^{-3}/s. Charpy test was employed to conduct the impact test. The impact test was performed in accordance with ASTM E23 standards on the ZA-27 alloys for as-cast and heat treated specimens. Specimen of size 10 x10 x 55 mm^3 was used with a notch of dimension 2mm x 2mm x 45. Reported data correspond to an average of three measurements. Hardness tests of the ZA-27 alloys for as-cast and heat treated specimen were done using Vickers hardness tester at an applied load of 0.2 kg and the dwell time of 10 s. Five different readings were performed on each sample and readings within the margin of ±2% the average value taken as a measure of the hardness of the specimen.

D. Wear test

The tribological tests are carried out using a pin-on-disc wear tester (Model: TR-20, DUCOM) as per ASTM: G99-05. It is used to measure the volumetric wear rat of modified ZA27 alloy under dry non lubricated condition. The counterpart disc was made of quenched and tempered EN-32 steel having a surface hardness of 65 HRC. The specimens of size Ø10×33 mm were machined out from all the as cast and heat treated specimens. The track diameter of 80mm enabled the sliding speeds 2.5 m/ s, at constant applied load of 4kg and constant sliding distance of 2,500 m.

III. RESULTS AND DISCUSSIONS

Table 2 shows the Mechanical properties of ZA-27 alloy obtained from the experiments

Table 2: Mechanical properties of ZA-27 alloy

Composition	Type	Tensile strength (MPa)	% of elongation	Hardness (HRB)	Impact energy (J)
ZA-27/0.2% Mn	Furnace cool	410.23	10.46	61.33	2.67
ZA-27/0.2% Mn	As Received	398.06	10.45	69.46	2.28
ZA-27/0.2% Mn	Quenched	389.21	8.12	95.73	1.98
ZA-27/0.2% Mn	T6 type	408.38	11.35	98.27	2.04
ZA-27/0.5% Mn	Furnace cool	457.34	12.47	64.46	2.12
ZA-27/0.5% Mn	As Received	425.42	11.44	81.86	2.04
ZA-27/0.5% Mn	Quenched	386.41	10.23	90.36	1.24
ZA-27/0.5% Mn	T6 type	438.46	13.48	99.45	1.56
ZA-27/1% Mn	Furnace cool	394.24	8.32	80.16	2.43
ZA-27/1% Mn	As Received	349.34	7.41	98.2	2.26
ZA-27/1 % Mn	Quenched	385.61	6.72	108.64	1.09
ZA-27/1 % Mn	T6 type	412.35	9.58	114.23	1.17

A. Hardness

It can be observed from Fig 1, Rockwell hardness of the alloys increases with increase in the content of manganese. Enhance in the hardness can be recognized to the presence of hard Al-Mn precipitates, but also their shape and distribution. And also formation of fine lamellar, as long as the presence of manganese is detected, could contribute to the measured increase in hardness. T6 type heat treated specimens show highest hardness for all Mn content compared to quenched, as- received and furnace cool specimens.

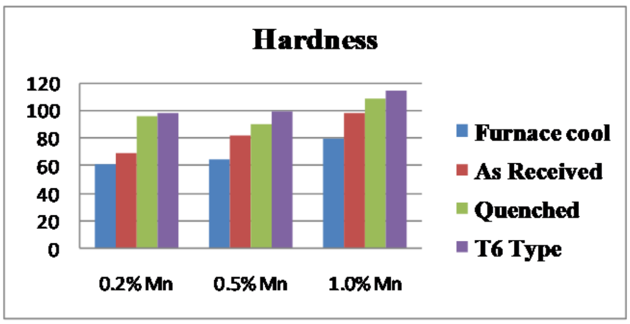

Fig.1: Effect of Mn content on hardness

B. Tensile strength

It can be observed from Fig 2 and Fig 3 at the room temperature, an obvious increase in the tensile strength and elongation with increase in Mn content of 0.5%, the decreased with further increase in the Mn content. This can be attributed for size and volume fraction of the hard phases increases with increase in the Mn content. Thus tensile strength first increases with increasing in the volume fraction of hard phases then decreases with the coarsening of the hard phases. Furnace cooled specimens show highest strength for all Mn content compared to T6 type heat treatment, as-received and quenched specimens. T6 type heat treated specimen's shows highest elongation when compared with rest of the specimens.

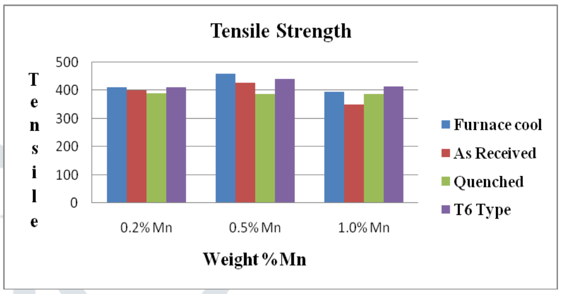

Fig.2: Effect of Mn content on tensile strength

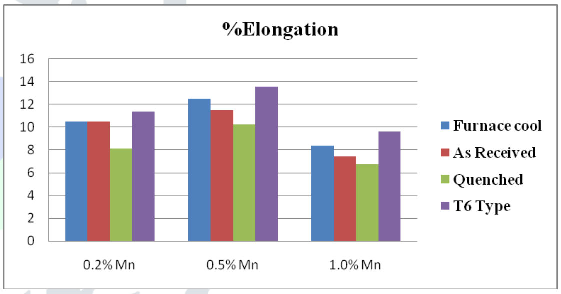

Fig.3: Effect of Mn content on % of elongation

C. Impact strength

It is observed from the Fig 4, the furnace cooled specimen shows higher impact energy compared to as-received and quenched specimens and T6 type heat treated specimens. Impact strength is nothing but the absorption of energy. Furnace cooled specimens have absorbed more energy than the other specimens due to its softness. On the other side, quenched specimens show lowest impact energy due to its hardness.

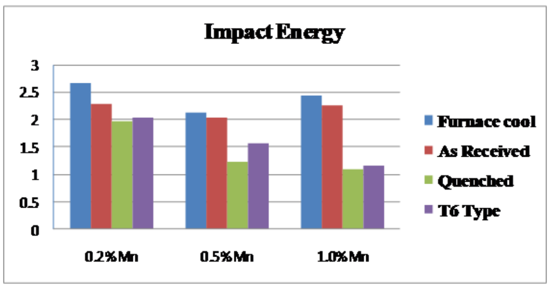

Fig.4: Effect of Mn content on Impact energy

D. Volumetric wear rate

The dry sliding wear behaivour experiments was conducted by using pin-on-disc testing apparatus at constant load of 4kg ,sliding speed of 2.5m/s and sliding distance of 2,500 m. From the fig 5, it is clearly understood that, T6 type heat treated specimens shows lower volumetric wear rate as compared with other specimens. This is due to increase in the elongation. The table 3 shows the volumetric wear rate for all specimens.

Table 3: Wear data

S.No	% Mn	Volumetric wear rate (mm^3/m)			
		Furnace cool	As-cast	Quenched	T6 type
1	0.2	0.00359	0.00107	0.0009	0.00024
2	0.5	0.00165	0.00059	0.00033	0.00015
3	1.0	0.00375	0.00084	0.00315	0.00045

During wearing actually instead of 100% of contact few asperities comes in contact with the sliding disc. Due to few asperities contact the stress on the asperities is very high and due to high stress micro weld takes place with the sliding disc. Under low sliding speed the residential contact time between the asperities with the sliding disc is more due to this more residential time the growth of micro welds is more hence under low sliding speed wear loss is more with increase in the sliding speed the residential time decrease and the corresponding micro weld growth reduced and result in decrease in the volumetric wear loss.

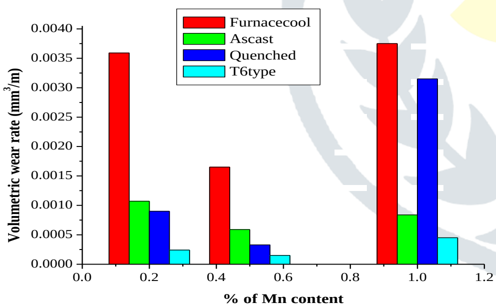

Fig.5: Effect of % of Mn content on volumetric wear rate

During sliding these adhered asperities tears from the surface and makes the surface rough and remove some of the material from the parent material. Under high operational conditions, adhesive wear mechanism is observed but the amount of material removal is little more than the low operational conditions are observed in Fig 6. The corresponding debris shows bigger size of debris as shown in Fig 7 and XRD is shown in Fig 8.

Fig.6: SEM micro graph of 0.2% Mn as received specimen, Speed-2.5 m/s, Nr. Pressure 0.49962 MPa

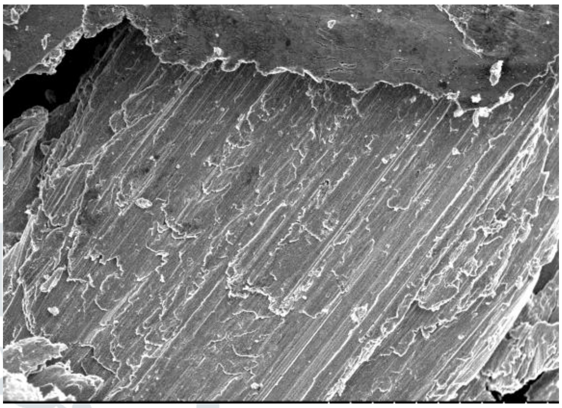

Fig.7: Wear debris of 0.2% Mn as received specimen, Speed-2.5 m/s, Nr. Pressure 0.49962 MPa

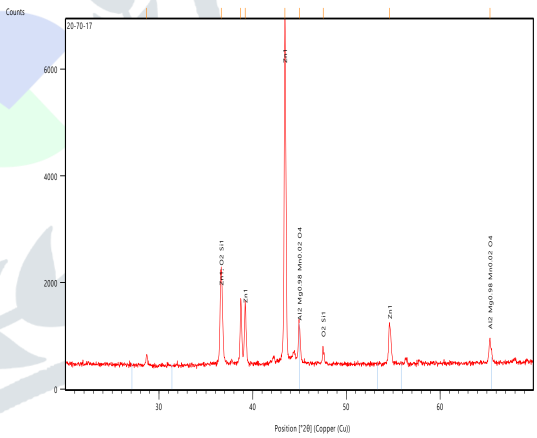

Fig.8: XRD results of 0.2% Mn as received specimen, Speed-2.5 m/s, Nr. Pressure 0.49962 MPa

CONCLUSIONS

Based on the experimental observations of present investigation, the following conclusions can be drawn.

1. T6 type heat treated specimens ZA-27/0.5% Mn alloy has observed minimum volumetric wear when compared with the other specimens.
2. Tensile strength, elongation and hardness have highest value for T6 type heat treated specimens when compared with the others.
3. Furnace cooled specimen have highest impact energy when compared with the others.
4. Adhesive wear mechanism is observed.

References

1. G. Amontons, Mem. Acad.T, Ser. A, (1699), pp 257-282.
2. N. P. Petrov, Friction in machines and the effect of the lubricant, Inzh. Ah, (1983) 71-140; 2 (1893) 227-279, 3 (1893) 377-436, 4 (1893), pp 535-564.
3. B. Tower, First report on friction experiments, Proc., Inst. Mech. Eng., London, (1883), pp 632-659.
4. O. Reynolds, on the theory of lubrication and its application to Mr. B Beauchamp Tower's experiments, Plilos. Trans. T. Society. London, 177 (1886), pp 157-234.
5. R.Holm, The frictional force over the real areas of contact, Wiss. Veroeff, Siemans Werken.17 (4) 1938, pp 38-42.
6. W.J. Schumacher, Corrosive wear principles, Mater. Perform. 23(7), (1993), pp. 50.
7. H. Czichos, Tribology- A Systems Approach to the Science and Technology of Friction, Lubrication and Wear, Elsevier, Amsterdam, 1978.
8. K.H. Habig, Advanced wear simulation in sheet forming, Elsevier, (1980),
9. pp 49 54.
10. Slobodan Mitrovic, Miroslav Babic, LLija Bobic, Fatima Zivic, Dragan Dzunic, Marko Pantic, Wear behaviour of composites based on ZA-27 alloy reinforced with graphite particles, 13th International conference on tribology, Kragujevac, Serbia, 15-17 May 2013.
11. Fei CHEN, Tong-min WANG, Zong- ning CHEN, Feng MAO, Qiang HAN, Zhi-qiang CAO, Microstructure, mechanical properties and wear behaviour of Zn−Al−Cu−TiB2 in situ composites, Trans. Nonferrous Met. Soc. China, 25,(2015), pp 103−111
12. G. Ranganath, S.C. Sharma, M. Krishna, and M. S. Muruli, A Study of Mechanical Properties and Fractography of ZA-27/Titanium-Dioxide Metal Matrix Composites, Journal of Materials
13. Engineering and Performance, 11(4), (2002), pp 408-413.
14. Cuvalc H., Bas H., Investigation of the tribological properties of silicon containing zinc–aluminum based journal bearings, Tribology International, 37, (2004), pp 433–440
15. Modi O. P., Rathod S., Prasad B. K., Jha A. K., and Dixit G., The influence of alumina article dispersion and test parameters on dry sliding wear behavior of Zinc-based alloy, Tribology International, 40, (2007), pp 1137-1146.
16. M. A. Savas, S. Altintas, The Microstructural control of cast and mechanical properties of Zinc-Aluminium alloys, Journal Material Science, Volume 28, (1993), pp 1775-1780.
17. A. Zyska, Z. Konopka, M. Łągiewka, M. Nadolski, Structure and selected properties of high-aluminium Zn alloy with silicon addition, Archives of foundry engineering, Vol. 11(3), (2011), pp 261-264.
18. K. J. Altorfer, Zinc-alloys compete with bronze in bearings and bushings, Metal Progress 122 (6), (1982), pp 29-31.
19. L. Nirmala, C. Yuvaraj, K. Prahlada Rao, Seenappa, Microstructural and Mechanical Behaviour of Zinc aluminium Cast Alloys, International journal of mechanical engineering, Vol. 4(4), (2013), pp 243-248.
20. E. Gervais, R. J. Barnhurst, C. A. Loong, An Analysis of Selected Properties of ZA Alloys, J. Met., Vol. 37(11), (1985), pp 43-47.
21. A. Pola, M. Gelfi, G. M. La Vecchia, L. Montesanom, On the aging of a hyper-eutectic Zn-Al alloy, Metalli non ferrosi, Vol. 4, (2015), pp 37-41.
22. Jim Birch, New alloys for zinc castings, J. Materials & Design, Vol. 11(2), (1990), pp 83-87.
23. Li Jian, E. E. Laufer, J. Masounave, Wear in Zn-Al-Si Alloys, Wear, Vol. 165(1), (1993), pp 51-56.
24. Pekwah Pearl Lee Temel Savaskan Emmanuel Laufer, Wear resistance and microstructure of Zn-Al-Si and Zn-Al-Cu alloys, Vol. 117(1), (1987), pp 79-89.
25. M Z Huq, J P Celis, "Expressing wear rate in sliding contacts based on dissipated energy", Wear, Vol. 252, (2002), pp 375-383.
26. J F Archad, J. Appl. Phys. Vol. 32, (1961), pp 1420.
27. E Rabinowciz, Friction and wear materials, wiley, New York, (1965).
28. T O Mulhearn, L E Samuels, Wear, Vol. 5, (1962), pp 478.
29. M A Moore, Abrasive wear, in: D A Rigney (Ed.), Fundamentals of friction and wear, American society of Metals, Metals Park, OH, (1980), pp 73.
30. D. Dowson. "Wear oh where" International Conference on Wear of materials, Vancouver, Canada, (1985), pp14-18
31. Kragelskii I. V. Friction and wear. Butterworth's, Washington, (1965).pp 264
32. L. S. Eyre. "Wear characteristics of metals", Tribology International, (1976). pp 203-212.