Journal of Information Systems Engineering and Management
2025, 10(1)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Impact of Si3n4 Addition on the Mechanical Properties of Zinc-Aluminium Composite

Fatima Firdous Nikhat[1*], K.Prashant G[2]

[1*]PhD scholar, Industrial & Production Engineering Department, PDA college of Engineering, Kalaburagi
[2]Professor, Industrial & Production Engineering Department, PDA college of Engineering, Kalaburagi

ARTICLE INFO

Received: 30 Nov 2024

Revised: 17 Dec 2024

Accepted :21 Jan 2025

ABSTRACT

This study investigates the influence of silicon nitride (Si_3N_4) ceramic particulates on the hardness, tensile strength, impact resistance, wear characteristics, and microstructure of reinforced zinc-aluminum composites. The composites were synthesized using the stir casting method, wherein both the particulates and the alloy matrix were preheated and melted prior to mixing. Compositions of Si_3N_4 particulates were varied at 0%, 1%, 2%, 3%, 4%, and 5% to fabricate the composites. A Vickers hardness tester was utilized to assess hardness, while a universal testing machine was employed to evaluate ultimate tensile strength. The experimental results clearly demonstrated an enhancement in the mechanical properties of the composites compared to the base zinc-aluminum alloy, with the most significant strength improvement observed at 5% reinforcement.

Keyword: *Si3N4; Stir casting; Zinc Aluminium; Metal Matrix Composites; Mechanical properties, Microstructure.*

1. INTRODUCTION

The development of the ZA (zinc-aluminum) alloys during the 1970's have radically changed zinc's product design and manufacturing capabilities. ZA-27 require special melting procedures and must be die cast like aluminum using the less efficient cold chamber die casting process. Distinguishing features of ZA alloys include high as-cast strength, excellent bearing properties, as well as low energy requirements for melting.
ZA alloys make good bearings because their final composition includes hard eutectic zinc-aluminium-copper particles embedded in a softer zinc-aluminium matrix. The hard particles provide a low friction bearing surface, while the softer material wears back to provide space for lubricant to flow, similar to Babaitt metal.
Nevertheless, there have been initiatives to create materials that possess superior properties compared to aluminum alloys and can perform effectively in situations where aluminum alloys may fail, such as under thermal stress, fatigue, high-temperature corrosion, and wear. In the pursuit of finding durable solutions to address the structural weaknesses that could emerge from the conditions mentioned above, composite materials are being explored [1].
The two main phases that make up metal matrix composites are chemically and physically distinct from one another, but they have amazing properties that aren't found in the individual constituent phases. Metal matrix composites based on aluminum are known for having better properties than their alloy. Strength and other improved qualities are primarily obtained when reinforced with a discontinuous ceramic phase, such as SiC, TiB_2, Al_2O_3, B_4C, etc[2]
The cobalt-base tribaloy alloys are important wear-resistant materials, especially for high temperature applications, because of the outstanding properties of the strengthened cobalt solid solution and the hard Laves intermetallic phase that make up the alloys[4].
The non-ferrous bearing materials are available for using for specific application. The choice can be made by comparing all the required properties for the particular application, design aspects of the bearing. There is no single best bearing material, every material promising individual property to meet particular service requirements [9].
The integration of Si_3N_4 particles into Zn-Al composites can profoundly influence their properties, notably their hardness, tensile strength, and resistance to wear and friction. The primary mechanisms by which Si_3N_4 enhances the mechanical properties of Zn-Al composites include its capacity to form a solid dispersion within the metal matrix, serving as a reinforcing phase that resists plastic deformation and wear during operation.

Journal of Information Systems Engineering and Management
2025, 10(1)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
Research Article

This introduction aims to examine the impact of Si_3N_4 addition on the mechanical properties of Zn-Al composites, elucidating the ways in which these ceramic reinforcements enhance the overall performance of the material. The focus will be on understanding the relationship between Si_3N_4 content, composite microstructure, mechanical behavior (such as hardness, tensile strength, and elongation).

2. EXPERIMENTAL WORK

A metal matrix composed of Zinc Aluminium alloy and ceramic particulates of Si_3N_4 is needed to create the composites with 1, 2, 3, 4, and 5 weight percent of particulates as outlined in Table 1 below. First, the furnace was heated, and the measured amount of aluminum billet was melted to reach the desired superheating temperature of 850°C (which is above the melting point of the alloy) using a graphite crucible in the charged furnace.
The specified amount of Si_3N_4 particulates was preheated to approximately 400°C in an oven to oxidize and degas the surface layer, thereby enhancing wettability, ensuring uniform dispersion, and minimizing porosity. The molten materials were placed in a crucible and transferred to another one equipped with a separate stirring mechanism. The graphite stirrer was subsequently immersed into the molten pool and gradually stirred to create a vortex. Next, pre-heated Si_3N_4 was introduced into the molten metal, ensuring that the temperature remained at 700°C.
To promote good wettability, 0.03% by weight of magnesium powder was incorporated while continuously stirring at a speed of 400 rpm for 5 minutes. The stirring was continued for an additional 5 minutes until a homogeneous mixture was obtained.
The resulting molten composite from the stirring apparatus was then withdrawn and poured into a cast iron die at a temperature of 700°C. Sufficient precautions were taken to guarantee that the melt fully solidified within the mold. Once solidification was achieved, the composites were removed from the mold and accurately machined to the specified shapes and dimensions for various mechanical evaluations.

Table 1: Chemical Composition of ZA-alloys in weight percent

Sample Nomenclature	**Aluminium in wt.%**	**Magnesium in wt.%**	**Copper in wt.%**	**Silicon Nitride in wt.%**	**Zinc in wt.%**
ZA-27/0	27	0.03	2-2.5	0	Balance
ZA-27/1	27	0.03	2-2.5	1	Balance
ZA-27/2	27	0.03	2-2.5	2	Balance
ZA-27/3	27	0.03	2-2.5	3	Balance
ZA-27/4	27	0.03	2-2.5	4	Balance
ZA-27/5	27	0.03	2-2.5	5	Balance

The above samples of mentioned compositions have been produced with the help of Induction furnace as shown in below figure.1 and Silicon Nitride of various weight percentages is added between 0% to 5 % and Silicon nitride(Si_3N_4) is shown in the figure 2.

Fig.1 Induction furnace with Crucible

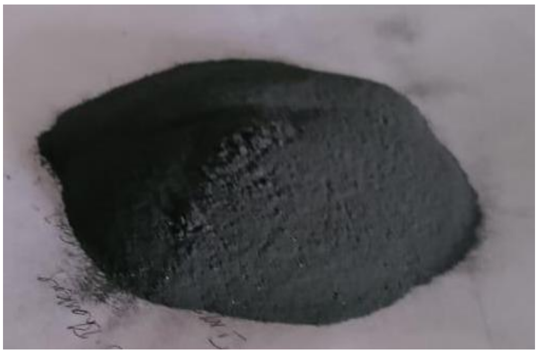


Fig.2 Silicon Nitride (Si_3N_4)

Journal of Information Systems Engineering and Management
2025, 10(1)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
Research Article

Fig.3 Cast Iron Die with cast

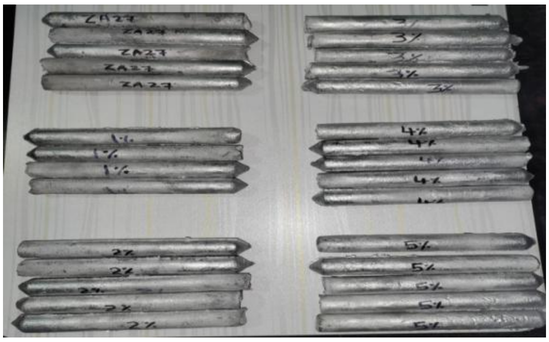


Fig.4 Casted Specimens

The Zinc Aluminium has been taken in the Graphite ceramic crucible as shown in figure 1. To the crucible Silicon Nitride has been added as per the quantities mentioned in the table.1Then the mixture is heated to 850° C. Then the molten metal with reinforcement is poured into the Cast Iron die (As shown in figure.3) to get the sample pieces of different compositions (As shown in Fig.4).

3. TESTING OF TENSILE, IMPACT AND HARDNESS PROPERTIES:

The prepared tensile samples had 12.5mm gauge diameter and 60 mm gauge length. Tensile tests were conducted as per ASTM A-370 standards at ambient temperature at a strain rate of 1.3x10-3/s using a universal testing machine. Charpy test was employed to conduct the impact test. The impact test was performed in accordance with ASTM E23 standards. Specimen of size 10 x10 x 55 mm3 was used with a notch of dimension 2mm x 2mm x 450.

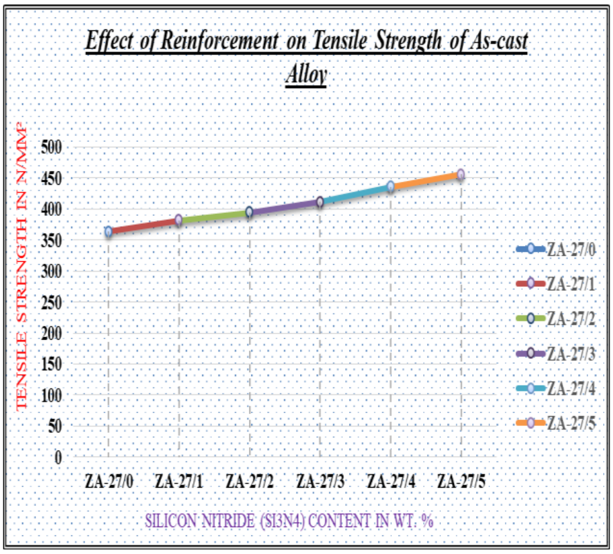
Reported data correspond to an average of three measurements Hardness of metallographically prepared samples was measured using a Micro Vickers hardness tester consists of 10 & 40x magnification and automatic turret mechanism. Fully computerized and automated software enhance the quality of the testing. Hardness test was carried according to the ASTM E-10 standards. The test results are as shown in the following table2.

Table 2: Experimental results of various composition of silicon nitride in ZA-27 alloy for as-cast specimens

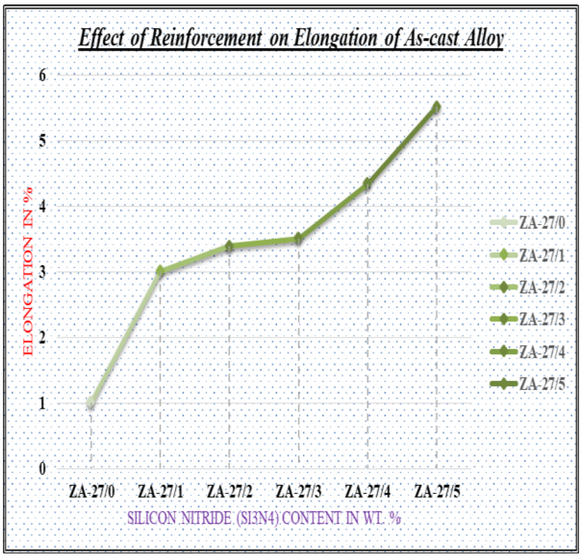
Sl.No.	Sample Nomenclature	Avg.UTS (N/mm^2)	Avg. Percent Elongation	Avg. Impact strength in J	Avg. HVN
1	ZA-27/0	363.38	1.01	24.19	102.51
2	ZA-27/1	381.94	3.01	32.22	110.52
3	ZA-27/2	394.89	3.39	37.69	120.47
4	ZA-27/3	411.26	3.51	42.73	132.49
5	ZA-27/4	435.77	4.34	46.31	140.63
6	ZA-27/5	455.80	5.52	51.12	145.33

Journal of Information Systems Engineering and Management
2025, 10(1)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

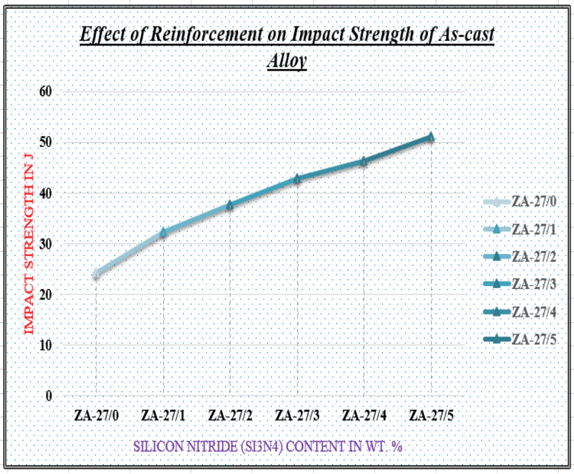
Research Article



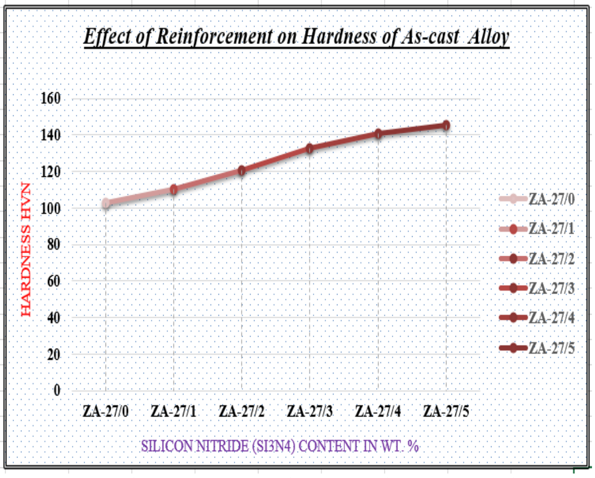
Graph.1: Percentage change in Si_3N_4 vs. Tensile strength



Graph.2: Percentage change in Si_3N_4 vs. Elongation



Graph No.3: Impact Strength vs. % Change in Si_3N_4



Graph No 4: Hardness Value vs. % Change in Si_3N_4

4. MICROSCOPY STUDY:

Microstructural characterization of the alloys was carried out using optical microscopy on samples. The specimens were polished according to standard metallographic practice and etched. The etching agent used was consists of 200 g CrO3, 15 g Na2SO4, 1000 ml H2O.

Journal of Information Systems Engineering and Management
2025, 10(1)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

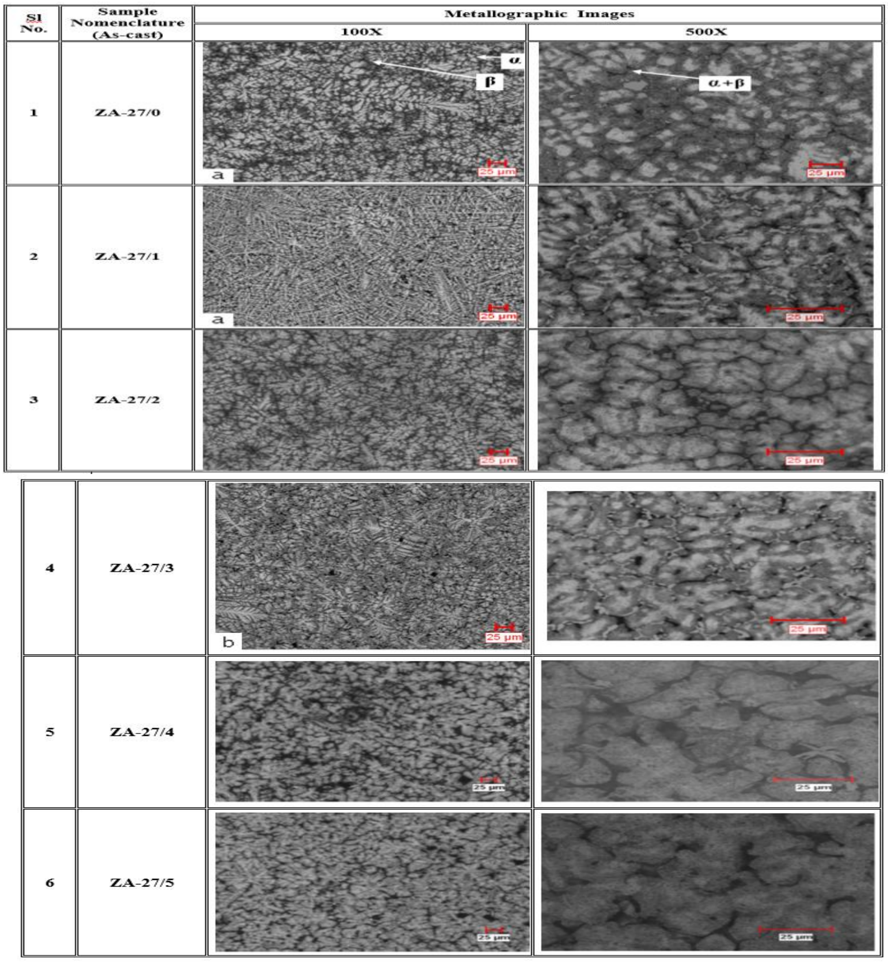


Fig. 5: Metallographic images of various composition of silicon nitride in ZA-27 alloy for as-cast specimens

The microstructure of the ZA-27 alloy consist of a cored aluminum rich matrix (α, FCC) and an interdendritic zinc-rich phase (η, HCP). The ZA-27 based alloy fall in the hypereutectoid range of the zinc-aluminium phase diagram. The phase first to form upon solidification is primary α (solid solution of zinc in aluminium). In the process the excess zinc is rejected to the surround liquid, which transform to eutectic zinc + aluminium. Subsequently, the aluminium solid solution under goes a eutectoid solution to form a mixture of α – aluminum + zinc.

5. RESULTS AND DISCUSSIONS

After observing the graph no 1 and 2, it can be said that the change in Si_3N_4 has changed the Tensile strength of the composite material .Initially at 0% of Si_3N_4 the Tensile strength was 363.38 N/mm². After adding 1 % of Si3N4 by weight the Tensile strength is 381.94N/mm². And after increasing the reinforcement percent to 2%, 3%, 4% and 5% the tensile strength and ductility of the composite has increased. It is the result of proper wettability of the reinforcements and the proper bonding between the reinforcement particle and the metallic Aluminium alloy. The adhesive force between the reinforcement and the metal matrix will resist the deformation of the material prepared hence it enhances the tensile strength of the composite material prepared.

From the graph.3 it can be seen that the Impact strength of the metal matrix composite could be enhanced with the addition of reinforcement like Si_3N_4.The energy needed to fail the composite material increases with the increase in percentage from 1% to 5 %.The proper bonding between the reinforcement and the metal matrix will enhances the impact strength of the composite. After applying the sudden load some amount of energy is consumed the break of the bond between the matrix and reinforced particles. Because of this reason the enhancement of impact strength could be seen. The maximum energy absorbed is 51.12 J at 5% of reinforcement in the Zinc Aluminium Matrix.

From the graph 4 it can be seen that the initial hardness value of un reinforced Zinc Aluminium Alloy is 102.51HVN and it has been increased to 145.33HVN .Which indicates that the force needed for the Indentation of the prepared composite material sample increases with the increase in Si_3N_4 Percentage by weight. The hardness test gives information about the resistance offered by the material for the Indentation force applied on it. Stronger the material then the force needed for the indentation will be more. From the above hardness test it could be observed that the force needed to cause the indentation has gone up after the addition of Si_3N_4 in increasing order.
The results obtained from this investigation indicate that the addition of silicon nitride in the range 1–5 wt. % caused grain refinement to certain extent and increased the volume fraction of eutectic phase accompanied by a more regular form as it shown in figure 5.

6. CONCLUSION

The Zinc Aluminium - Si3N4 composites were developed successfully using liquid metallurgy route with varying weight percent of reinforcement, the mechanical properties were investigated. The mechanical properties of the composites increased with the volume fraction of the Si3N4 particulates, the ultimate tensile strength and the yield propagation was found to increase with the increase in weight percent of the reinforcement. The Zinc-Aluminium is having a better cast ability; because of this its properties can be changed by adding reinforcement to it in varies quantities.
To mix the reinforcements to the metal alloy, the stir casting method is the best suitable method. From the above study it can also be seen that the mechanical Properties like Tensile strength, Impact strength and Hardness of the composite materials could be enhanced by adding reinforcements to it in the increasing order from 1% to 5%.As the percentage goes more than 5% by weight it could be found that the lump of Si_3N_4 do forms at the bottom of the graphite crucible because of density issues and stirring speed constraints.
The modified alloys have a fairly uniform distribution of the intermetallic particles. The Al_3Co_4 phase is formed in ZA-27/1, ZA-27/2, ZA-27/3, ZA-27/4 and ZA-27/5 are very hard intermetallic phase. The morphology of the zinc based cobalt alloys exhibit both flaky and rod shape with an increase in silicon nitride.

REFERENCES:

[1] Zulkuf Balalan And Mehmet Kaplan, University of Firat, Faculty of Technical Education, Department of Metallurgy, 23119 Elazıg, Turkiye, "Investigation of the microstructure and wear properties of a cast Zinc-Aluminium alloy" Volume 2, No 1, 75-81, 2007.
[2] K. Zhang, N.Y. Tang and A.B. Filc, Teck Cominco Metals Ltd. Product Technology Centre ,Sheridan Science and Technology Park ,2380 Speakman Drive,Mississauga, Ontario, Canada L5K 1B4, "A practical approach to enhance wear resistance of bearings in molten Zinc". Vol. 10, No 1, 2003
[3] Mukundadas Prasanna Kumar, Kanakuppi Sadashivappa, Gundenahalli Puttappa Prabhukumar, Satyappa Basavarajappa, "Dry sliding wear behaviour of garnet particles reinforced Zinc-Aluminium alloy metal matrix composites", ISSN 1392–1320 Materials Science (Medžiagotyra). Vol. 12, No. 3. 2006.
[4] Rong Liu, Matthew X. Yao, Prakash C. Patnaik and Xijia Wu, Department of Mechanical and Aerospace Engineering, Carleton University, "Effects of heat treatment on mechanical and tribological properties of cobalt-base tribaloy alloys", Received: 30 May 2005, Revised: 8 June 2005.
[5] P. Choudhury, S. Das and B. K. Datta, Department of Metallurgical and Materials Engineering, Indian Institute of Technology, Kharagpur,India,"Effect of ni on the wear behavior of a Zinc-Aluminum alloy",Volume 37, Number 10 / May, 2002.
[6] K. Zhan,Teck Cominco Metals Ltd., Product Technology Centre, 2380 Speakman Drive,Mississauga, Ont., Canada L5K 1B4, " Wear of cobalt-based alloys sliding in molten Zinc" Volume 255, Issues 1-6, August-September 2003.
[7] M. A. Savas and S. Altintas, "The microstructural control of cast and mechanical properties of Zinc-Aluminium alloys" ,Volume 28, Number 7,1993.
[8] M. Babic, S. Mitrovic, R. Ninkovic, "Tribological Potencial of Zinc- Aluminium Alloys Improvement" ,Volume 31, No. 1&2, 2009.
[9] Dr. P. Sriram, Joint M. D., Ch. Visweswara Rao, Rapsri Engineering Industries Ltd. "Recent developments in cast non ferrous bearing materials",February 2006.
[10] Temel Savas Kan and Ali Pas "Mechanical and sliding wear properties of Zinc based alloys", Tribology International 37(2004).

[11] M. Durman, S. Murphy, “An electron metallographic study of pressure die-cast commercial Zinc-Aluminum-based alloy ZA27”, Material science 32(1997), 11603–11611.
[12] W. Hongmin, L. Meihua, C. Yungui, W. Yigui, “The time–temperature-transition (TTT) of ZA27 alloy”, Material science 15(1996), 1008.
[13] T .Savaskan, M.S. Turhal, “Relationships between cooling rate, Copper content and mechanical properties of monotectoid based Zn–Al–Cu alloys”, Materials Characterization 51 (2003), 259– 270.
[14] Ahmet Turk, Can Kurnaz and Huseyan Sevik, “Comparision of wear properties of modified ZA-8 alloys and conventional bearing bronze”, Materials & Design 28 (2007), 1889-1897.
[15] Pekwah Pearl Lee. Emmanuel Laufer, “Wear resistance and Microstructure of Zn-Al-Si and Zn-Al-Cu alloys”, Wear 117 (1987), 79-89.
[16] Prasad B. K,” Effect of microstructure on the sliding wear performance of Zn – Al – Ni alloy”, wear 240 (2000), 100 – 112.
[17] Prasad B. K. A.K.Patwardhan and A.H.Yegneswaran, “Influence of heat treatment parameters on the microstructure and properties of some Zinc – based alloys”, Material science 31 (1996), 6317 – 6324.
[18] Li jian, E E Laufer and J Masounave, “wear in Zn – Al – Si alloys”, wear 165 (1995), 51- 56.
[19] Rosiza kovacheva, Russi dobrev, Stoyan zadgorski and Albena lilova, “Phase transformation in Zn – Al – Cu Alloys”, Material characterization 31(1993), 217-224
[20] Temel Savas Kan and Zeki Azakh, “An investigation of lubricated friction and wear properties of Zn – 40Al – 2Cu – 2Si alloy in comparison with SAE 65 bearing bronze”, Wear 264(2008), 920-928.