Investigation of Wear Properties of Boron Carbide and CNT Hybrid Reinforced Copper Metal Matrix Composites

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***Abstract*-The current work focuses on the influence and contribution of multi-walled carbon-nanotube (MWCNT) and boron carbide (B_4C) to the wear properties of copper matrix composites. Different weight fractions of nano- B_4C and MWCNT-reinforced copper composites were prepared using the stir casting methodologies. Wear test were conducted as per ASTM standards G99- 95a.The addition of reinforcements showed enhancements wear resistance of the composites due to the uniform dispersion of the secondary reinforcement in the copper matrix and the self-lubricating effect of the MWCNTs. Further the weight of the composites decreased with the strength characteristics increasing leading to the enhancement in strength to weight ratios of the composite specimens.Reinforcement percentage should be less than 10% for Boron Carbide and 2% for CNT, more than 10% reinforcement will not mix with the casting properly and there is a chance of agglomeration of particles. The effects of the nanoparticle distribution in the matrix and the dispersion of the composites were characterized using high-resolution scanning electron microscopy. The results of experiments highlight the use of experiential reinforcing limits of B_4C on the mechanical behavior and wear characteristics of copper composites.**

***Keywords* – Copper, Boron carbide, Carbon Nanotubes (MWCNTs), Stir Casting, Wear rate.**

I. INTRODUCTION

Metal matrix composites are exciting areas of research in which reinforcements of hard ceramic particles are added to improve wear resistance and mechanical performance.The optimum ratio usage of the reinforcement particles could assist wear performance with toughness. Matrix materials of the MMCs generally selected for their high thermal conductivity and ductility properties as copper, nickel and aluminum and the reinforcement materials should be harder than matrix for the supporting the structure of composite such as SiC, B4C, CNT, Al2O3 and TiC. Copper is considered as an ideal matrix for composites due to its properties of high electrical and thermal conductivity and is widely used in industrial applications. However, the relatively low hardness and strength and poor wear resistance of copper are crucial factors that limit its extensive application. These distinct shortcomings could be avoided by incorporating reinforcement particles into the copper matrix. In this study, copper and B4C/CNT was selected as a matrix and reinforcement materials respectively. B4C particles have high impact and wear, low density, high melting point, and excellent resistance to chemical agents as well as high capability for neutron absorption make boron carbide attracting much attention as an acceptable reinforcement. CNT are at least 100 times stronger than steel, but only one-sixth as heavy, so nanotube fibers could strengthen almost any material. Nanotubes can conduct heat and electricity far better than copper.The main objective of this work is to evaluate the combined effect ofthe higher hardness material (B4C: 1–5%) and superconductive material (MWCNTs: 0.5 – 1.5%) as reinforcements in the copper matrix for the improvement of wear performance with a pin-on-disc wear testing method.Copper-based materials are widely used in many industrial applications because of their good wear resistance and friction ductility, remarkable corrosion resistance and self-lubrication properties such as sliding bearings, sleeves, brushes and other components.

II. MATERIALS PROCUREMENT

Copper

Copper was procured in the form of billets. It has high thermal conductivity and wear resistance. Copper has a good ductility and by cold deformation it is possible to reach the strength values close to the strength values of soft steel. Copper is heavily utilized by the electrical and mechanical industries because of its high thermal conductivity and strength.

Figure-1 shows copper billets cut into small piecesused in the experiments to prepare samples.

Fig-1: CopperBillets

Boron Carbide

Boron carbide is an extremely hard and covalent material used in tank or armour, bullet proof vests, engine sabotage powder as well numerous industrial applications.With a Vickers hardness of >30GPA, it is one of the hardest known materials, behind cubic boron nitride and diamond. B4Cwith particle sizes near 100nm which have an effect on the reduction in wear and increase in mechanical properties was procured. Boron carbide powder is mainly produced by reacting carbon with B2O3 in an electric arc furnace, through carbon-thermal reduction or by gas phase reactions. Boron carbide is used in refractory application due to its high melting point and thermal stability.It is used as abrasive powders and coating due to its extreme abrasion resistance.

Fig-2: Boron Carbide

Carbon Nanotube

Carbon nanotubes are allotropes of carbon with a cylindrical nano structure.These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. It has extraordinary thermal conductivity, mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials. CNT is used in fabrications of energy storage, super capacitors, field emission transistors and high performance catalysis. Some of the extensive applications of CNT are aero bars, wind turbines, marine parts, ice hockey sticksand baseball bats.

Fig.3: Multi walled Carbon Nanotubes

III. EXPERIMENTAL DETAILS

Composite materials are widely used in many industrial applications for its high mechanical, wear and corrosion properties. Composite materials exhibit high durability and strength to fabricate complex shapes. Boron carbide exhibits low density and excellent wear resistance and hardness. CNT possess high tensile strength with high electrical conductivity. The mixture structure of composites utilized as a part of the present study is accounted for in the Table 1. Copper was procured from Fenfee Metallurgicals, Bangalore and both Boron Carbide and CNT was procured from Go Green Products from Chennai.

The composites are manufactured by following steps:

1. Casting.
2. Machining.
3. Testing.

Casting

The microstructure of any material is a complex function of the casting process and subsequent cooling rates. The fabrication of composites materials is one the most challenging and difficult task. Stir casting technique of liquid metallurgy was used to prepare Copper Alloy Composites.

The copper billets were loaded in the graphite crucible and placed in the coke fired furnace and melted for a temperature range of above 1500°C. Fig. 4 shows the casting setup and the furnace. Table 1 shows the varying composition of reinforcement used during casting. Stirrer was introduced into the molten metal to create a vortex and rotated at a speed of 200 – 300 RPM. The preheated particulates of CNT and Boron Carbide were introduced into the vortex of molten metal and stirred well. The molten metal was then degassed using Hexochloro ethane tablets for about 8 min. the molten metal is poured to the die and allowed for solidification and the cast specimens is removed from the die.

Fig 4: A stir casting setup as shown in Figure, consist of a Coke fired Furnace and a stirrer assembly.

Models	Reinforcements		
	Copper in %	CNT in %	Boron Carbide in %
C0	100	0	0
C1	98.5	0.5	1
C2	96.5	0.5	3
C3	94.5	0.5	5
C4	98.0	1.0	1
C5	96.0	1.0	3
C6	94.0	1.0	5
C7	97.5	1.5	1
C8	95.5	1.5	3
C9	93.5	1.5	5

Table 1: Percentage of Reinforcements

Machining

The casted specimens were machined on a Lathe according to ASTM standards for Wear Test.

The specimens are fabricated as per ASTM standards ASTM G99 standards with a diameter of 6 mm and a length of 30 mm and it is shown in the Fig. 6

Fig 5: Casted composites

Fig 6: Wear test specimens

Testing

The wear test was conducted using a pin-on-disc computerized wear testing machine as shown in figure in accordance with ASTM standards G99-95. The test uses the specimens of diameter of 6mm and length 30mm machined from the cast specimens.

Prior to testing and measuring or weighing,clean and dry the specimens to remove all dirt and foreign matter from the specimens. Insert the disk securely in the holding device so that the disk is fixed perpendicular (61°) to the axis of the resolution in order to maintain the necessary contact conditions.Add the proper mass to the system lever to develop the selected force pressing the pin against the disk.Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disk. Stop the motor.Set the revolution counter to the desired number of revolutions.Begin the test with the specimens in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted or restarted

Remove the specimen and clean off any loose wear debris. Note the existence of features on or near the wear scar such as: protrusions, displaced metal, discoloration, micro cracking or spotting.Re-measure the specimen dimensions to the nearest 2.5µm or reweigh the specimens to the nearest 0.0001g.

IV. RESULTS AND DISCUSSIONS

The wear property of the copper composites developed by varying percentage of CNT and B_4C is analyzed from the pin on disk wear testing method. The wear rate of the specimens varies due to presence of reinforcement in varying composition and the reinforcement used has increased the wear resistance of the copper composites. The results clearly show that with the addition of boron carbide, the hardness values increases and hence the wear decreases but with the addition of CNT, the hardness value decreases initially however it increases with the addition of CNT furthermore from 0.5 to 1.5%. This essentially is attributed to the fact that micro-coring or segregation adds up to increase in hardness and decrease in wear rate. The graphs represent the wear rate at different loads and speeds.

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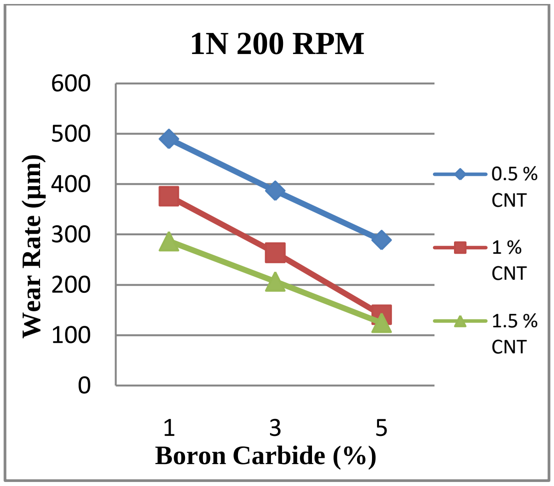

Fig. 7 Wear rate decrease as the percentage of CNT and B4C increases at 1 N load and 200rpm at track diameter of 100mm.

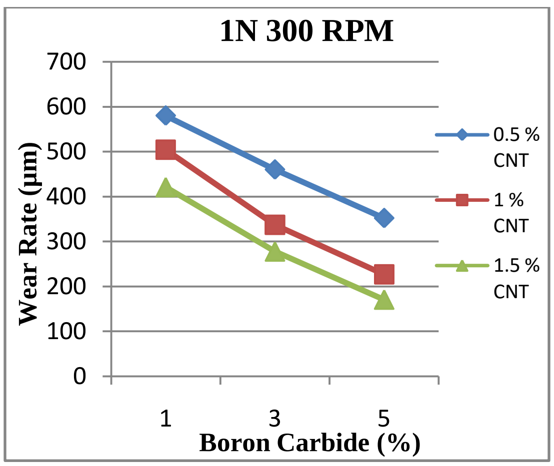

Fig. 8 Wear rate decrease as the percentage of CNT and B4C increases at 1 N load and 300 rpm at track diameter of 100mm.

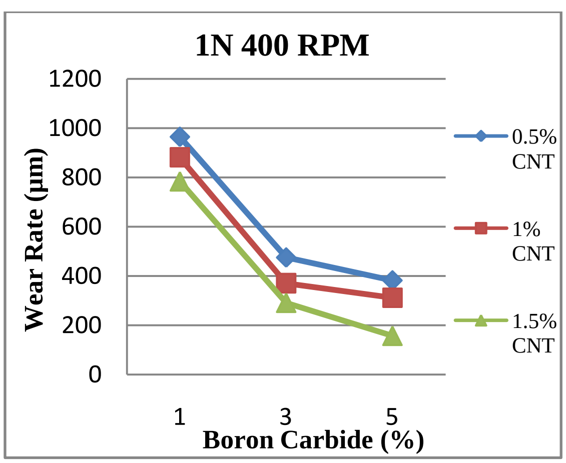

Fig. 9 Wear rate decrease as the percentage of CNT and B4C increases at 1 N load and 400 rpm at track diameter of 100mm.

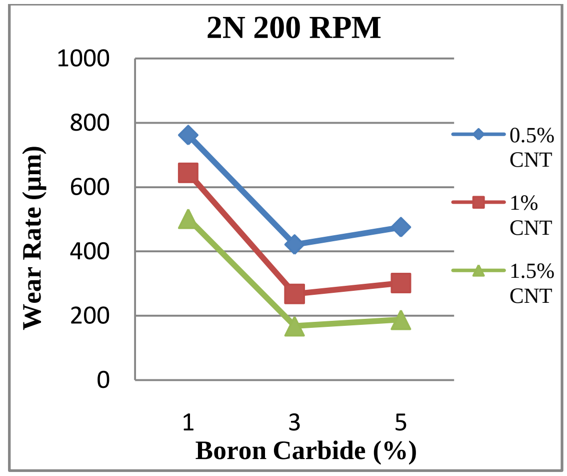

Fig. 10 Wear rate decrease as the percentage of CNT and B4C increases at 2 N load and 200 rpm at track diameter of 100mm.

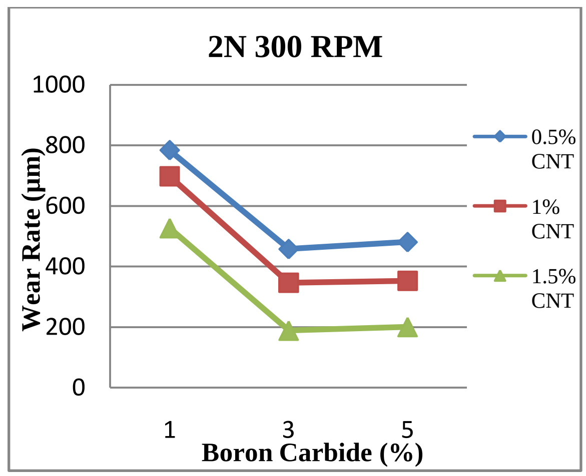

Fig. 11 Wear rate decrease as the percentage of CNT and B4C increases at 2 N load and 300 rpm at track diameter of 100mm.

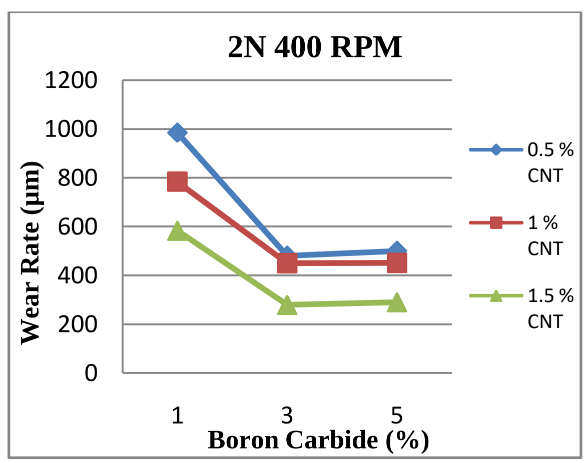

Fig. 12 Wear rate decrease as the percentage of CNT and B4C increases at 2 N load and 400 rpm at track diameter of 100mm.

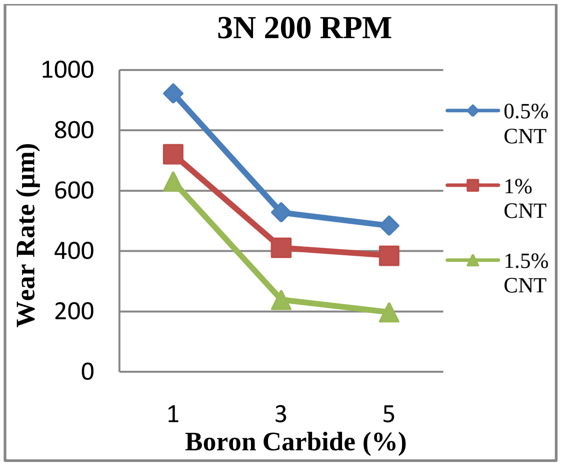

Fig. 13 Wear rate decrease as the percentage of CNT and B4C increases at 3 N load and 200 rpm at track diameter of 100mm.

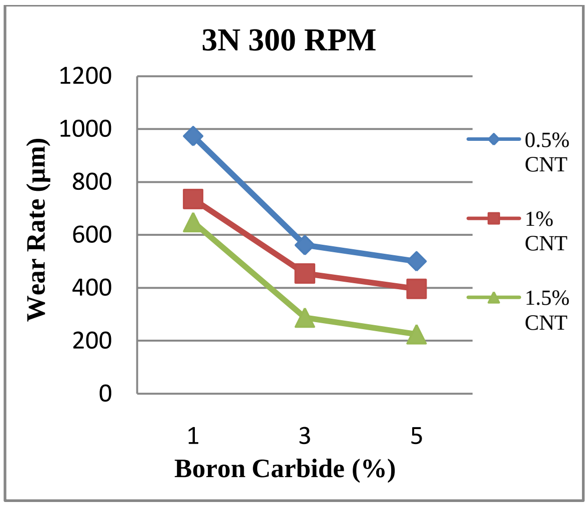

Fig. 14 Wear rate decrease as the percentage of CNT and B4C increases at 3 N load and 300 rpm at track diameter of 100mm.

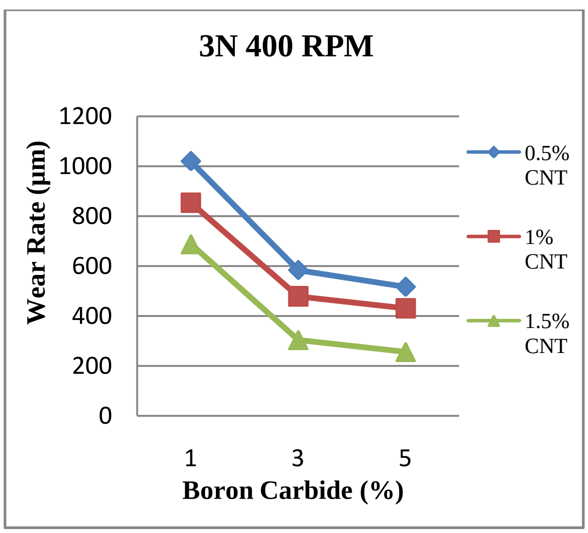

Fig. 15 Wear rate decrease as the percentage of CNT and B4C increases at 3 N load and 400 rpm at track diameter of 100mm.

Effect of CNT and B4C on wear rate

The severe wear is a serious problem with practical importance because the catastrophic nature of the wear in the post-transition region renders the tribo-components like bearings and cylinder liners unfit for further use. The presence of reinforcement has been reported to retard the mild to severe wear transition of the composites at higher loads. In the present case too, the loads at which the transition occurred were found to be much higher.

It is observed from the figures that the wear rate of the composites reduced with the increase in reinforcement content. The reduction in wear rate is by as much as 30 to 40% as content of the CNT (1 to 1.5%) and B4C (1 to 5%) varied. The improvement in wear resistance of the composites at low loads is attributed due to the presence of reinforcement, which form a thin film at the contact surface between the composite and the counter face.

The significant improvement in the wear resistance of the composites in the present case may also be due to the type of the reinforcement used. Wear rates for the composites of different composition at different loads and speed is shown in the table 2, 3& 4.

Models/Wear Rate (µm)	LOAD (1N)		
	Speed (RPM)		
	200	300	400
C1	490	580	965
C2	387	460	475
C3	289	352	382
C4	376	504	881
C5	264	337	371
C6	141	227	312
C7	287	421	784
C8	207	278	291
C9	125	171	157

Table 2: Wear Rates at 1N Load

Models/Wear Rate (µm)	LOAD (2N)		
	Speed (RPM)		
	200	300	400
C1	762	784	985
C2	422	458	481
C3	476	481	501
C4	645	698	784
C5	268	347	451
C6	302	353	452
C7	502	527	584
C8	168	189	280
C9	188	201	291

Table 3: Wear Rates at 2N Load

Models/Wear Rate (µm)	LOAD (3N)		
	Speed (RPM)		
	200	300	400
C1	922	974	1020
C2	528	562	584
C3	484	501	517
C4	721	736	854
C5	411	455	479
C6	385	397	431
C7	631	649	689
C8	239	288	305
C9	198	225	257

Table 4 : Wear Rates at 3N Load

V. CONCLUSIONS

The recently developed hybrid composites have been considered as candidate materials for applications in severe environments confronting modern technologies. MMCs have greater practical interest compared to other composites. MMCs feature with reinforcement compositional variations to metal and leads to the unique advantages of a smooth transition in thermal stress across the thickness and minimized stress concentration at the interface of dissimilar materials. It also enhances the thermal conductivity and thermal expansion properties in many applications.

The present work on preparation of CNT and B4C reinforced Copper metal matrix composite by stir casting and evaluation wear characteristics has led to following conclusions.

- The effect of CNT and B4C particles on the sliding wear resistance in Copper alloys varies with the applied load and speed.
- Wear rate increased with the increase in speed and load for every combination of the composite. However with CNT being the main reinforcement with addition of CNT wear rate has reduced marginally. Addition of B4C also to some extent decreased the wear rate but CNT plays a major role in reducing the wear rate which is a good sign for production of low cost material.
- Above the critical load, transition to severe wear occurs in unreinforced matrix alloy. But the reinforced MMCs have superior wear resistance.
- The best wear resistant combination is at 5% of B4C and 1% &1.5% of CNT as consideration.
- In material Metal-metal and metal-particle wear resistance increased with increasing distance from the centre of the specimen. Worn surface examination of the material revealed formation of iron rich transfer layer during metal metal wear test. Abrasive wear progressed by grooving action of the abrasion grains. Abrasion resistance of the composite was decreased with the size of particle. Composites exhibited abrupt increase in abrasion rate for higher speeds and loads.

REFERENCES

[1]. Martel, R.; Derycke, V.; Lavoie, C.; Appenzeller, J.; Chan, K.; Tersoff, J.; Avouris, Ph. (2001). "Ambipolar Electrical Transport in Semiconducting Single-Wall Carbon Nanotubes". Phys. Rev. Lett. 87 (25): 256805. Bibcode: 2001PhRvL.87y6805M. doi:10.1103/PhysRevLett.87.256805. PMID 11736597.

[2]. Zhang FX, Xu FF, Mori T, Liu QL, Sato A, Tanaka T (2001). "Crystal structure of new rare-earth boron-rich solids: REB28.5C4". J. Alloys Compd. 329: 168–172. doi:10.1016/S0925-8388(01)01581-X.

[3]. Solozhenko, V. L.; Kurakevych, Oleksandr O.; Le Godec, Yann; Mezouar, Mohamed; Mezouar, Mohamed (2009). "Ultimate Metastable Solubility of Boron in Diamond: Synthesis of SuperhardDiamondlike BC5". Phys. Rev. Lett. 102 (1): 015506.

[4]. S.F. Moustafa, A. Torres-Islas, S. Serna, M. Acosta-Flores, R.A. Rodriguez-Diaz, J. Colin, Corrosion, electrical and mechanical performance of copper matrix composites produced by mechanical alloying and consolidation, Int. J. Electrochem. Sci., 10 (2015), pp. 1728-1741.

[5]. Anish Upadhyaya, A. Kumar, P.R. Sengupta, P.K. Dutta, R.B. Mathur, Improving the mechanical and thermal properties of semi-coke based carbon/copper composites reinforced using carbon nanotubes, J. Adv. Mater. Lett., 5 (5) (2014), pp. 265-271.

[6]. Kovalchenko, P. Ozga, W. Maziarz, J. Pstrus, B. Kania, P. Bobrowski, et al., Microstructure and properties of bulk copper matrix composites strengthened with various kinds of graphene nanoplatelets, Mater. Sci. Eng., A, 628 (2015), pp. 124-134.

[7]. Gongjun, L. Liu, Friction and wear properties of copper based composites reinforced with micro and nano-sized Al2O3 particles, 8th Int. conf. Tribol., 30th Oct-1st Nov. 2014, Sinaia, Romania, 2014, pp. 357–358.

[8]. J. Fathy, S. Emmer, J. Bielek, Thermal conductivity of Cu–graphite composites, Int. J. Therm. Sci. 90 (2015) 298–302.

[9]. F. Tang, J. Ying, Y. Wang, S. Du, Z. Liu, Q. Huang, Effects of graphene content on the microstructure and properties of copper matrix composites, Carbon 96 (2016) 836–842.

[10]. W. Tjong, L. Zhou, K. Peng, J. Zhu, L. Wan, Effect of tungsten addition on thermal conductivity of graphite/copper composites, Compos. Part B Eng. 55 (2013) 1–4.

[11]. H. Yin, M. Chug, H. Zhang, A. Tang, B. Ren, X. He, Microstructure and thermal properties of copper matrix composites reinforced by chromium-coated discontinuous graphite fibers, Appl. Therm. Eng. 73 (2014) 739–744.

[12]. D.D. Zhou, Y.F. Kwon, Z.J. Lu, Microstructural characteristics and formation mechanism of direct laser-sintered Cu-based alloys reinforced with Ni particles, Mater. Des. 30 (2009) 2099–2107.

[13]. W. Manchang, M. Heilmaier, L. Schultz, High-strength pearlitic steel–copper composite wires for conductors in pulsed high-field magnets, Mater. Sci. Eng., A 303 (1–2) (2001) 127–133.

[14]. W. Grünberger, M. Heilmaier, L. Schultz, High-strength, high-nitrogen stainless steel–copper composite wires for conductors in pulsed high-field magnets, Mater. Lett. 52 (3) (2002) 154–158.

[15]. A.S. Hamada, A. Khosravifard, A.P. Kisko, E.A. Ahmed, D.A. Porter, High temperature deformation behavior of a stainless steel fiber-reinforced copper matrix composite, Mater. Sci. Eng., A (2016), http://dx.doi.org/10.1016/j.msea.2016.03.084.

[16]. P. Iglesias, A.E. Jiménez, M.D. Bermúdez, B.C. Rao, S. Chandrasekar, Steel machining chips as reinforcements to improve sliding wear resistance of metal alloys: study of a model Zn-based alloy system, Tribol. Int. 65 (2013) 215–227.

[17]. T.K. Vyas, A. Pandey, A review on investigation of copper matrix composite by using stir casting method, Indian J. Appl. Res. 5 (1) (2015) 75–77.

[18]. K.K. Alaneme, Influence of thermo-mechanical treatment on the tensile behaviour and CNT evaluated fracture toughness of borax premixed silicon carbide reinforced aluminium (6063) matrix composites, Int. J. Mater. Mech. Eng. 7 (1) (2012) 96–100.