Vol. 36, No. 2 (2014) 155-162

Tribology in Industry

www.tribology.fink.rs

RESEARCH

The Effects of Cocos Nucifera (Coconut Shell) on the Mechanical and Tribological Properties of Recycled Waste Aluminium Can Composites

J.O. Agunsoye[a], S.I. Talabi[b], S.A. Bello[a], I.O. Awe[c]

[a] *Department of Metallurgical and Materials Engineering, University of Lagos, Akoka, Yaba, Lagos,*
[b]*Department of Metallurgical Engineering, Yaba College of Technology, Yaba, Lagos,*
[c]*Department of Materials and Metallurgical Engineering, University of Ilorin, Ilorin, Kwara.*

Keywords:

Metal Matrix composites
Cocosnucifera particles
Mechanical properties
Wear behaviour

Corresponding author:

J.O. Agunsoye
Department of Metallurgical and Materials Engineering,
University of Lagos,
Akoka, Yaba, Lagos.
E-mail: jagunsoye@unilag.edu.ng

A B S T R A C T

The dry sliding wear behaviour and mechanical properties of recycled aluminium metal matrix composite reinforced with 5 and 10 % coconut shell particles (CSp) has been investigated. The particle size of Cocosnucifera (coconut shell) that were used ranges from 50-300µm. The wear behaviors of developed samples were investigated under varied loads and speed using pin on disc equipment. The samples were also subjected to tensile, impact and hardness test. The result shows that the additions of coconut shell particles improved the wear resistance of the recycled aluminium can/CSp composites at low Speed (2.36 m/s). However, with increase in Speed (4.72 m/s), an increase in the specific wear rates were observed. Increasing the coconut shell particles additions to the recycled waste aluminium cans (RWAlC) reduced the impact resistance, hence the toughness of the RWAlC/CSp composite samples. However, the impact resistance of the composites increased as the Cocosnucifera particle size increased. The result of the filler size variation shows that decrease in filler particles size improved the tensile strength and yield strength of the developed aluminium metal matrix /CSp composite. The hardness of the composite increased with increased additions of the filler within the matrix.

1. INTRODUCTION

It has been noticed that the limited mechanical properties (strength and hardness) of aluminium and its alloys adversely affect its applications in automobile and aerospace industries (Lai, 2000; Wang, 2002). This constitutes a major concern in its fabrication to suit its different applications. Hence, there has been growing interest in the use of aluminium based metal matrix with improved mechanical properties and wear resistance ability, especially in the transport industries, where component weight reduction, enhanced friction and wear performances, are key objective. This growing requirements of materials with high Specific mechanical properties with weight savings characteristic has increased significant research activities in recent times focused primarily on further development of aluminium based composites (Ajoy Kumar Ray et al, 2002; Walker et al, 2005; Joel, 2009). Their distinctive properties of high stiffness, high strength and low density have promoted an increasing number of applications for these materials. The demand for structural materials to be cost effective and also to provide high performance has also resulted in continuous attempts being made particularly in areas of alloy design and the use of novel processing techniques to develop composites that will compete favorably with traditional engineering alloys (Lorella and Roberto, 2011). The largest improvement in properties (strength and stiffness) has obtained with the introduction of fiber reinforcements (Clyne and Withers, 1993; Guo et al, 1995), but the properties of fiber-reinforced composites are not isotropic. Particle-reinforced metal matrix composites (MMCs) are attractive in that they exhibit near-isotropic properties when compared with the continuously-reinforced matrices (Peng and Zhu, 2003) and have better wear resistance (Pruthvira, 2011; Rajaneesh and Kanakuppi, 2011).

Most of the researches on MMCs that are carried out on the aluminium based composites to improve its mechanical properties involve incorporation of hard ceramic oxides, carbides or nitrides into the metal matrices. Typical reinforcements in particulate-reinforced MMC are ceramics, such as Al_2O_3 and SiC (Slipenyuk et al, 2006; Kainer, 2006; El-Daly et al, 2013). In Al-SiC composites, the reinforcing SiC phase is incorporated in the form of particulate, fiber or whiskers into the matrix of aluminium metal by a large number of techniques (Soon-Jik et al 2003; Joel, 2009). The promising use of SiC as reinforced material to the aluminium metal matrix is restricted due to the reaction of Al with SiC above 720 °C forming Al_4C_3, which has poor mechanical properties and severe corrosion problem (Ahmad, 2003). Low composite toughness may be another disadvantage of conventional SiC reinforcement particles with sharp pointed corners; because it has been shown that the reinforcement particle shape has a great effect on strain field localization in composites under stress (Qin et al, 1999). Fly ash has also been successfully used as reinforcement in Al-based MMCs (Rohatgi et al, 2006; Mohanty and Chugh, 2007; Sarkar et al, 2008).

In the present study, MMCs produced from reinforced recycled aluminium with Cocosnucifera (coconut shell) particulate were produced by stir cast process, and their sliding tribological behaviors and mechanical properties were investigated. The objective is to determine how the particulate volume fractions of Cocosnucifera affect these properties. The Cocosnucifera that was used is classified as waste which causes environmental pollution. Hence, the work was also aimed at optimizing the properties of the recycled waste aluminium cans at reduced cost and to solve the environmental menace associated with Cocosnucifera waste and aluminium can.

2. MATERIALS AND METHODOLOGY

The unprocessed coconut shell was sun dried, ground and sieved into different sizes (50, 75, 150, 212, 300 μm) using BS 1377: 1990 standard.

The recycled waste aluminium cans were remelted in a pit furnace with ladle capacity of 20 kg. After the aluminium cans have become molten, the ladle with melt was taken out of the furnace. A control sample was casted by pouring the molten metal without any filler addition into the metal mould at 660 °C ± 5 °C. Thereafter, the melt was poured into a red hot crucible containing 5 % weight of coconut shell particles with 50 μm particle size. The mixture was stirred manually for about 60 seconds. The crucible containing the mixture was returned to the furnace and the mixture was reheated after which the melt was poured into a metal mould at 660 °C ± 5 °C. Similarly, the composite sample containing 10 % weight fraction of coconut shell particulates of 50 μm particle size was produced. At each instance, the cast was allowed to solidify and cooled to room temperature (35 °C) in the mould before it was knocked out. The same procedure was repeated for casting the remaining samples using coconut shell particulate of different particle sizes (50, 75, 150, 212, 300 μm).

The $RWAlC/CS_p$ composite sample was subjected to XRD analysis to determine the phases and their compounds. Samples were prepared for microstructural examination to investigate the microstructure and distribution of reinforcement within the matrix. Scanning

Electron Microscope model EVOMA 10 LaB6 Analytical VP-SEM at 20 KV was used. The results of the SEM micrographs are presented in Figs. 2-4. The tensile test was conducted on the RWAlC/CS_p composite samples using an Instron Testing Machine with a strain rate 2 X $10^{-3}s^{-1}$ in accordance with the American Society for testing and Materials (ASTM-D3039). The response of the RWAlC/CS_p composite samples to the tensile loading was plotted as a function of particulate sizes and shown in Figs. 5 and 6.

The hardness of the RWAlC/CS_p composite samples was estimated based on the American Society for testing and Materials (ASTM E10). Brinell Hardness Tester (Dynamic Hardness Tester by Fasne Test Equipment), Model: DHT-6. The test was carried out under a load of 300 kg at four different points on the surface of the samples and the average reading was recorded. The response of samples to surface indentation was plotted against the particle sizes of coconut shell and shown in Fig. 7.

Based on ASTM D256-93, the impact energy test was carried out on the notched samples of dimensions 60 x 10 x 10 mm using the Avery-Denison Universal Impact –Testing Machine (machined by Adcock Shipley Milling Machine, Model 2E operating at maximum Speed 1200 rev/min). Impact energy of the composite samples produced was plotted against the particulate sizes of the coconut shell. This is shown in Fig. 8.

The wear behavior of RWAlC/5CS_p (50 µm size) and RWAlC/10CS_p (50 µm size) samples was investigated. Emery paper of 180 grit size was mounted on circular rotating disc. The surface of the test sample (60 x 10 x 10 mm) was placed against the rotating disc for a period of 60s each, under varied loads of 6.37 N, 10.29 N, 14.21 N and 16.17 N and a rotating speed of 2.36 m/s. The coupon sample was placed at a fixed sliding distance of 62.86 m. A surface contact was maintained between the samples and the abrasive materials. After each test, the worn out samples were cleared from the emery paper with a compressed dry air blower. The experiment was repeated at higher speed of 4.72 m/s. In each case, the test was carried out twice and corresponding weights were measured with an electronic scale with accuracy 0.001 mg. The volume loss was determined from the average weight loss.

Sliding moment was calculated using equations 1.

Sliding moment = Applied load x sliding distance (1)

The graph of volume loss as a function of sliding moment was plotted for the samples both at low (2.36 m/s) and high (4.72 m/s) speed. The slope of each graph gives the specific wear rate of (a parameter that defines the wear severity of the samples).

3. RESULTS AND DISCUSSION

3.1 XRD Analysis and SEM Micrographs

The coconut shell particulates were subjected to XRD test to analyses the substance and elemental compositions of the coconut shell. The identified substances and elements are presented in Table 1 and 2 respectively.

Table 1. Percentage Weight of Identified Substances in Coconut Shell.

Composition	%weight
Lignin	29.2
Pentosans	27.8
Cellulose	26.5
Moisture	7.8
Solvent extractives	4.4
Uronic anhydrides	3.6
Ash	0.7

Table 2. Elemental Analysis of Coconut Shell.

Elements	%weight
Carbon	53.88
Hydrogen	6.56
Oxygen	38.56
Nitrogen	0.97
Sulphur	0.03

The identified phases with their corresponding compound formulas of the composites from the XRD test are presented in Table 3. One sample was selected for XRD analysis because all the identified compounds are presumed to be the same for all the developed composites. The XRD profile of elemental segregation is shown in Figure 1. The density of the control sample and developed composites is shown in Table 4.

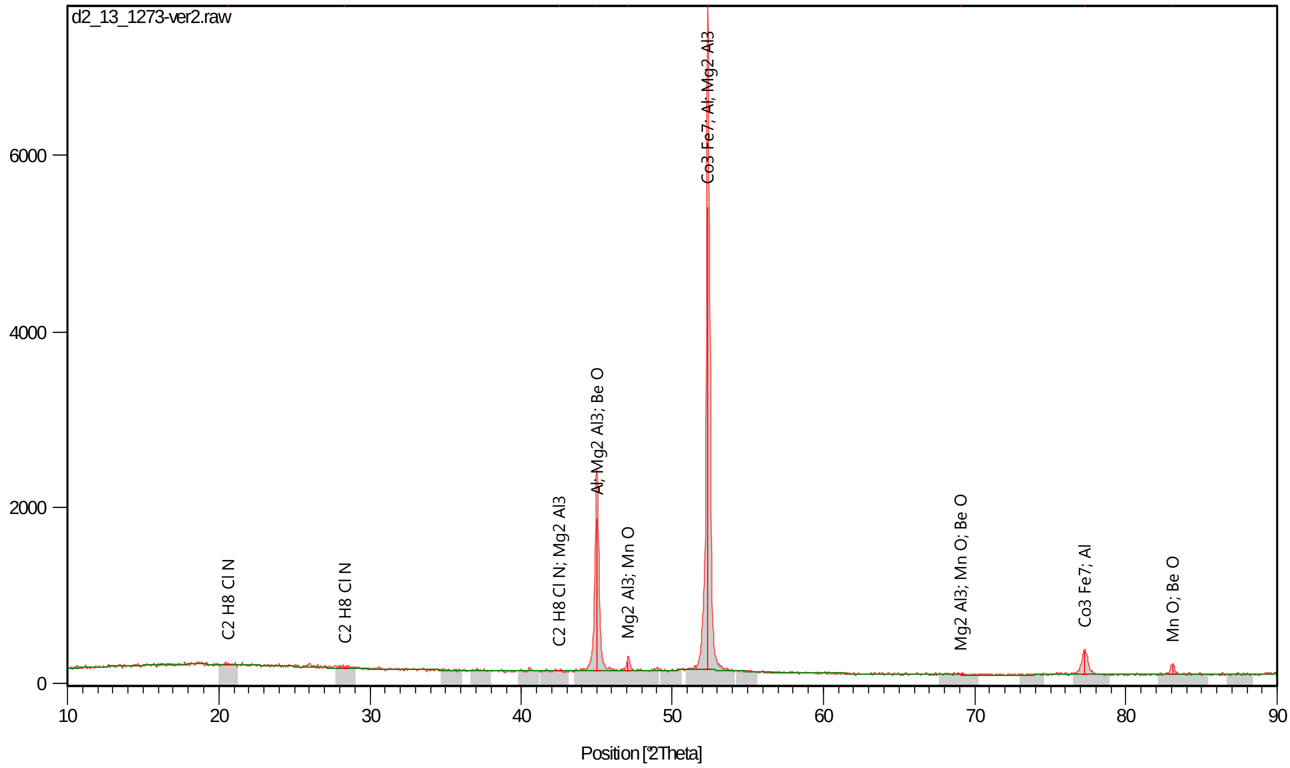

Figure 1. XRD Profile of Elemental Segregation of RWAlC/10CSp Composite.

Table 3. RWAIC/10CSp composites phases and their chemical formulas.

Score	Compound	Chemical Formula
63	Cobalt Iron	Co_3Fe_7
45	Aluminium	Al
30	Dimethylamine chloride	C_2H_8ClN
18	Magnesium Aluminum	Mg_2Al_3
35	Manganosite	MnO
11	Bromellite	BeO

Table 4. Density of RWAIC/CSp composites.

Composites	Density g/cm³
Control Sample	2.40
RWAlC/5CSp (50μm)	2.43
RWAlC/10CSp (50μm)	2.46

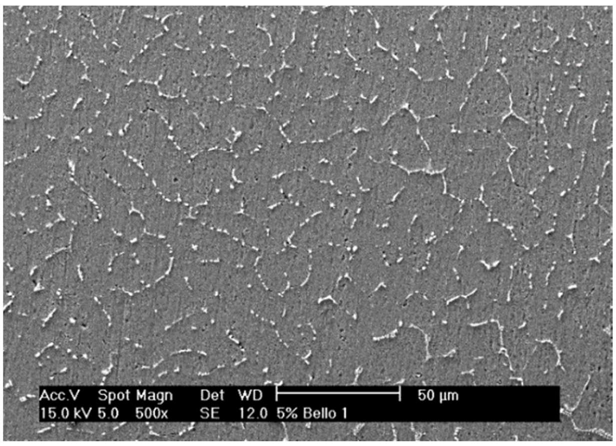

Fig. 2. SEM Micrograph of RWAlC/5CSp (50μm) composite (X500).

Figure 2 shows the SEM micrograph of the RWAlC/5CSp (50 μm size) composite sample. There is a uniform distribution of the coconut shell particulates within the matrix of the recycled waste aluminium can. The observed homogeneity is reflected in the almost consistency of the hardness values taken at different points on the composite (See Table 5).

Table 5. Hardness Values of the RWAlC/CSp Composites.

Coconut shell addition (%)	Particle Size (μm)	HB_1	HB_2	HB_3	HB_4	HB_{AV}
0	N/A	29	29	29	29	29
5	50	35	36	34	35	35.00
10	50	48	49	49	49	48.75

Figure 3 shows the SEM micrograph of the RWAlC/10CSp (50 μm size) composite sample. It can be seen that the volume of particulate coconut shell does not affect the homogeneity of the RWAlC/CSp composite significantly. However, the composites hardness/tensile strength were affected (see Table 5 and Fig. 5). The hardness and tensile strength values obtained for RWAlC/10CSp (50 μm) is higher than that obtained in RWAlC/5CSp (50 μm).

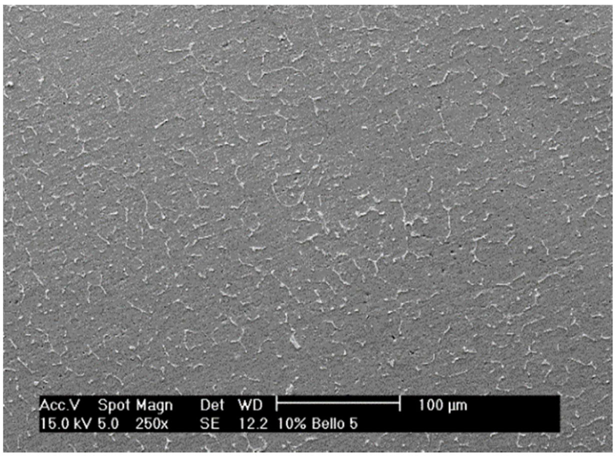

Fig. 3. SEM Micrograph of RWAlC/10CSp (50μm) Composite (X250).

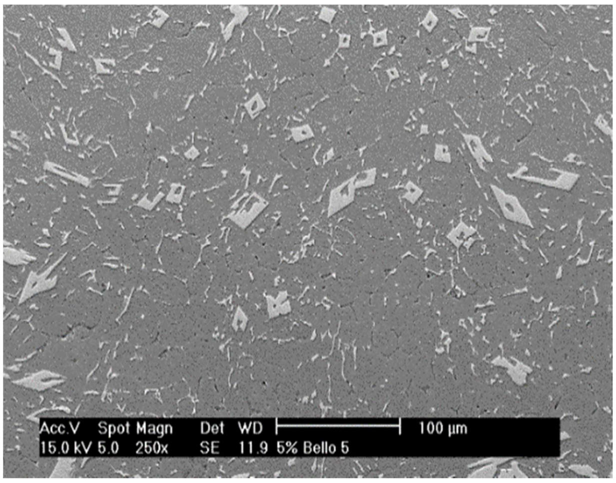

Fig. 4. SEM Micrograph of RWAlC/5CSp (300μm) Composite (X250).

Figure 4 shows the SEM micrograph of the RWAlC/5CSp (300 μm size) composite sample. The micrograph is similar in morphology to that in Fig. 2 but with increased size of the filler phase. The samples with the highest filler particle size show the highest resistance to impact but a corresponding low hardness, yield and tensile strength values (Figs. 5-8). Hence, for applications where impact energy is of significant important, increasing the particle size of the filler within the composite matrix is recommended.

3.2 Tensile Strength, Hardness and Impact Energy

The result of the filler size variation shows that decreased in filler particle size improved the tensile strength of the developed aluminium metal matrix composite (Fig. 5). This agrees with Hall-Petch equation (Equation 2).

$$\sigma_y = \sigma_0 + KD^{-1/2} \ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Where σ_y is the yield stress of the material; σ_o is a materials constant for the starting stress for dislocation movement of the material; K is a measure of resistance to dislocation and D is the diameter of the particulate size. As D decreases, that is decrease in particulate size, the repulsion stress felt by a grain boundary dislocation decreased and the applied stress needed to propagate dislocations through the material increased. There was about 28 % increase in the strength of RWAlC/10CSp (50 μm) sample than that of RWAlC/5CSp (50 μm) sample (Fig. 5). This is due to greater hindrance which coconut shells particulates offer to dislocation movement. From Fig. 6, it can be seen that increased in the filler content improved the yield stress of the composite at all particle sizes.

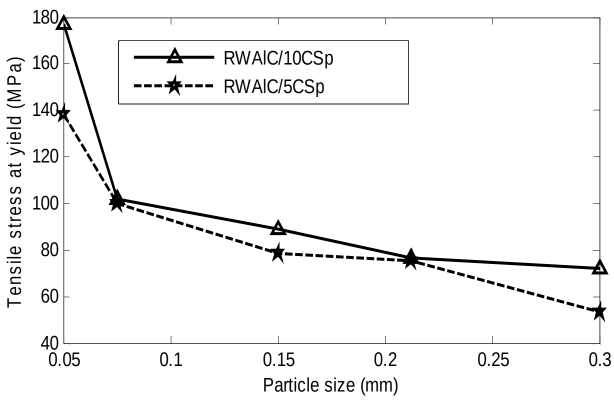

Fig. 5. Tensile Stress of composites with Particulates Size Curve.

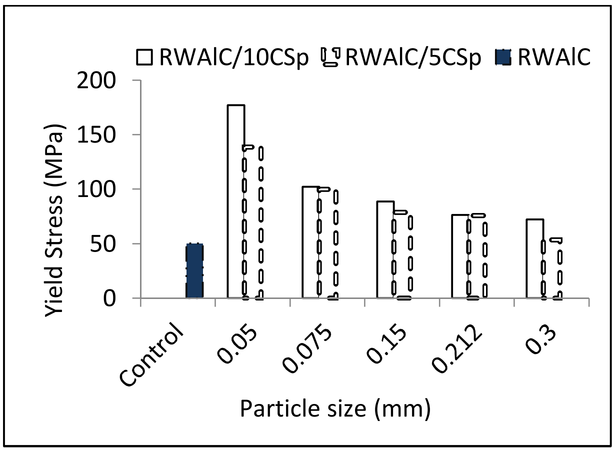

Fig. 6. Yield Stresses of Composites Particulates Size Curve.

The effect of particle size of coconut shell filler on hardness of the aluminium matrix composite is shown in Fig. 7. The resistance of the composite to surface indentation increased with increased addition of the filler within the matrix. Compared to the hardness values of control sample (30HB), all the samples showed increase in hardness. With respect to 50 µm particles size, about 40 % increase was observed when the filler addition was increased from 5 % volume to 10 % volume fraction of coconut shell particulates in the composites. The higher resistance to localized deformation during indentation can be attributed to the harder coconut shell particles distributed with the aluminium matrix. It was also observed that the hardness of the material increased with decreased in the filler particle size. This is due to the presence and distribution of more fines of coconut shell within the matrix.

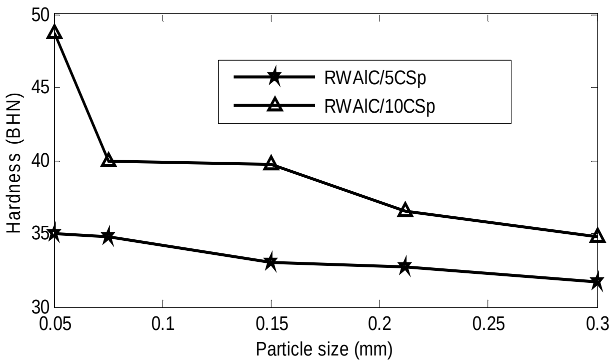

Fig. 7. Hardness Values with Grain Size Curve of the RWAlC/CSp Composites.

It was observed that increasing the additions of coconut shell particles to the recycled waste aluminium reduced the impact resistance; hence the toughness of the RWAlC/CSp composite samples (see Fig. 8). However, as the particle size increased, the impact resistance of the composite increased. The tougher surface provides a higher resistance to impact flow. This is in agreement with the result from the hardness test (Fig. 7).

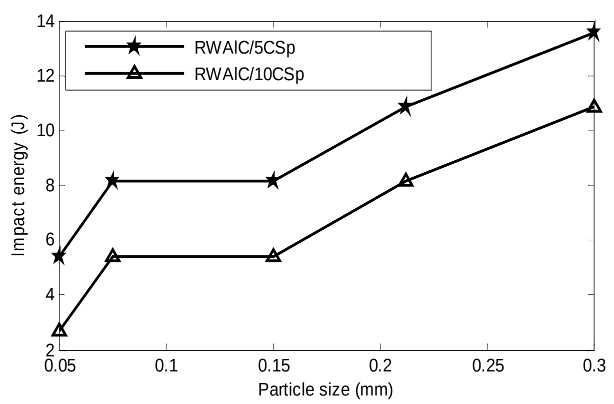

Fig. 8. Impact Energy with Grain Size of RWAlC/CSp.

3.3 Wear

The specific wear rate being a parameter used for measuring wear severity was evaluated with MATLAB program as slope of the lines of best fit in the Figs. 9 and 10. The resulting equations are shown in equations 2-7. From Figs. 9 and 10, it can be deduced that increased load affect significantly the wear behaviour of the developed composites. In addition, significant transition in volume loss was observed after the load of 14.21 N at both speed of 2.36 m/s and 4.32 m/s. Hence, for the specific composites, it will be appropriate to use them in service under a maximum load of 14.21 N to prevent rapid wear rate.

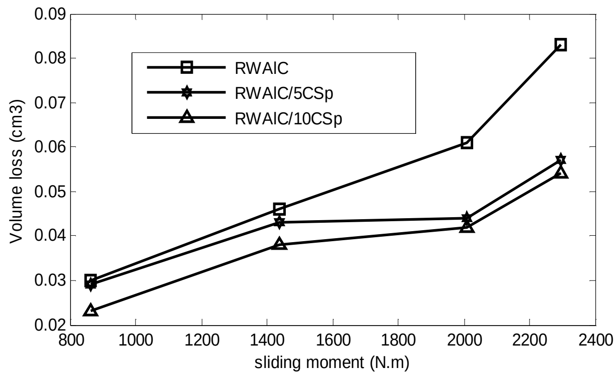

Fig. 9. Volume Loss at 2.36 ms^{-1} with sliding moment curves.

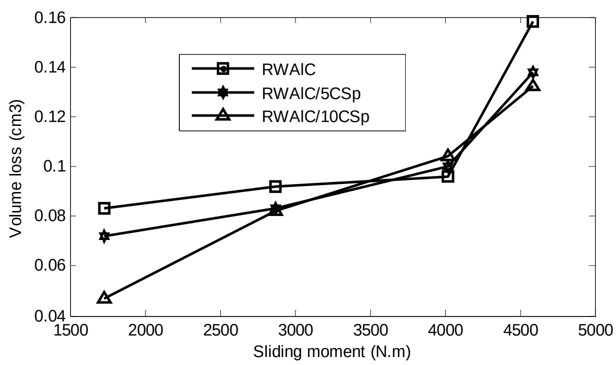

Fig. 10. Volume Loss at 4.72 ms^{-1} with Sliding Moment Curves.

Subsequently, the specific wear rate values (Table 6) extracted from the equations was plotted against volume percentage of filler as shown in Figs. 11 and 12.

$$y_1 = 0.000035x - 0.002066 \quad (3)$$

$$y_2 = 0.000019x + 0.015 \quad (4)$$

$$y_3 = 0.000017x + 0.011 \quad (5)$$

$$y_4 = 0.000042x + 0.038 \quad (6)$$

$$y_5 = 0.000047x + 0.023 \quad (7)$$

$$y_6 = 0.000056x - 0.0011 \quad (8)$$

Table 6. Specific wear rates (cm^3/Nm).

	@2.36m/s		
	Samples	Wear rate	Norm of Residuals
y_1	Control	0.000035	0.0090378
y_2	5%	0.000019	0.069843
y_3	10%	0.000017	0.0045044
	@4.72m/s		
y_4	Control	0.000042	0.037052
y_5	5%	0.000047	0.20611
y_6	10%	0.000056	0.0091574

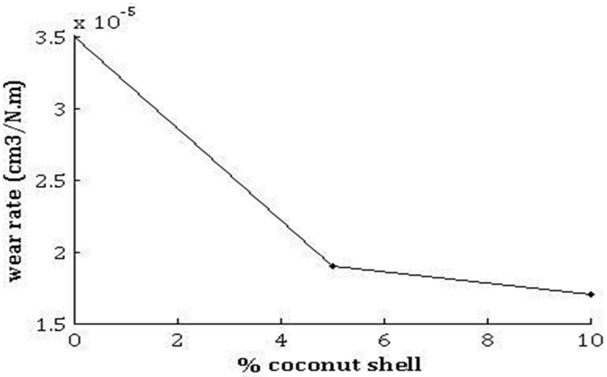

Fig. 11. Specific wear rates-% coconut shell at 2.36 ms^{-1}.

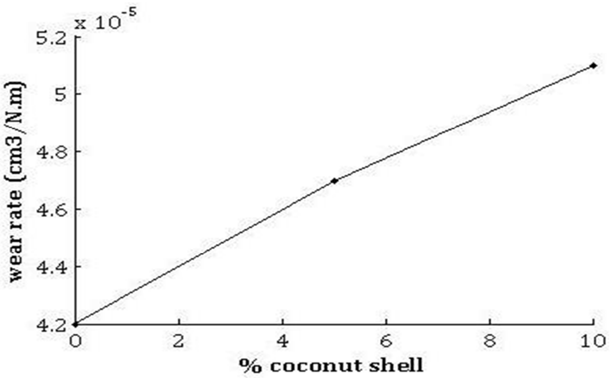

Fig. 12. Specific wear rate -% coconut shell at 4.72 ms^{-1}.

A reduction in specific wear rate, hence wear severity was observed at low Speed of 2.36 m/s as the volume percentage of the filler increased (Fig. 11). This infers that the addition of coconut shell improves the wear resistance of Recycled Waste Aluminium Can/CSp composites. The improved wear behaviour of the composite may be attributed to high bearing capacity of the hard reinforcing material as well as better interfacial bonding between the filler and the matrix which prevent the possibility of pull (Agunsoye et al., 2013; Basavarajappa et al., 2009). However, with increase in speed (4.72 m/s), an increase in the specific wear rate was observed (Fig. 12). The increased in wear rate may be due to thermal softening effect which lowers the interfacial bonding between the particulate coconut shell and the aluminium matrix (Singla and Mediratta, 2013).

4. CONCLUSION

From the results and discussion of this work, the following conclusions can be made:

1. Increased addition of coconut shell particles content improved the strength and yield stress of the composite at all particle sizes. Hence, the strength of the Recycled Waste Aluminium Can/CSp composite increases with increase in amount of the coconut shell particles. This is due to greater hindrance which coconut shell particulates offer to dislocation movement.
2. The resistance of the composite to localized surface indentation increased with increased addition of the coconut shell particulates within the matrix.
3. Increased additions of coconut shell particles to the recycled waste aluminium cans reduced the impact resistance, hence the toughness of the RWAlC/CSp composite. However, as the particle size increased, the impact resistance of the composite increased.
4. The addition of coconut shell improves the wear resistance of RWAlC/CSp composites at low speed. However, with increase in speed (4.72 m/s) an increase in the specific wear rate was observed. Also, significant increase in volume loss was observed after a maximum load of 14.21 N. Hence, in service the composites should be used under a load that is below 14.21 N to prevent rapid wear rate.
5. Recycled aluminium cans and coconut shell can be processed and used for the production of useful engineering materials.
6. The use of recycle waste aluminium cans for production of engineering materials will reduce its dangerous use in the production of local bombs by suicide bombers and terrorists. Also, the environmental menace associated with agricultural waste (coconut shell) and empty aluminium cans are solved.

Note

- *CSp = Coconut Shell particles.*
- *RWAlC = Recycled Waste Aluminium Can.*
- *RWAlC/nCSp (xxμm) = n% CSp at xxμm particulate size + (100-n)% RWAlC.*

REFERENCES

[1] J.O. Agunsoye, S.I. Talabi, V.S. Aigbodun, A. Olumiyiwa: *Effects of Silica Ceramic particle sizes on the properties of recycled Polyethylene Composites*, Advances in Natural Science, Vol. 6, pp. 1-8, 2013.

[2] Z. Ahmad, P.T. Paulette, B.J.A. Aleem: *Mechanism of localized corrosion of aluminum-silicon carbide composites in a chloride containing environment*, Journal of Materials Science, Vol. 35, No. 10, pp. 2573-2579, 2000.

[3] K. Ajoy Kumar Ray, S.K. Venkateswarlu, S.K. Chaudhury, B. Das, L.C. Ravi Kumar: *Fabrication of TiN reinforced aluminium metal matrix composites through a powder metallurgical route*, Materials Science and Engineering A, Vol. 338, pp. 160-165, 2002.

[4] K. Basavarajappa, B. Arun, J. Paulo Davim: *Wear studies on glass fibre reinforced epoxy composites along with fillers sic and graphite*, Journal of Minerals and Materials Characterization and Engineering, Vol. 8, pp. 379, 2009.

[5] A.A. El-Daly, M. Abdelhameed, M. Hashish, M.D. Walid: *Fabrication of silicon carbide reinforced aluminum matrix nanocomposites and characterization of its mechanical properties using non-destructive technique*, Materials Science & Engineering A, Vol. 559, pp. 384–393, 2013.

[6] Guo, B. Derby: *Solid-state fabrication and interfaces of fiber reinforced metal matrix composites*, Prog. Mater. Sci, Vol. 39, pp. 411–495, 1995.

[7] Joel Hemanth: *Development and property evaluation of aluminum alloy reinforced with nano-ZrO_2 metal matrix composites (NMMCs)*, Materials Science and Engineering A, Vol. 507, pp. 110–113, 2009.

[8] M.O. Lai: *Development of ductile Mg composite material using Ti reinforcement*, Journal of Materials Sciences, Vol. 31, pp. 2155-2167, 2009.

[9] Lorella Ceschini and Roberto Montanari: *Advances in Metal Matrix composites*, Trans Tech Publications, Inc. ISBN-13: 978-3-03785-057-2, pp. 170, 2011

[10] S. Mohanty, Y.P. Chugh: *Development of fly ash-based automotive brake lining*, Tribology International, Vol. 40, pp. 1217–1222, 2007.

[11] L. M.Peng and S. J. Zhu: *Creep of metal matrix composites reinforced by combining nano-sized dispersoids with micro-sized ceramic particulates or whiskers (review)*, Int. J. of Materials & Product Technology, Vol. 18, No. 1/2/3, pp. 215-255, 2003.

[12] R.D. Pruthvira: *Wear characteristics of Chilled Zinc-Aluminium Alloy reinforced with Silicon Carbide Particulate composites*, Research Journal of Chemical Sciences, Vol. 1, No. 2, pp. 17-24, 2011.

[13] S.Y. Qin, C.R. Chen, G.D. Zhang, W.L .Wang, Z.G. Wang: *Characterization of thermal residual strain in SiCp/6061 Al composites by ultramicrohardness*, Journal of Materials Science Letter, Vol. 18, No. 14, pp. 363–370, 1999.

[14] N.M. Rajaneesh, S. Kanakuppi: *Dry Sliding Wear Behaviour of SiC Particles Reinforced Zinc-Aluminium (ZA43) Alloy Metal Matrix Composites*, Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No. 5, pp. 419-425, 2011.

[15] P.K. Rohatgi, D. Weiss, and Gupta Nikhil: *Applications of Fly Ash in Synthesizing Low-Cost MMCs for Automotive and Other Applications", Journal of the Minerals*, Metals and Materials Society, Vol. 58, pp. 71-76, 2006.

[16] R.Q. Guo, P.K. Rohatgi: *Preparation of aluminum–fly ash particulate composite by powder metallurgy technique*, J. Mater. Sci., Vol. 32, pp. 3971–3974, 1997.

[17] S. Sarkar, S. Sen and S.C. Mishra: *Aluminum – fly ash composite produced by impeller mixing*, Journal of reinforced plastics and composites, pp. 1-6, 2008.

[18] V. Slipenyuk, Y.M. Kuprin, V. Goncharuk and J. Eckert: *Properties of P/M Processed Particle Reinforced Metal Matrix Composites Specified by Reinforcement Concentration and Matrix-to-Reinforcement Particle Size Ratio*, Acta Materialia, Vol. 54, No. 1, pp. 157-166, 2006.

[19] H. Soon-Jik, K. Hong-Moule, H. Dae, C. Suryanarayana, C. Byong Sun: *Effect of clustering on the mechanical properties of SiC particulate reinforced aluminum alloy 2024 metal matrix composites*, Materials Science and Engineering A, Vol. 347, pp. 198-204, 2003.

[20] J.C. Walker, W.M. Rainforth, H. Jones: *Lubricated sliding wear behaviour of aluminium alloy composites*, Wear, Vol. 259, pp. 577–589, 2005.

[21] C.R. Wang, J.M. Yang: *Materials characterization by scanning electron microscopy*, Mater. Chem. Phys., Vol. 14, pp. 272-286, 2002.

[22] Deepak Singla, S.R. Mediratta: *Effect of load and speed on wear properties of al 7075-fly ash composite material*, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, No. 5, pp. 1-9, 2013.