# Corrosion and Wear Properties on Synthesized Silicon Carbon Nanotubes

**P.S. Senthil Kumar, S. Marichamy, B. Stalin, M. Ravichandran, K. Vinothbabu**

***Abstract: The purpose of adding Carbon nanotubes (CNT) to metal is to obtain excellent atomic structure and material properties. The strength, wear and corrosion resistance was improved when the addition of carbon nanotubes to the silicon metal. A uniform mixing of carbon nanotubes were achieved by molecular level mixing through the Spark plasma sintering (SPS) process. The interfacial bonding strength is also improved by this process. The material properties and wear properties were also studied. The most influential factor was found by analysis of variance during wear behavior experiment. The deflection test was also conducted under various load conditions.***

***Index Terms: Carbon nanotubes, Spark plasma sintering, Wear behavior, Corrosion resistance, Deflection test.***

## I. INTRODUCTION

In recent days, the demand of carbon nanotubes has been increased due to their exclusive atomic structure and smart properties like as high tensile strength, high aspect ratio thermal and electrical conductivity [1-5]. The high temperature and high pressure were applied to for the processing of carbon nanotube composites and its properties were studied [6]. The interfacial bonding strength was improved due to the addition of carbon nanotubes [7-8]. Silicon composites were used in manufacturing industries, electronics industries, pipelines, construction and automobile brake systems [9]. The silicon carbide based hybrid metal composites coated with carbon nanotubes were fabricated [10]. One-dimensional nanostructure was analyzed in silicon nitride based nano rods and nano wires [11-14]. The silicon based carbon nanotubes were synthesized and used for template purpose [15-17].

In the present work describe about a synthesis, characterization analysis of silicon carbon nanotube. The material properties and wear properties were also studied. The most influential factor was found by analysis of variance during wear behavior experiment.

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## II. MATERIALS AND METHODS

### A. Synthesis

The Silicon carbon nanotube was fabricated through the spark plasma sintering process. The uniform mixing of carbon nanotubes and silicon was carried out by ball milling process for 20 hours with 500 rpm. The 6% volume fraction of carbon nanotubes was maintained to the uniform mixture. The carbon nanotubes and silicon powders were compact by mold and the pressure was applied around 10MPa. After that, this mixture was transferred to sintering process. The sintering process temperature and rate of heat were maintained at 1420°C for 10 min. The copper, aluminium based carbon nanotubes were fabricated through the spark plasma sintering process [18-19].

## III. RESULTS AND DISCUSSION

The morphological information about the material was confirmed. Si with CNTs provides better refined grain structure. CNTs were uniformly distributed throughout the material structure. The carbon nanotubes were scattered uniformly in titanium alloy which was produced by the spark plasma sintering process [20]. The cluster of silicon particles, inter phase and interlink between silicon and carbon nanotubes. The grain refinement and growth was developed when addition of carbon nanotubes particles. The stability of the grain structure was also achieved by CNTs.

The high extent of grain refinement and mechanical properties were improved due to better interfacial bonding between CNT and Si matrix. The properties of pure silicon and Si/CNT were shown in the Table 1. All material properties were increased due to the addition of carbon nanotube particles.

**Table 1: Comparisons of properties**

| Sample of Material | Grain size (µm) | Hardness (Mohs) | Yield strength (Mpa) | Ductility (%) | Density (g/cm$^3$) |
|---|---|---|---|---|---|
| Pure Silicon | 20 | 6.5 | 160 | 50 | 2.33 |
| Si/CNT | 6 | 7.8 | 370 | 30 | 6.24 |

## IV. ANALYSIS OF CORROSION RESISTANCE

The corrosion experiment was carried out in 2 weight percentage of sodium chloride and hydro choleric acid medium.


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After preparation of the solution, 25 grams of sodium chloride were mixed with 400ml of water. The temperature was maintained at 30ºC. The working metal was submerged in the solution for one hour. The potential range was maintained between -220mv to +220mv. The corrosion behavior has been analyzed using potential E corrosion, current density $i_a$, and anodic tafel slope βa. The corrosion potential values are increased and anodic current density has been decreased in the acid medium. A Tafel plot was studied in copper graphite substrate [21]. The corrosion potential values were obtained from sea water and acid medium and recorded in the Table 2.

**Table 2: Experimental results for corrosion test**

| Medium | Ecorr | $i_a$ | βa |
|---|---|---|---|
| Sea water | -7.12 | $1.934 \times 10^{-3}$ | 0.424 |
| Acid | -6.46 | $1.432 \times 10^{-3}$ | 0.523 |

## V. ANALYSIS OF WEAR BEHAVIOR

The experiment was conducted by a pin-on-disc wear-testing apparatus. The pin was prepared by 8 mm diameter and 20 mm length. The hardened steel disc was used with HV650 hardness. The constant track diameter of 100 mm was considered for all the tests for 15 min at room temperature. The carbon nanotubes reinforced metal composites reveals admirable tribological properties, like as lower coefficient of friction and high wear resistance [22-24]. The low coefficient of friction was obtained with copper based carbon nanotubes [25]. The Experimental results from frictional wear were shown in Figures 1- 6.

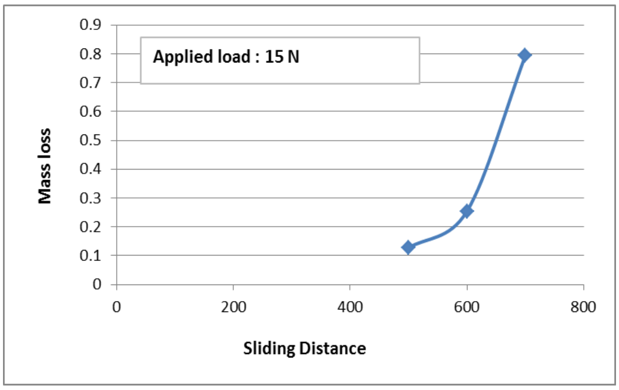


**Fig. 1: Sliding distance Versus Mass loss at Applied load 15 N**

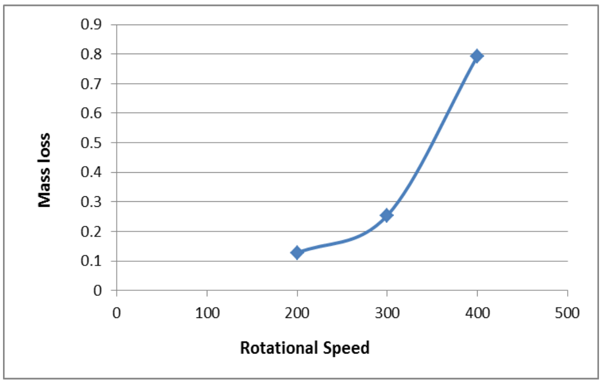


**Fig. 2: Rotational speed Versus Mass loss at Applied load 15 N**

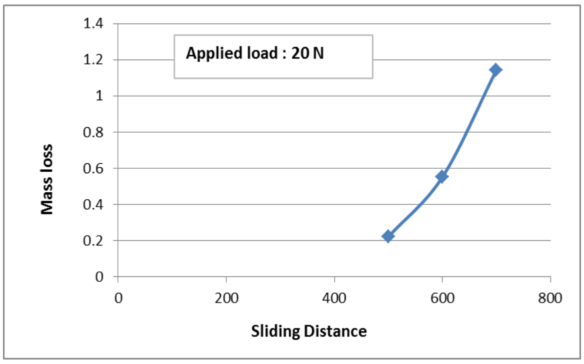


**Fig. 3: Sliding distance Versus Mass loss at Applied load 20 N**

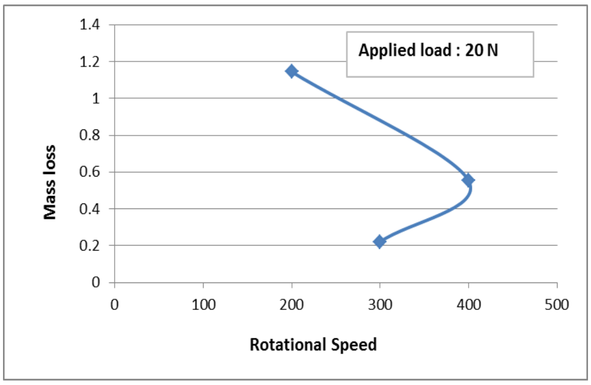


**Fig. 4: Rotational speed Versus Mass loss at Applied load 20 N**

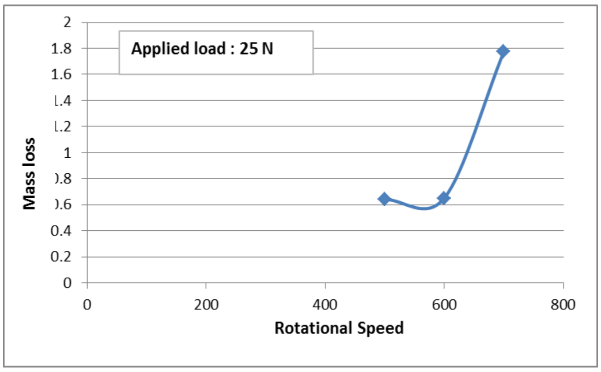


**Fig. 5: Sliding distance Versus Mass loss at Applied load 25 N**

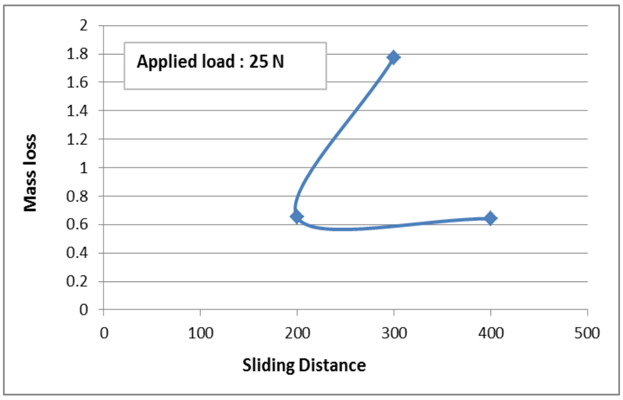


**Fig. 6: Rotational speed Versus Mass loss at Applied load 25 N**

By using analysis of variance (ANOVA), sliding distance was the most influential parameter for wear test and shown in Table 3. The applied load was second most influential parameter.

**Table 3: Analysis of variance for wear**

| Source | DF | Adj. SS | Adj. MS | F-Value | P-Value | Percentage % |
|---|---|---|---|---|---|---|
| A: Applied load | 2 | 0.54005 | 0.27003 | 6.88 | 0.127 | 24.89 |
| B: Sliding distance | 2 | 1.52311 | 0.76155 | 19.41 | 0.049 | 70.21 |
| C:Disc rotational speed | 2 | 0.02783 | 0.01391 | 0.35 | 0.738 | 01.28 |
| Error | 2 | 0.07845 | 0.03923 | ---- | ---- | 03.62 |
| Total | 8 | 2.16945 | ---- | ---- | ---- | 100 |

The developed model of mass loss with respect to the various input parameters like as the applied load (A), sliding distance (B) and disc rotational speed (C) were derived and mentioned in equation 1.

$$\text{Mass loss} = 0.6702 - 0.2582\,A\text{- }15 - 0.0709\,A - 20 + 0.3291\,A - 25 - 0.3479\,B - 500 - 0.2299\,B - 600 + 0.5778\,B - 700 - 0.0506\,C - 200 + 0.0774\,C - 300 - 0.0269\,C - 400 \quad (1)$$

## VI. DEFLECTION TEST

### A. Simply Supported Beam

This CNT based alloy is used in various civil engineering applications such as production of survey equipments, trusses, pipes, valves, turbines, nozzles and notches etc. The length, breadth and thickness of the specimen were 1000 x 30 x 5 mm respectively. The deflection was measured by simply supported beam attached with a dial gauge. Due to its high strength and hardness, there was no deflection occurred. The experimental results for deflection test under simply supported beam are presented in Table 4.

**Table 4: Experimental results for deflection test under simply supported beam**

| S.No. | Weight | Distance (mm) | Deflection |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 1 | 250 | 0 |
| 3 | 3 | 250 | 0 |
| 4 | 5 | 400 | 0 |
| 5 | 7 | 400 | 0 |
| 6 | 9 | 400 | 0 |
| 7 | 11 | 500 | 0 |
| 8 | 13 | 500 | 0 |
| 9 | 15 | 500 | 0 |

### B. Cantilever Beam

The deflection was measured under cantilever beam. The same dimension of the specimen was used for this experiment. The experimental results for deflection test under cantilever beam are presented in Table 5.

**Table 5: Deflection test under cantilever beam**

| S.No. | Weight | Distance (mm) | Deflection |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 1 | 200 | 0 |
| 3 | 3 | 200 | 0 |
| 4 | 5 | 300 | 0 |
| 5 | 7 | 300 | 0 |
| 6 | 9 | 400 | 0 |
| 7 | 11 | 400 | 0 |
| 8 | 13 | 600 | 0 |
| 9 | 15 | 600 | 0 |

The both experiment deflection was measured under different load. Based on the experimental results, this CNT based alloy has withstand more load without any deflection. Hence it can be used in roof, trusses and beams.

## VII. CONCLUSION

- Silicon carbon nanotubes were fabricated by molecular level mixing through the spark plasma sintering (SPS) process.
- The corrosion resistance properties of Silicon carbon nanotubes were analyzed. The corrosion potential values were obtained from sea water and acid medium and recorded.
- The wear properties of Silicon carbon nanotubes were analyzed and sliding distance was the most influential parameter found by ANOVA.
- The deflection test was carried out through simply supported and cantilever beam. It has withstands high load without any deflection.
- Industrial and civil engineering applications were also discussed.

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## REFERENCES

1. H. Kwon, M. Estili, K. Takagi, T. Miyazaki and A. Kawasaki (2009). Combination of hot extrusion and spark plasma sintering for producing carbon nanotube reinforced aluminum matrix composites. Carbon 47, pp. 570-577.
2. Y. Zhang, T. Ichihashi, E. Landree, F. Nihey, and S. Iijima (1999). Heterostructures of single-walled carbon nanotubes and carbide nanorods. Science 285, pp. 1719-1722.

3. J.-z. Liao, M.-J. Tan, and I. Sridhar (2010). Spark plasma sintered multi-wall carbon nanotube reinforced aluminum matrix composites. Materials & Design 31, pp. S96-S100.
4. K. Chu, C.-c. Jia, L.-k. Jiang, and W.-s. Li (2013). Improvement of interface and mechanical properties in carbon nanotube reinforced Cu-Cr matrix composites. Materials & Design 45, pp. 407-411.
5. C. Guiderdoni, C. Estournès, A. Peigney, A. Weibel, V. Turq, and C. Laurent (2011). The preparation of double-walled carbon nanotube/Cu composites by spark plasma sintering, and their hardness and friction properties. Carbon 49, pp. 4535-4543.
6. S. C. Tjong (2013). Recent progress in the development and properties of novel metal matrix nanocomposites reinforced with carbon nanotubes and graphene nanosheets. Materials Science and Engineering: R: Reports 74, pp. 281-350.
7. K. Chu, C.-c. Jia, L.-k. Jiang, and W.-s. Li (2013). Improvement of interface and mechanical properties in carbon nanotube reinforced Cu–Cr matrix composites. Materials & Design 45, pp. 407-411.
8. B. Stalin, M. Meignanamoorthy, M. Ravichandran (2018). Synthesis of metal matrix composites and alloys by mechanical alloying: A Review. IOP Conf. Series: Materials Science and Engineering 402, pp.1-6, 012097.
9. M. Sangeetha and S. Prakash (2017). Experimental investigation of process parameters in drilling LM25 composites coated with multi wall carbon nano tubes using sonication process. Arch. Metall. Mater. 62( 3), pp. 1761-1770.
10. K.L. Meena, A. Manna S.S. Banwait and Jaswanti (2013). Parametric Effects during Nonconventional Machining of PR-AL-SiC-MMC, s by CNC Wire cut EDM. International Journal of Engineering and Innovative Technology 3(1), pp. 341-345.
11. F. Wang, G. Jin, and X. Guo (2006). Formation mechanism of Si nanowires via carbothermal reduction of carbonaceous silica xerogels. Journal of Physical Chemistry B 110(30), pp. 14546–14549.
12. D. Pan, Z. Shuyuan, Y. Chen, and J.G. Hou (2002). Hydrothermal preparation of long nano wires of vanadium oxide. Journal of Materials Research 17(8), pp.1981–1984.
13. C.N.R. Rao, G. Gundiah, F.L.Deepak, A. Govindaraj and A.K. Cheetham (2004). Carbon-assisted synthesis of inorganic nanowires. Journal of Materials Chemistry 14(4), pp. 440–450.
14. X.C. Wu, W.H. Song and B. Zhao et al (2000). Synthesis of coaxial nanowires of silicon nitride sheathed with silicon and silicon oxide. Solid State Communications 115(12), pp.683–686.
15. W. Han, S. Fan, Q. Li, B. Gu, X. Zhang, and D. Yu (1997). Synthesis of silicon nitride nanorods using carbon nanotube as a template. Applied Physics Letters 71(16), pp. 2271–2273.
16. S. D. Kumar, M. Ravichandran (2018). Synthesis, Characterization and Wire Electric Erosion Behaviour of AA7178-10 wt.% $ZrB_2$ Composite. Silicon 10(6), pp. 2653-2662.
17. B. Stalin, M. Ravichandran, S. Arivukkarasan, V. Mohanavel (2018). Weight Loss Corrosion Studies of Aluminium-LM4 Reinforced With Alumina Silicate ($Al_2O_3SiO_2$) Particulates Composites in Sodium Chloride (NaCl) Solution. International Journal of Mechanical and Production Engineering Research and Development, Special Issue, pp. 329-336.
18. J. Hwang, T. Yoon, S. H. Jin, J. Lee, T.-S. Kim, S. H. Hong et al. (2013). Enhanced Mechanical Properties of Graphene/Copper Nanocomposites Using a Molecular-Level Mixing Process. Advanced Materials 25, pp. 6724-6729.
19. D. H. Nam, S. I. Cha, B. K. Lim, H. M. Park, D. S. Han, and S. H. Hong (2012). Synergistic strengthening by load transfer mechanism and grain refinement of CNT/Al–Cu composites. Carbon 50, pp. 2417-2423.
20. K. Kondoh, T. Threrujirapapong, H. Imai, J. Umeda, and B. Fugetsu (2009), Characteristics of powder metallurgy pure titanium matrix composite reinforced with multi-wall carbon nanotubes. Composites Science and Technology 69, pp. 1077-1081.
21. D. Prasai, J.C. Tuberquia, R.R. Harl, G.K. Jennings, and K I. Bolotin (2012). Graphene: corrosion-inhibiting coating. ACS Nano. 6, pp. 1102-1108.
22. H. J. Choi, S.M. Lee and D.H. Bae (2010). Wear characteristic of aluminum-based composites containing multi-walled carbon nanotubes. Wear 270, pp. 12-18.
23. S.-m. Zhou, X.-b. Zhang, Z.-p. Ding, C.-y. Min, G.-l. Xu, and W.-m. Zhu (2007). Fabrication and tribological properties of carbon nanotubes reinforced Al composites prepared by pressure less infiltration technique. Composites Part A: Applied Science and Manufacturing 38, pp. 301-306.
24. B. Stalin, G.T. Sudha, M. Ravichandran (2018). Investigations on Characterization and Properties of Al-$MoO_3$ Composites Synthesized Using Powder Metallurgy Technique. Silicon 10(6), pp. 2663- 2670.
25. S. R. Dong, J. P. Tu, and X. B. Zhang (2001). An investigation of the sliding wear behavior of Cu-matrix composite reinforced by carbon nanotubes. Materials Science and Engineering: A 313, pp. 83-87.
26. Karthick, S., Perumal Sankar, S., and Raja Prathab, T. "An approach for image encryption/decryption based on quaternion Fourier transform", 2018 International Conference on Emerging Trends and Innovations In Engineering And Technological Research, ICETIETR 2018, art. no. 8529014, 2018. DOI: 10.1109/ICETIETR.2018.8529014
27. Karthick, S., Perumal Sankar, S., and Arul Teen, Y.P. "Trust-distrust protocol for secure routing in self-organizing networks", In Proceedings of 2018 International Conference on Emerging Trends and Innovations In Engineering And Technological Research, ICETIETR 2018, art. no. 8529016, 2018. DOI: 10.1109/ICETIETR.2018.8529016
28. Vijayan, V., Parthiban, A., Sathish, T., Siva Chandran, S., Venkatesh, R. "Performance Analysis in End Milling operation", International Journal of Mechanical Engineering and Technology, Vol. 09, Issue. 11, pp. 2263-2271, 2018.
29. Venkatesh, R., Vijayan, V., Parthiban, A., Sathish, T., Siva Chandran, S. "Comparison of Different Tool path in Pocket Milling", International Journal of Mechanical Engineering and Technology, Vol. 09, Issue. 12, pp. 922-927, 2018.
30. Madan, D., Sivakandhan, C., Sagadevan, S., Sathish, T. "Ocean Wave Energy Scenario in India", International Journal of Mechanical and Production Engineering Research and Development, Special Issue, pp. 582-590, 2018.
31. Sathish, T., Vijayakumar, M.D., Krishnan Ayyangar, A. "Design and Fabrication of Industrial Components Using 3D Printing", Materials Today Proceedings, Elsevier Publisher, Vol. 05, Issue 6, pp. 14489-14498, 2018.
32. Sathish, T., and Karthick, S. "HAIWF-based fault detection and classification for industrial machine condition monitoring", Progress in Industrial Ecology, vol. 12, no. 1-2, pp. 46-58, 2018

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