Wear experimentation and parametric optimization on synthesized copper titanium composite

J Vairamuthu*, P Velmurugan2, N Janaki Manohar3, C Ramesh Kannan4, S Manivannan5 and B Stalin6

1 Department of Mechanical Engineering, Sethu Institute of Technology, Pulloor- 626 115, Kariapatti, Tamil Nadu, India.
2 Department of Mechanical Engineering, School of Mechanical and Automotive Engineering, College of Engineering and Technology, Dilla University, Dilla, Ethiopia.
3Department of Mechanical Engineering, Sri Venkateswaraa College of Technology, Sripurumbudur, Tamil Nadu 602105
4Department of Mechanical Engineering, PET Engineering College, Tirunelveli, Tamil Nadu, India.
5Department of Mechanical Engineering, Karpagam Academy of Higher Education, Coimbatore -21, Tamil Nadu, India.
6 Department of Mechanical Engineering, Anna University, Regional Campus Madurai, Madurai - 625 019, Tamil Nadu, India.

* Corresponding author: vairamuthuj@yahoo.com

Abstract. The applications of non ferrous alloys have been significantly increased due to its desirable substance properties. The material strength and hardness were depend on the nature of reinforcements were added to it. In this chapter was utilized to formulate the Copper Titanium (Cu-Ti) Metal Matrix Composite (MMC) has been reinforced with Tungsten Carbide (WC). The stir casting of material fabrication technique was considered. The tungsten carbide was the suitable reinforcement for Cu-Ti composite because of thermodynamic stable system of compound was attained. The mechanical, corrosion and wear behaviors have been discussed. The wear parameters have been optimized through Taguchi and Response Surface Methodology (RSM). The influential factor on wear rate was found and compared with the variance test.

Keywords: Copper tungsten composite, tungsten carbide, stir casting, optimization, wear and corrosion.

1. Introduction

The copper has excellent corrosion resistance, electrical and thermal conductivity. It has mainly used in electrical equipments, valves, pumps and domestic purposes. Titanium has better mechanical and wear behaviors. It was used in marine, aerospace and architecture. The both titanium and copper was converted to MMC through tungsten carbide. The wear and friction behaviors have been investigated on Mg-MMC and Taguchi optimization was used to found the optimal wear factors. The sliding velocity was provided the least effect on wear [1]. The pin on disc wear experimentation was
conducted on stir casted Al-MMC and its worn surfaces was analyzed through scanning electron microscope [2]. The surface layer, hardness and wear behaviors were discussed in titanium based alloy [3]. Thermal, corrosion and wear behaviors were analyzed in alumina and graphite reinforced copper MMC [4-6]. The corrosion and wear experiment was carried out in stir casted aluminium silicon MMC [7]. The heat treatment and its effect on wear and hardness were reported [8-10]. MMC have a much lower weight, greater strength and stiffness and are greater resistant to corrosion and wear [11,12]. Many researchers have focused on the Taguchi method with SN ratio and variance analysis to assess optimal conditions [13-35]. The present chapter was provides the details of mechanical, corrosion and wear behaviors of synthesized copper titanium composite. The wear optimizations were conducted and it was compared with an optimal results.

2. Material processing method
Stir casting was the suitable technique for the production of Cu-Ti composite. Before staring of the experiment, the stirrer and mold was preheated at 300ºC to remove moisture and gases from the surface. The weighted quantity of copper and titanium were placed in a graphite crucible at 1270ºC. Degassing agents were used to remove the film oxides and unstable chemical elements. It was used to reduce the casting defects. The 6 weight percentage of tungsten carbides was added to matrix alloys. The uniform stirrer has been applied at 600 rpm for 2 minutes. The very minimum percentage (0.2%) of magnesium was added to control the surface tension and viscosity of the molten metal. The composite was contains copper (58%), zinc (12%), aluminium (6%), vanadium (4.5%), iron (0.5%), titanium (7.5%) and tungsten carbide (1.5%). It has better substance behaviors such as hardness (417 BHN), tensile strength (522 MPa) and impact strength (14 J).

3. Wear experimentation and discussions
The pin on disc tribometer was applied to estimate the wear behavior of composite. The DUCOM Indian make with TR20 model wear testing apparatus was selected for these experimental investigations. The different level of factors such as load (10-20N), sliding distance (1200-1600m) and sliding velocity (2-6m/s) were taken for found out the wear rate. The copper titanium pin was fabricated with 8mm diameter and 30mm length. The experimental outcomes of wear rate were exposed in Table 1.

| Exp.No | Load(N) | Sliding distance (m) | Sliding velocity (m/s) | Wear rate (mm3/min) |
|--------|---------|----------------------|------------------------|---------------------|
| 1      | 10      | 1200                 | 2                      | 0.32                |
| 2      | 10      | 1400                 | 4                      | 0.30                |
| 3      | 10      | 1600                 | 6                      | 0.44                |
| 4      | 15      | 1200                 | 4                      | 0.54                |
| 5      | 15      | 1400                 | 6                      | 0.63                |
| 6      | 15      | 1600                 | 2                      | 0.53                |
| 7      | 20      | 1200                 | 6                      | 0.82                |
| 8      | 20      | 1400                 | 2                      | 0.69                |
| 9      | 20      | 1600                 | 4                      | 0.92                |

3.1. Taguchi optimization
The experimental was conducted with related to Taguchi L9 based orthogonal array. The present topic was to increase the wear resistance through addition tungsten carbides. The signal to ratios (SN) was determined through smaller was the better condition which was provided the better wear resistance.
The optimal wear rate was confirmed through SN ratio plot and it was shown in Fig. 1. It was achieved at applied load of 20N, sliding distance of 1600 m and sliding velocity of 6m/s. The role of factor on the response was exposed in Table 2. The load factor was produced highest effect on wear rate.

Table 2. Variance test for Cu-Ti MMC

| Source            | DF | SS        | MS        | F       | P       | % Role |
|-------------------|----|-----------|-----------|---------|---------|--------|
| Load              | 2  | 0.313267  | 0.156633  | 31.75   | 0.031   | 87.65  |
| Sliding distance  | 2  | 0.013400  | 0.006700  | 1.36    | 0.424   | 03.75  |
| Sliding velocity  | 2  | 0.020867  | 0.010433  | 2.11    | 0.321   | 05.84  |
| Error             | 2  | 0.009867  | 0.004933  | ---     | ---     | 02.76  |
| Total             | 8  | 0.357400  | ---       | ---     | ---     | 100    |

3.2. Response surface methodology

For RSM optimization, the three input and one response factors have been considered. The Box Behnken design was executed for the experimental design. Based on it, again wear rate experimentation was conducted and its outcomes were exposed in Table 3. The interception of factors was used for the developed model. Finally, the quadratic model has been developed to predict the wear rate and it’s shown in Table 4.

Table 3. Wear experimental outcomes - RSM

| Std | Run | A:Load | B:Sliding distance | C:Sliding velocity | Wear rate |
|-----|-----|--------|--------------------|--------------------|-----------|
| 1   | 15  | 10     | 1200               | 4                  | 0.23      |
| 2   | 12  | 20     | 1200               | 4                  | 0.35      |
| 3   | 6   | 10     | 1600               | 4                  | 0.25      |
| 4   | 14  | 20     | 1600               | 4                  | 0.42      |
| 5   | 11  | 10     | 1400               | 2                  | 0.28      |
| 6   | 2   | 20     | 1400               | 2                  | 0.38      |
| 7   | 5   | 10     | 1400               | 6                  | 0.3       |
| 8   | 16  | 20     | 1400               | 6                  | 0.49      |
3.2.1. Signal to noise (S/N) ratio analysis for MRR

The experiments have been carried out based on the orthogonal array which was able to reduce the number of trails. All experimental results have been transformed and evaluated through the signal to noise ratio. It was used to found the variations of the performance for desired values. The performance of the responses is related to the S/N ratio. Mean of S/N ratio has been shown in Table 4. From the SN ratio analysis, the water pressure is the prime factor to affect MRR and it is ensured by the delta rank value.

Table 4. Developed model for Cu–Ti MMC

| Basis                  | SS   | DF | MS       | F-value | P-value |
|------------------------|------|----|----------|---------|---------|
| Mean and Total         | 4.01 | 1  | 4.01     |         |         |
| Linear and Mean        | 0.0680 | 3 | 0.0227   | 0.5325  | 0.6680  |
| 2FI and Linear         | 0.0057 | 3 | 0.0019   | 0.0345  | 0.9909  |
| Quadratic and 2FI      | 0.3785 | 3 | 0.1262   | 5.21    | 0.0334  |
| Cubic and Quadratic    | 0.0025 | 3 | 0.0008   | 0.0200  | 0.9956  |
| Residual               | 0.1671 | 4 | 0.0418   |         |         |
| Total                  | 4.64 | 17 | 0.2727   |         |         |

The variance test was shown in Table 5. All individual factors and combination factors have been investigated through variance test. The developed model was significant and it has F value of 4.09. The next highest F value was allocated for applied load. Hence, it was the influential factor on wear rate. The same influential factor was achieved from Taguchi optimization method.

Table 5. Variance test for Cu-Ti MMC - RSM

| Basis            | SS    | DF | MS    | F-value | P-value |
|------------------|-------|----|-------|---------|---------|
| Model            | 0.4522 | 9  | 0.0502 | 4.09    | 0.0342  |
| A-Load           | 0.0421 | 1  | 0.0421 | 1.74    | 0.2292  |
| B-Sliding distance | 0.0098 | 1  | 0.0098 | 0.4045  | 0.5450  |
| C-Sliding velocity | 0.0162 | 1  | 0.0162 | 0.6687  | 0.4404  |
| AB               | 0.0006 | 1  | 0.0006 | 0.0258  | 0.8769  |
| AC               | 0.0020 | 1  | 0.0020 | 0.0836  | 0.7809  |
| BC               | 0.0030 | 1  | 0.0030 | 0.1249  | 0.7342  |
| A²               | 0.3132 | 1  | 0.3132 | 12.93   | 0.0088  |
| B²               | 0.0362 | 1  | 0.0362 | 1.50    | 0.2610  |
| C²               | 0.0077 | 1  | 0.0077 | 0.3176  | 0.5906  |
| Residual         | 0.1696 | 7  | 0.0242 |         |         |
| Lack of Fit      | 0.0025 | 3  | 0.0008 | 0.0200  | 0.9956  |
| Pure Error       | 0.1671 | 4  | 0.0418 |         |         |
The optimal solutions were found through response surface methodology. The optimal outcome was shown in Table 6. The same optimal result was obtained in Taguchi method.

**Table 6. Optimal outcome for Cu-Ti MMC - RSM**

| Number | Load | Sliding distance | Sliding velocity | Desirability |
|--------|------|------------------|------------------|--------------|
| 1      | 20   | 1600             | 6                | 1.000        |

The expected and residuals were shown in Fig. 2. All the expected values have been good agreements and lies within limits.

**Figure 2.** Schematic of stir casting set up for fabricating composite.

**Figure 3.** Cause on wear rate with load and sliding distance
The desired wear rate was derived at sliding distance of 1400m and its corresponding load of 14 – 16 N. From variance analysis, the applied load was the maximum effect on wear rate. The same effect has been noticed in the graph (Fig.3). The load and wear rate have more changeability on its graphical values.

4. Corrosion test
The gravity weight loss based corrosion experiment was conducted on Cu-Ti composite. Before dipping to the solution, the initial weight of the test specimen was deliberated. The polished MMC was immersed in to the 88ml of hydro choleic solution for 20-80 hours. After that it was taken out from the solution and then it was transferred to the acetone solution for 1-2 minutes. After completion of all processes, it was dried for 3 hour. The corrosion particles were observed through visual inspection. Similar, way the experimental procedure was repeated. The corrosion rate was decided between the deviation of weight of the samples before and after the experiments. For this corrosion experimentation, the initial and final weight of the composite was the same (100grams). Hence, no corrosion particles were accumulated on the composite surface.

5. Conclusions
- The tungsten carbide reinforced copper titanium MMC was formulated through stir casting method.
- It has hardness (417 BHN), tensile strength (522 MPa) and impact strength (14 J).
- The composite wear behaviors were evaluated under pin on disc tribometer. The wear factors were optimized through Taguchi and RSM.
- The optimal results were compared with two optimization methods. Both results were indicated with good agreements.
- The optimal wear rate was arrived at applied load of 20N, sliding distance of 1600 m and sliding velocity of 6m/s.
- From variance analysis, the applied load was the dominant factor on wear rate.

References
[1] V.Kavimani, K. Soorya Prakash, Titus Thankachan 2019, Experimental investigations on wear and friction behaviour of SiC@r-GO reinforced Mg matrix composites produced through solvent-based powder metallurgy, Composites Part B: Engineering, 162:508-521.
[2] S. Jeyaparakasam, R. Venkatachalam, C. Velmurugan (2019), Experimental investigations on the influence of TiC/Graphite reinforcement in wear behavior of Al 6061 hybrid composites, Surface Review and Letters 26(4):185-190.
[3] LIU Zheng-jun,JIA Hua,LI Meng 2018. Effect of Self-shielded Flux Cored Wire Surfacing and In-situ Synthesis TiB2-TiC Particles on Microstructure and Properties of Surfacing Alloy [J]. Journal of Materials Engineering, 46(7):106-112.
[4] Venkatesh R, Vaddi Seshagiri Rao 2018, Thermal, corrosion and wear analysis of copper based metal matrix composites reinforced with alumina and graphite, Defence Technology 14 (4): 346-355.
[5] A. Fathy, F. Shehata, M. Abdelhameed (2012), Compressive and wear resistance of nano metric alumina reinforced copper matrix composites, Mater Des. 36:100-107.
[6] S.G. Sapate, A. Uttarwar, R.C. Rathod, R.K. Paretkar (2009), Analyzing dry sliding wear behavior of copper matrix composites reinforced pre-coated SiCp particles, Mater Des. 30: 379-386.
[7] Khalid Abd El-Aziz, Dalia Saber, Hossam El-Din M. Sallam (2015), Wear and Corrosion Behavior of Al–Si Matrix Composite Reinforced with Alumina, Journal of Bio- and Tribo-Corrosion 1: 46-52.
[8] Sameezadeh M, Emamy M, Farhangi H (2011) Effects of particulate reinforcement and heat treatment on the hardness and wear properties of AA 2024-MOSi2 nanocomposites. Mater Des 32: 2157–2163.
[9] Rao R N, Das S (2011) Effect of sliding distance on the wear and friction behavior of as cast and Heat-treated Al–SiCp composites. Mater Des 32: 3051-3057.

[10] V.C. Uvaraja, N. Natarajan, K. Sivakumar, S. Jegadheeshwaran, S. Sudhakar 2014, “Tribological behavior of heat treated Al 7075 aluminium metal matrix composites,” Indian Journal of Engineering & Materials Sciences 22: 51–61.

[11] Stalin B, Sudha G T, Kailasanathan C and Ravichandran M 2020 Mater. Today Commun. 25 101655 https://doi.org/10.1016/j.mtcomm.2020.101655

[12] Stalin B, Vidhya V S, Ravichandran M, Naresh Kumar A and Sudha G T 2020 Metallofiz. Noveishie Tekhnol. 42(4) 497 https://doi.org/10.15407/mft.42.04.0497

[13] Sudha G T, Stalin B and Ravichandran M 2019 Mater. Res. Express 6 096520 https://doi.org/10.1088/2057-899X/988/1/012106

[14] Arravind R, Sankar V, Marichamy S and Stalin B 2020 Abrasive water jet experimentation on zirconium boride and boron carbide reinforced molybdenum metal matrix Mater. Today: Proc. https://doi.org/10.1016/j.matpr.2020.07.667

[15] Vairamuthu J, Senthil Kumar A, Stalin B and Ravichandran M 2020 Optimization of powder metallurgy parameters of TiC and B4C reinforced aluminium composites by Taguchi method Trans. Can. Soc. Mech. Eng. https://doi.org/10.1139/tcsme-2020-0091

[16] Malini T, Sudha R, Anantha Christu Raj P and Stalin B 2020 The role of RTD and liquid sensors in electric arc furnace for melting of aluminium Mater. Today:. Proc. https://doi.org/10.1016/j.matpr.2020.08.371

[17] Rajaparthiban J, Saravanavel S, Ravichandran M, Vijayakumar K and Stalin B 2020 Mater. Today:. Proc. 24 1282 https://doi.org/10.1016/j.matpr.2020.04.443

[18] Stalin B, Sudha G T and Ravichandran M 2020 Mater. Today:. Proc. 22 2622 https://doi.org/10.1016/j.matpr.2020.03.393

[19] Alagarsamy S V, Ravichandran M, Raveendran P and Stalin B 2019 J. Balk. Tribol. Assoc. 25(3) 730

[20] Stalin B, Ramesh Kumar P, Ravichandran M, Siva Kumar M and Meignanamoothy M 2019 Mater. Res. Express 6 106590 https://doi.org/10.1088/2053-1591/ab3d90

[21] Athijayamani A, Stalin B, Sidhardhan S and Boopathi C 2016 J. Compos. Mater. 50(4) 481 https://doi.org/10.1177/0021998315576555

[22] Stalin B, Ravichandran M, Vadivel K and Vairamuthu J 2020 Mater. Today:. Proc. 21 237 https://doi.org/10.1016/j.matpr.2019.04.226

[23] Saravanan S, Ravichandran M, Stalin B, Saravanavel S, Sukumar S, Optimization of Process Parameters of Electrochemical Machining of TiC-Reinforced AA6063 Composites, In: S. Hiremath, N. Shamugam, B. Bapu (eds) Advances in Manufacturing Technology, Lecture Notes in Mechanical Engineering, Springer, Singapore, 2019, pp.281-287. https://doi.org/10.1007/978-981-13-6374-0_33

[24] Stalin B, Sudha G T and Ravichandran M 2018 Silicon 10 (6) 2663 https://doi.org/10.1007/s12633-018-9803-6

[25] Marichamy S, Stalin B, Ravichandran M and Sudha G T 2020 Mater. Today:. Proc. 24 1400 https://doi.org/10.1016/j.matpr.2020.04.458

[26] Stalin B and Athijayamani A 2016 Int. J. Mater. Eng. Innov. 7(1) 15 https://doi.org/10.1504/IJMATEI.2016.077312

[27] Stalin B, Ramesh Kumar P, Ravichandran M and Saravanan S 2018 Mater. Res. Express 5(10) 106502 https://doi.org/10.1088/2053-1591/aad99c

[28] Marichamy S, Saravanan M, Ravichandran M and Stalin B 2017 Int. J. Mech. Mech. Eng. 21(1) 57

[29] Stalin B, Ravichandran M, Mohanavel V, Praveen Raj L 2020 J. Min. Metall. Sect. B. 56(1) 99 https://doi.org/10.2298/JMMB190315047S

[30] Pritima D, Vairamuthu J, Gopi Krishnan P, Marichamy S, Stalin B and Sheeba Rani S 2020 Response analysis on synthesized aluminium-scandium metal matrix composite using unconventional machining processes Mater. Today:. Proc. https://doi.org/10.1016/j.matpr.2020.07.672
[31] Balasubramanian M, Stalin B, Marichamy S, Anandan K and Ram Subbiah 2020 Assessment of weld joint strengths on dissimilar alloys of Inconel 625 and aluminium 7068 using FSW process Mater. Today:: Proc. https://doi.org/10.1016/j.matpr.2020.08.315

[32] Dhinakaran V, Stalin B, Swapna Sai M, Vairamuthu J, Marichamy S 2020 Recent developments of graphene composites for energy storage devices Mater. Today:: Proc. https://doi.org/10.1016/j.matpr.2020.08.631

[33] Martin Sahayaraj J, Arravind R, Subramanian P, Marichamy S, Stalin B 2020 Artificial neural network based prediction of responses on eglin steel using electrical discharge machining process Mater. Today:: Proc. https://doi.org/10.1016/j.matpr.2020.07.664

[34] Bagavathy S, Ramesh Kumar P, Anantha Christu Raj P, Stalin B 2020 Frequency measurement through electric network analyzer for ultrasonic machining of steel Mater. Today:: Proc. https://doi.org/10.1016/j.matpr.2020.08.629

[35] Anix Joel Singh J, Vishnu Vardhan T, Vairamuthu J, Stalin B, Ram Subbiah 2020 Analyses of particle size and abrasive water jet drilling of synthesized chromel metal matrix Mater. Today:: Proc. https://doi.org/10.1016/j.matpr.2020.08.441

Acknowledgments
The authors thank the Department of Mechanical Engineering, Sethu Institute of Technology, Kariapatti and Anna University, Regional Campus Madurai, Madurai, Tamil Nadu, India for their continuous encouragement to carry out this research work.