The Influence of TiO2/Si3N4 Nano-Particles on the wear Properties of Aluminium hybrid composites through stir casting process

T. Satya Prasad [1], K T Balaram Padal [2], J. Ramesh Babu[3], Arun K. K [4], R. Ramaswamy [5], Shikha [6]

[1]Department of Mechanical Engineering, Andhra University, visakhapatnam, Andhra Pradesh

[2]Department of Mechanical Engineering, Andhra University , visakhapatnam, Andhra Pradesh.

[3]Department of Mathematics, CVR College of Engineering, Hyderabad, Telangana

[4]Department of Mechanical Engineering , Kumaraguru College of Technology, Coimbatore, Tamilnadu.

[5]Department of Mechanical Engineering ,Gokaraju Rangaraju Institute of Engineering and Technology,Hyderabad, Telangana.

[6] Faculty of Pharmaceutical Sciences, Research & Incubation Centre, Rayat Bahra University, Chandigarh-Ropar NH 205, Greater Mohali, Punjab, 140103, India.

Abstract. The Wear tests for Al-Zn alloys reinforced with TiO_2 and Si_3N_4 were conducted using the Pin-on-Disc method to estimate the wear rate under different load conditions, sliding distance, and reinforcement percentage. The time period for each test was kept constant at 10 minutes. The results presented that when the load of 30 N was applied with a sliding distance of 1000 m, the wear rate decreased to 0.00154 mm^3/Nm. Nevertheless, as the load increased to 50 N and the sliding distance prolonged to 2000 m, the wear rate increased significantly to 0.00356 mm^3/Nm. This increase in wear rate could be attributed to the combined belongings of developed load and longer sliding distances, lead to greater frictional heat generation at the sliding interface. Moreover, at load of 50 N and a sliding distance of 2000 m, with 6 wt% TiO_2 and 2 wt% Si_3N_4 reinforcement, the wear rate further increased to 0.00503 mm^3/Nm. This suggested that the combination of raised load, extended sliding distance, and specific reinforcement percentages aggravated the wear due to intensified mechanical stress and heat buildup.

Keywords: Wear test, Al-Zn alloys, load, TiO_2 and Si_3N_4

1. Introduction

Industry uses Metal Matrix Composition (MMC) extensively to modify the base metal's characteristics as needed. The mechanical and tribolgical qualities of metal can both be improved with the aid of these composites. In MMC, a base metal is strengthened by a substance to give it more strength [1][2].Strongness to weight ratio and good formability are characteristics of aluminium and aluminium alloys. Because of these characteristics, aluminium alloys have been a viable material for many automotive and aviation fuselage applications [3].To create products with improved tribological characteristics aluminium alloy usage for automotive applications is solely dependent on metallurgical process and mechanical property improvements.

Corresponding author: ram4mgriet@gmail.com

To comprehend the impact of element additions upon the wear resistance of aluminium alloys, numerous studies have been developed [4]. Aluminium alloy (AA5083)/nano-Al2O3 metal matrix composites were investigated for their tribological behaviour, with different weight percentages of 2, 4, 6, and 8 wt.-% nano-Al2O3 particles used as reinforcement. Stir casting was the method used to manufacture the Al/nano-Al2O3 composites. A pin-on-disc test setup was used to investigate sliding wear behaviour.
The three process parameters applied stress, sliding distance, and reinforcement weight percentage were used at five different levels in the experiment design, which followed Taguchi's L25 orthogonal array. The results show that composites enhanced with nanoparticles had better wear resistance. The main effects plot indicated that wear decreased with an increase in the percentage of reinforcement and increased with the load and sliding distance. According to the results of the ANOVA, the sliding distance had the most important contributing factor. The specimen subjected to the maximum load condition demonstrated signs of abrasive wear phenomenon based on the worn surface morphology [5].

Wu.X et.al [6]conducted wear experiments on Al/Sn and Al/Sn/Er/Zr alloys. The light delamination wear was replaced by adhesive wear and the delamination of the wear as load increased. Comparing the wear scars of various samples subjected to the same stress revealed that the mechanism of wear remained same with the inclusion of trace Er and Zr and the annealing process.

Pruthvi.H et.al [7] aimed to change the Al-Zn alloy in order to investigate the effects of zinc wear parameters on the rate of wear for the modified alloy under various circumstances. After undergoing Solutioning treatment, the transformed Al-Zn alloy underwent RRA heat treatment. The Al-Zn alloys were machined and cut in accordance with ASTM standard dimensions. Grain size and irregular grain boundary noted in the microstructure. It was discovered that wear rate decreased as zinc concentration and re-aging time increased. Furthermore, by employing an L27 (213) orthogonal array, Taguchi's Technique was implemented with 3 wear parameters and three levels for each. To determine the percentage contribution of each factor, an ANOVA has been performed. It is clear from the regression analysis that there exists good agreement between the experimental data and the predictable values.

In order to examine the impact of SiC particle percentage and the matrix alloy on the wear performance of the materials, stir casting of aluminium metal matrix composites was conducted using a recently designed stirring equipment. pin-on-plate tests were used to assess the composites' wear performance against train brake pad. The worn surface displayed signs of third body wear, while the composite enhanced with 19% of SiC showed an increased COF during wear. The metallic phases reserved the formation of the iron-based tribolayer, whereas the very rare earth and transition metals add to the matrix alloy elevated the composite hardness [8]. From the above existing works, we conduct the wear test on the Al-Zn/TiO2/Si3N4 composites with different Wt% of reinforcement.

2. Materials and reinforcements selection

Al-Zn alloy was designated as the matrix material for this investigation due to its excellent combination of strength, light weight, and corrosion resistance, which make it ideal for various engineering applications, including aerospace and automotive industries. To enhance wear properties, Si_3N_4 and TiO_2 were chosen as reinforcements to develop an Al-based hybrid composites. Si_3N_4 is recognized for its exceptional wear resistance, and thermal stability, making it an excellent property to recover the wear behavior of the composite. TiO_2 contributed to augmented corrosion resistance, and reduced friction, making the composite suitable for applications.The hybrid composite was prepared by varying Wt% of Si_3N_4 and TiO_2, integrating them at 2 wt%, 4 wt%, and 6 wt% . These reinforcement combinations were mixed into the Al-Zn matrix to examine their effect on wear rate. The stir casting was employed to fabricate the composites, cost-effective method for producing Al matrix composites. This process involves vigorously stirring the molten Al alloy while gradually adding the reinforcements, ensuring uniform distribution of reinforcement particles within the matrix.

3. Wear test

The wear test was directed by using Pin on Disc apparatus to estimate the wear behaviour of the fabricated composites [9]. The experimental setup, as illustrated in Fig. 1, consist of a stationary pin made of the composite material that slide against the disc. Each composite sample was exposed to varying loads of 30 N, 40 N & 50 N to study the effect of load on the wear performance. the sliding distance was varied across three levels 1000 m,

1500 m, and 2000 mover at a constant test duration of 10 minutes. These parameters were selected to imitate operating conditions where materials experience different loads and sliding distances [6].

Fig. 1. pin on disc apparatus

The wear rate was found by measuring the weight loss of the sample before and after the test. After each test, the pins were cleaned and weighed to ensure accurate measurement of weight loss [10] [11][12].

Wear Rate= Loss of Weight / (Sliding Distance × Load) in mm^3/Nm

4. Result and discussion

Figs 2 and 3 depicted the wear rate of the Al alloy composite reinforced with the TiO_2 and Si_3N_4 under the different loading conditions and sliding distances. Fig. 2 illustrated the wear rate for the composition of 2 wt% of TiO_2 and 4 wt% of Si_3N_4, while Fig. 3 represented the wear behaviour for 4 wt% of TiO_2 and 4 wt% of Si_3N_4. The applied load was varied from 30 N to50 N, and sliding distance ranged from 1000 m to 2000 m.

Wear rate decreased to 0.00154 mm^3/Nm when load of 30 N was preserved with a sliding distance of 1000 m. The reduction in wear rate attributed to the formation of a protective tribo-layer at the contact surface. The occurrence of reinforcements further aid in the stability of this tribo-layer, enhancing wear resistance. At the lower loads and shorter sliding distances, the heat generated was minimal, avoiding excessive material softening and maintaining the hardness of the composite surfaces. when the load improved to 50 N & the sliding distance extended to 2000 m, the wear rate increased significantly to 0.00356 mm^3/Nm. The increase in wear explained by the combined effects of higher load and longer sliding distances, which leading to more frictional heat generation at the sliding interface. The elevated temperatures can cause softening of the Al matrix, reducing hardness and making it more vulnerable to wear. The heat generated at the interface may also degrade the protective tribo-layer or even cause it to break down, exposing the fresh material to direct wear. Besides, increased load amplifies the mechanical stresses at the contact points, makes to higher material loss. The role of reinforcements, while beneficial at lower loads, may be insufficient to fully mitigate wear at the higher loads and longer distances, when thermal effects come into play.

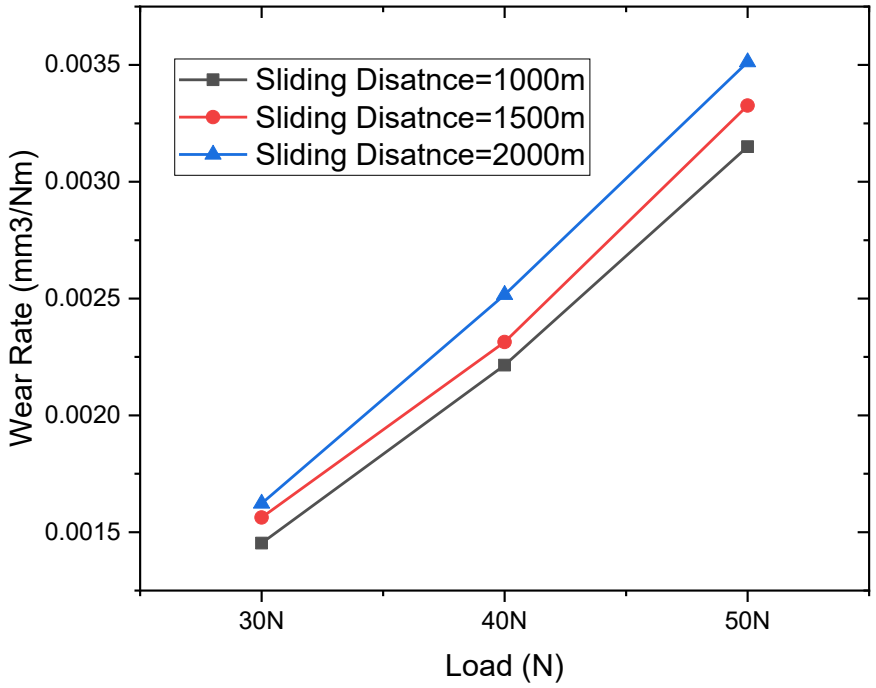

Fig. 2. Wear rate of Al-Zn alloy with TiO_2 2wt% + Si_3N_4 4wt%

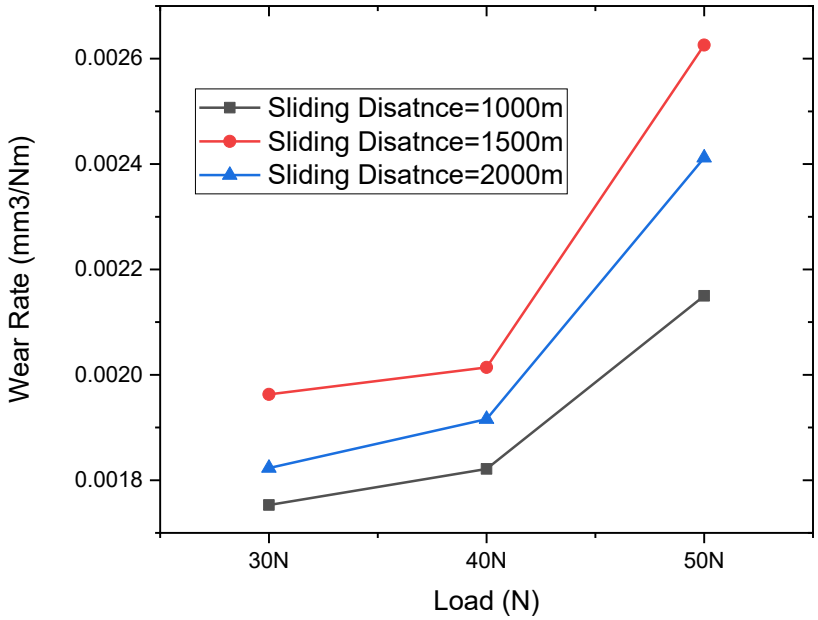

Fig. 3. Wear rate of Al-Zn alloy with TiO_2 4wt% + Si_3N_4 4wt%

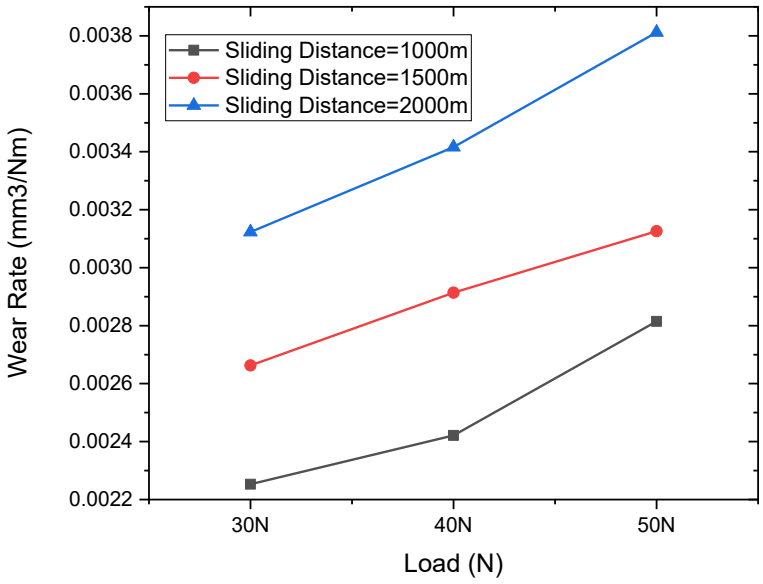

Fig. 4. Wear rate of Al-Zn alloy with TiO_2 6wt% + Si_3N_4 4wt%

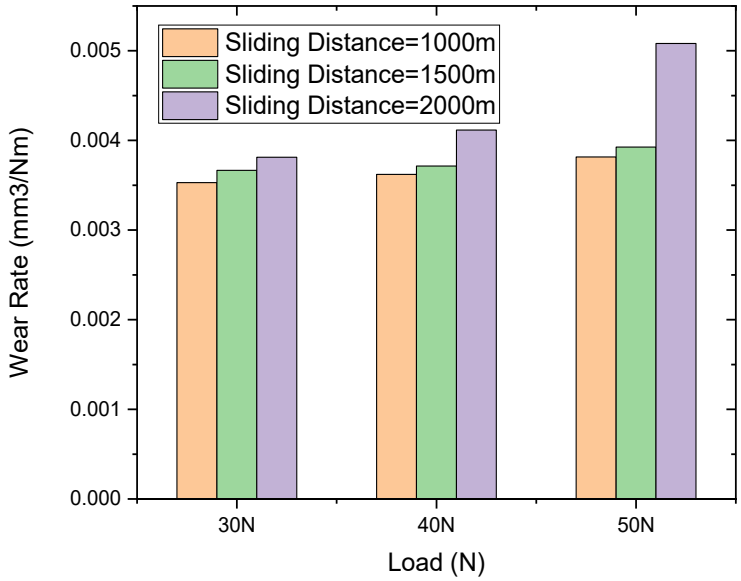

Fig. 5. Wear rate of Al-Zn alloy with TiO_2 6wt% + Si_3N_4 2wt%

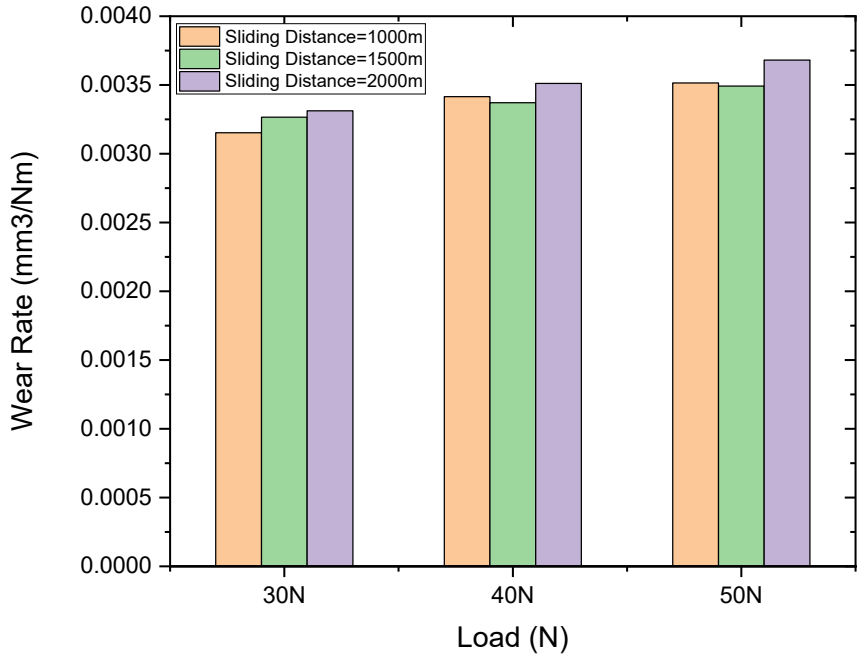

Fig. 6. Wear rate of Al-Zn alloy with TiO_2 6wt% + Si_3N_4 4wt%

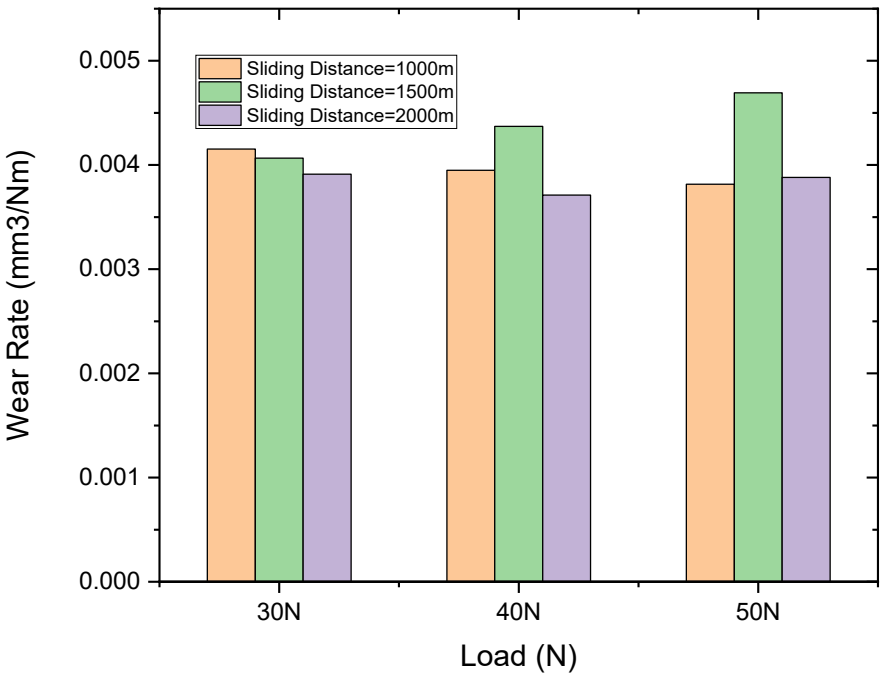

Fig.7. Wear rate of Al-Zn alloy with TiO_2 6wt% + Si_3N_4 6wt%

Table 1. Wear test parameters

parameters	**values**
Load	30N,40N and 50N
Sliding distance	1000m, 1500m, 2000m,
Disk speed	1000rpm
Time duration	10 mins
Temperature	Room temperature

From Figure 4, it was evident that the wear rate of Al alloy composite with TiO_2 6 wt% and Si_3N_4 4 wt% increases to 0.00387 mm^3/Nm under load ranging from 30 N to 50 N and sliding distances between 1000 m and 2000 m. This wear rate is noticeably higher compared to the composites depicted in Figures 2 and 3, which had lower reinforcement percentages of TiO_2 and Si_3N_4. The rise in wear rate can be explained by the behavior of the ceramic reinforcements under higher mechanical stresses and sliding distances.

TiO_2 and Si_3N_4 are both ceramic materials known for their high hardness, which contributed to the overall strength and wear resistance of the composite. However, ceramics, while hard, are also brittle and prone to microfractures under high loads and extended sliding distances. At elevated loads (30 N to 50 N) and longer sliding distances (1000 m to 2000 m), the ceramic particles within the composite can experience microfracture or even pull-out from the Al matrix. This phenomenon leads to abrasive wear, where the fractured ceramic particles become debris that further accelerates wear by acting as abrasives against the matrix material.

As these particles grind between the sliding surfaces, they increase material removal, thereby raising the overall wear rate of the composite.To further analyse the effect of Si_3N_4 content on the wear rate, Figure 5, Figure 6, and Figure 7 illustrate the wear rate as the Si_3N_4 weight percentage was varied while kept TiO_2 constant of 6 wt%. The observations reveal significant insights into the role of Si_3N_4 in determining wear rate. At the 50 N load, a sliding distance of 2000 m, TiO_2 6 wt% and Si_3N_4 2 wt%, the wear rate increases to 0.00503 mm^3/Nm. The lower content of Si_3N_4 (2 wt%) might not provide sufficient reinforcement to consistently protect the Al matrix. In this case, the reinforcement particles might not be sufficiently distributed throughout matrix, resulting in areas of the composites being less protected against the wear [13][14].

This uneven distribution caused the localized wear, where the softer Al matrix was exposed to high contact stresses, leading to greater material removal & higher wear rate. The lack of sufficient reinforcement means the composite did not effectively resist the load and extended sliding distances, resulting in increased the wear.At a 40 N load and the same sliding distance of 2000 m, when the Si_3N_4 was increased to 6 wt% (with TiO_2 held at 6 wt%), the wear rate reduced. The higher Si_3N_4 content enhanced the composite wear resistance. By increasing the Si_3N_4 weight percentage from 2 wt% to 6 wt%, the composite gained more effective protection against wear, chiefly under load of 40 N. The presence of a greater number of Si_3N_4 particles created a more uniform and robust erection that resists wear better, thereby dropping the wear rate significantly compared to lower reinforcement weight.the wear rate was heavily influenced by both the reinforcement content and the applied load. While TiO_2 and Si_3N_4 contributed to increased wear resistance, their effectiveness was highly dependent on the wt% and distribution within the matrix. Conversely, increasing the Si_3N_4 content significantly improves the composite's ability to resist wear, especially at moderate loads and extended sliding distances.

5. Conclusion

The composite was prepared by the varying the Si_3N_4 and TiO_2, incorporating them at levels of 2 wt%, 4 wt%, and 6 wt% . Wear tests were directed using a Pin-on-Disc to evaluate the wear rate of the fabricated composites. The results revealed that the wear rate decreased to 0.00154 mm^3/Nm when a load of 30 N was preserved with a sliding distance of 1000 m. This reduction in wear rate can be attributed to the formation of a protective tribo-

layer at the contact surface during sliding wear. This tribo-layer, composed of wear debris and surface oxides, serves to minimize direct metal-to-metal contact, thus enhancing the wear resistance of the composite. when the load was increased to 50 N and the sliding distance extended to 2000 m, the wear rate rose significantly to 0.00356 mm^3/Nm. This indicates that under higher loads and longer sliding distances, the wear rate for the Al alloy composite with TiO_2 6 wt% and Si_3N_4 4 wt% increased to 0.00387 mm^3/Nm. At the 40 N load with the same sliding distance of 2000 m, when the Si_3N_4 content was increased to 6 wt% , TiO_2 at 6 wt%, the wear rate decreased.

References

1. R. Praveen Kumar, P. Periyasamy, S. Rangarajan, and T. Sathish, Mater. Today Proc. **21**, 504 (2020)
2. T. Sathish and S. Karthick, J. Mater. Res. Technol. **9**, 3481 (2020)
3. B. Zahmatkesh, M. H. Enayati, and F. Karimzadeh, Mater. Des. **31**, 4891 (2010)
4. P. Paramasivam and S. Vijayakumar, Mater. Today Proc. **81**, 965 (2023)
5. R. Suresh, G. Joshi Ajith, and N. G. Siddeshkumar, Rev. Metal. **58**, e213 (2022)
6. X. Wu, D. Wang, V. De Andrade, Y. Jiang, W. Wang, S. Wen, K. Gao, H. Huang, S. Chen, and Z. Nie, J. Mater. Res. Technol. **9**, 14828 (2020)
7. H. M. Pruthvi and H. Ghanashyam Shenoy, Mater. Today Proc. **59**, 79 (2022)
8. A. Du, L. Lattanzi, A. E. W. Jarfors, J. Zheng, K. Wang, and G. Yu, Wear **530**–**531**, 204969 (2023)
9. S. Vijayakumar, S. Anitha, R. Arivazhagan, A. D. Hailu, T. V. J. Rao, and H. P. Pydi, Adv. Mater. Sci. Eng. **2022**, 1 (2022)
10. P. Anusha, M. N. S. Sri, S. Vijayakumar, T. V. J. Rao, P. Paramasivam, S. Jeyakrishnan, and K. K. Saxena, Int. J. Interact. Des. Manuf. **18**, 5773 (2024)
11. B. Gugulothu, P. S. S. Kumar, N. S. Rao, S. Vijayakumar, D. R. Rajkumar, T. V. J. Rao, and M. Naga Swapna Sri, in (2024), pp. 131–138
12. S. Sathees kumar, S. Seenivasan, I. J. Isaac Premkumar, S. Vijayakumar, P. Anusha, and A. Pradeep, Interactions **245**, 257 (2024)
13. B. Gugulothu, S. L. Sankar, S. Vijayakumar, A. S. V. Prasad, M. Thangaraj, M. Venkatachalapathy, and T. V. J. Rao, Adv. Mater. Sci. Eng. **2022**, 1 (2022)
14. H. P. Pydi, A. P. Pasupulla, S. Vijayakumar, and K. P. Indira, in (2022), p. 020004