Assessment of wear behavior analysis on normalized martensitic stainless steel for sustainable applications

S. Sathish[1], *T.* Beena[2], *V.* Rahul[3*], *M.* Saravana Kumar[4], *A*. Daniel Das[5], *B*anu Seema[6], *Ramaswamy* Ram[7]

[1]Mechanical Engineering Department, Sri Ramakrishna Engineering College, Coimbatore, Tamilnadu
[2]Physics Department, SRM Institute of Science and Technology, Ramapuram, Chennai Tamilnadu.
[3]Mechanical Engineering Department, CVR College of Engineering, Hyderabad, Telangana
[4]Mechanical Engineering Department, PSNA College of Engineering and Technology, Dindigul, Tamilnadu
[5]Mechanical Engineering Department, Karpagam Academy of Higher Education, Coimbatore, Tamilnadu.
[6]Master of Business Administration Department, BMS Institute of Technology & Management, Bengaluru, Karnataka
[7]Mechanical Engineering Department, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, Telangana.

Abstract. An alloy of iron and chromium is called stainless steel. The compositionratio of stainless steel will vary depending on the grade require d and the intended use of the steel, although it must contain at least 0.5% c hromium. Numerous applications exist for stainless steel in the industrial and consumer markets because of its superior corrosion resistance, high strength and good appearance aesthetic wise. Because of the chemical composition, martensitic steel is a kind of stainless steel that can be strengthened, hardened with heat and ageing processes. Because of these techniques, Martensitic steel is stronger than other kinds, which makes it a good option for manufacturing mechanical valves, turbine parts, medical equipment applications. AISI 410 martensitic stainless are strong and wear resistant one. The usage of this material is limited because of its hardness. For enhancing the ductility, these steels were subjected to normalizing process at 740°C, 840°C, 940°C and designated as N1, N2, N3 respectively. The samples were made cylindrical in shape with 11 mm diameter, length of 40 mm. The outcomes of the results like measurement of hardness, loss of wear were noted down and comparisons of microstructures with all the samples were carried out.

Keywords: Normalizing, hardness, wear, ductility, stainless steel.

* Corresponding Author - vudarahul@gmail.com

1 Introduction

The 400 Grade series of stainless steels includes martensitic stainless steels.They contain up to 1%, 11.9% to 14.8% chromium and a low to high carbon content. It is employed when ever high strength at low temperatures, creep resistances at high temperatures is needed in addition to corrosion and/or oxidation resistance [1-3]. Among the most potential desirable steels, AISI 410 steels are widely employed in the fabrication of components that has high toughness, strength and resistance to corrosion. AISI 410 steels are unique among the other steels due to their outstanding combination of properties that includes suitable corrosion resistance, its strength, durability and flexibility [4-6]. They can be heat treated to achieve desired mechanical characteristics for specific applications. At high temperatures, these steels exhibited face-centered cubic structure. During normalizing and normalizing treatment, transformations from the martensite to austenite phase were obtained, resulting in a body-centered cubic (BCC) structure [7-10].

AISI 410 steels have poor formability and weldability. However, addition of sulphur improves the machinability which makes them for cold work processing. Normalizing improves the mechanical characteristics, corrosion properties of martensitic stainless steels [11-15]. This process modifies the microstructure of the AISI 410 material, affecting its behavior. Normalizing and normalizing at different temperatures alters dislocation and grain size, affecting the delicate balance of strength and ductility. Higher normalizing temperatures reduce dislocation density and coarse grain, leading to decreased strength but increased ductility [16-20]. During normalizing, the cementite content in martensite phase gets decomposed and minimizes the property of hardness in martensite material. AISI 410 martensitic stainless steels are very strong and hard when hardened; they are not very ductile. It is common practice to temper these steels in order to impart desirable engineering characteristics [21-24]. Typically, martensitic stainless steels can be tempered anywhere from 480 to 750°C. Within this range, martensite hardness reduces with time and temperatures. Normalizing higher-Cr alloys for too long could cause the ferrite to undergo sigma phase precipitation, increasing the hardness [25-29].

2 Experimental Procedures

2.1 Materials specification

AISI 410 materials were treated with normalizing process. The samples were sheared to 40 mm in length, diameter of 11 mm for this research work as shown in Fig.1. The material composition were noted to be Chromium 13.7%, Phosphorus 0.0 %, Nickel 0.59 %, sulphur 0.03 %, carbon 0.14 %, silicon 1.2 %, manganese 1.2% and rest of the content Iron [30-33].

Fig. 1. AISI 410 Samples

2.2 Wear Test

The samples were polished with the help of emery papers graded with 1/0, 2/0, 3/0, 4/0. With the help of acetone, the specimen surfaces were cleaned. A pin on disc machine is used for analyzing the wear behavior. Treated and untreated samples are undergone under wear test. A load of 20N was applied as a constant load subjected to a speed of 750 rpm for a duration of 5 minutes. A load of 15N is applied on the pin for time duration of 3 minutes and the disc is rotated at a speed of 1500 rpm [34-37]. The specifications of the tribometer are magnum engineers make as shown in Fig.2, load range 200 N maximum, Frictional force range 200N maximum, diameter of the disc Ø170 mm maximum, track diameter 10 to 150 in mm, speed of the disc 100 - 2000 rpm, Length of the pin 10 to 30 mm, Pin diameter Ø3 mm to Ø14 mm [38-41].

Fig. 2. Wear Testing Machine

3 Results and discussion

3.1 Hardness Measurements

With the help of Rockwell hardness tester, the hardness of the normalized samples and untreated sample were measured. The specification of Rockwell hardness tester used for this research work is krystal industries make, maximum load 150 Kgf, maximum test height 260 mm, throat depth 135 mm, base size 2000x450mm, machine height 700mm, net weight 70kg. The specimens were loaded with 150 Kgf for 30 seconds and the hardness was monitored [41-43]. AISI 410 hardness was identified as 30 HRC, for N1- 26 HRC, N2 - 24 HRC, N3 - 23 HRC.

3.2 Microstructure analysis

From the scanning electron microscope, the microstructures of normalized and untreated samples were captured. The following are the specifications of scanning electron microscope machine used for this research work as shown in Fig.3 – Hitachi make - SU3800 model, 3.0 – 15 nm secondary resolution, 4 nm backscattered electron resolution, magnification range 5x to 35000x, 0.2 to 35 kV accelerating voltage, specimen size 10 to 300 mm, movable height 90 to 150 mm, 5 axis motor drive, cartridge type - tungsten hairpin filament electron gun, 5 hole objective lens aperture. The comparison on the surfaces of specimens was analyzed [44-46].

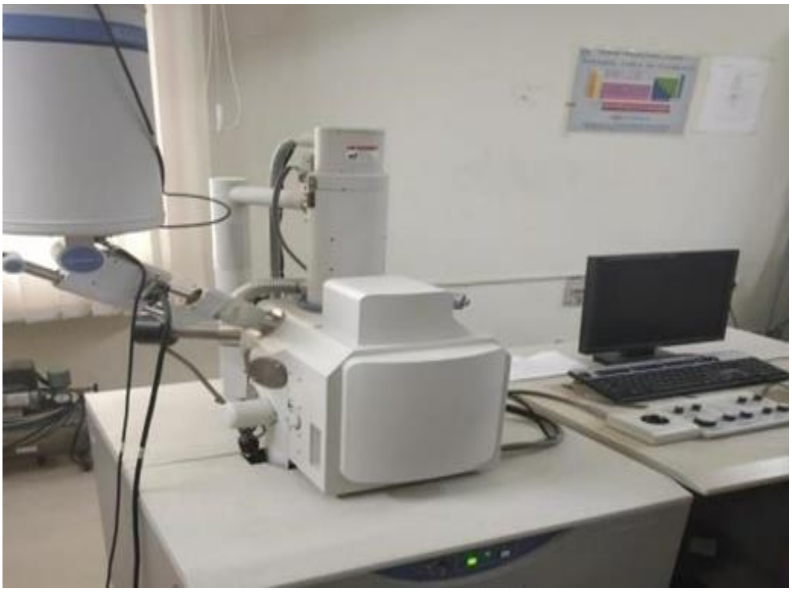

Fig. 3. Scanning Electron Microscope utililized for the Research work

After the wear test, the surfaces of the samples were subjected to micro structural analysis. Due to its hardness and brittleness, untreated AISI 410 material was found to have minimized peel of material during wear test. Due to the absence of heat treatment in the untreated material, the peel is reduced. Combined carbon was identified in microstructure of martensitic stainless steels with more hardness. Martensitic stainless steel has a tempered microstructure that is mostly formed due to combined carbon [47-49]. Low volume wear loss was achieved because the material is hardened due to the existence of residual austenite and cementite, which also ensures that the microstructure remains unchanged as shown in Fig.4.

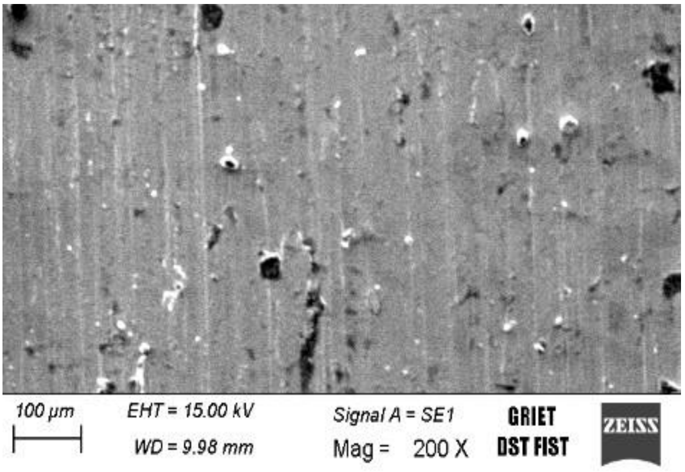

Fig. 4. AISI 410 Microstructure

Fig.5 reveals the microstructure of normalized sample at 740°C. The material became more soft and its hardness was reduced, making the material more ductile. The brighter phase revealed on the microstructure reveals the slow transformation of material from martensite to retained austenite. Minor cracks were noticed and it is because of the load acting on the material during the wear test. The diffusion zone revealed the presence of minute micro-etches in the compound layer.

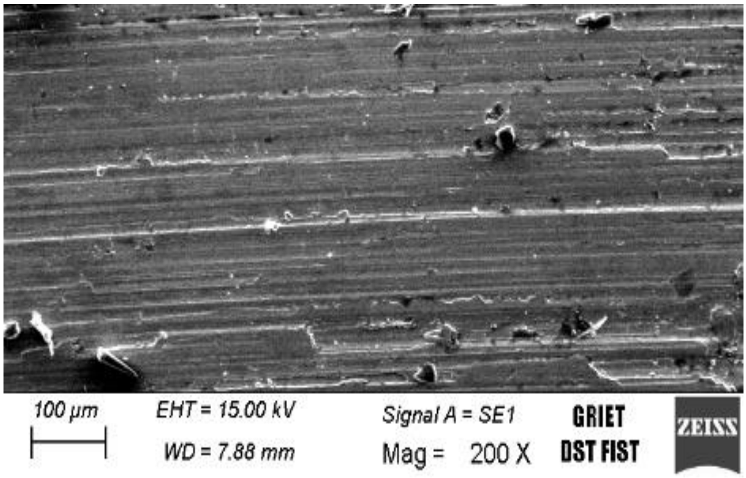

Fig. 5. Microstructure of normalized sample at 740°C

Fig. 6 shows the sample normalized to 840°C. As a result of normalizing at higher temperature and then slowly cooling, the hardness and strength of stainless steel material were significantly reduced. Compared to tempered samples, the material grew softer and wear loss was higher. This is due to decrease in wear resistance that increases the stainless steels ductility [50-53]. Within the microstructure, a layer with micro holes and cracks could be seen. Normalized samples wear resistance is affected by the production of ferrrite and enlarged austenite, which increases the wear. The combined carbon have got decomposed and increase in retained austenite phase were revealed in the microstructure inhibits the martensitic transition into expanded austenite phase.

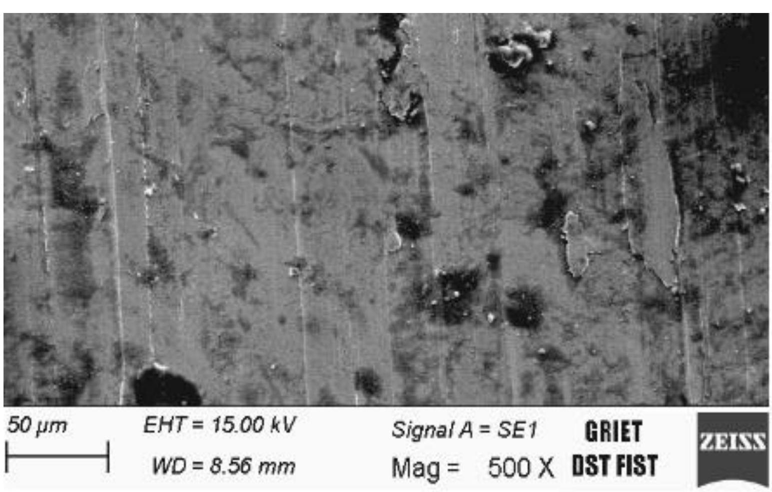

Fig. 6. Microstructure of normalized sample at 840°C

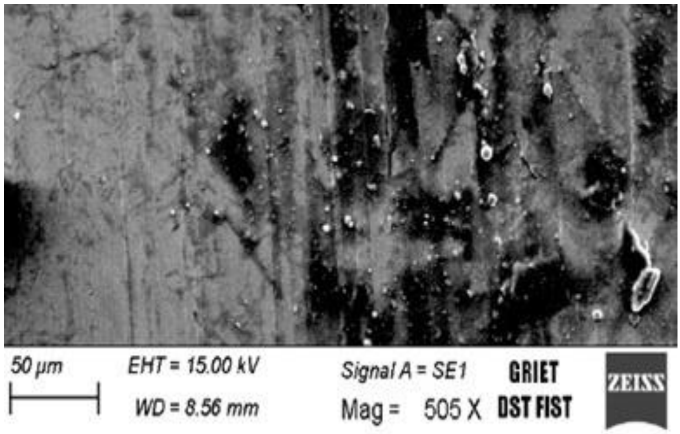

Fig. 7. Microstructure of normalized sample at 940°C

The sample's hardness was significantly reduced, which enhanced its ductility. A phase transition from martensitic to austenitic was achieved by air cooling the sample as shown in Fig.7. Delamination of the material and cracks that had formed on the normalized sample treated at 940℃ was noted in the microstructure. Tiny micro-etches and holes were visible in the compound layer and diffusion zone noted to have retained austenite phase. The production of carbides that are unstable notified in the microstructure and its due to delayed cooling process. The external load acting on the sample are the other reasons behind it. It was discovered that when hardness increases, the specimen's ductility decreases its stable wear resistance

4 Conclusions

Normalizing is a commercial heat treatment process applicable for hardened materials for stabilization with hardness, brittleness and preferred for various sustainable applications like solar power plant components. Very few works are made on AISI 410 material and the major findings from this work are:

1. From the wear behavior analysis, more material loss was obtained in the normalized sample and revealed wear resistance to be worse than untreated sample. Due to the presence of combined carbon in martensitic stainless steel material, the microstructure remained unchanged. No peel of material was noticed.
2. Normalizing revealed carbides in stabilization of hardness and ductility, while normalizing process has decomposed combine carbide transforming the material to retained austenite phase.
3. The treated samples revealed the hardness and were found to be lesser than untreated samples. It was found to be 23 HRC for the Normalized sample at 940°C, 30 HRC for the untreated stainless-steel sample.

References

1. Y Zhao, B Yu, L Dong, J Xiao, Surf Coat Tech. J. E, 210, 90 (2012).
2. M Laleh, F Kargar, M Velashjerdi, Mater Eng Perform. J. E, 22, (2013)
3. Tong, Z Han, LM Wang, J Lu, K Lu. Surf Coat Technol. J. E, 202, 3947 (2008).
4. D Majumdar, J. Alphonsa, A. Basu, Wear. J, E 62, 3117 (2008)

5. P. Tschiptschina, A. S. Nishikawaa, Luis Bernardo Varelaa, Thin Solid Films. J. E, 644 96 (2017).
6. T. BlesslinSheeba, A. AlbertRaj, D. Ravikumar, S. SheebaRani, P. Vijayakumar, Ram Subbiah, Materials Today: Proceedings, 45, 2440-2443 (2021).
7. A. Jayapradha, G. JimsJohnWessley, G. Vimalarani, P. RameshKumar, Ram Subbiah, S. Maniraj, Materials Today: Proceedings, 45, 2121-2124 (2021).
8. Veernapati Gitanjali, Panati Nithya, P. Pandiarajan, Nunna Dhruthi, TappaVineeth Raj, Ram Subbiah, Materials Today: Proceedings, 45, 2479-2481 (2021).
9. M. Makesh, G. Sivaraman, N. Saravanan, S. Prashanth, Ram Subbiah, K. Anand, Materials Today: Proceedings, 45, 2498-2500 (2021).
10. N. Ravikumar, P. Sharmila, S.P. Premnath, Rajakumar S. Rai, J. Mohammed Feros Khan, Ram Subbiah, Materials Today: Proceedings, 45, 2581-2583 (2021).
11. R. Ganesh, Ram Subbiah, K. Chandrasekaran, Materials Today: Proceedings, 2, 1441-1449(2015).
12. S. Surendarnath, Ram. Subbiah, K. Sankaranarayanasamy, B. Ravisankar, Materials Today: Proceedings, 4, 2544-2553(2017).
13. Ram Subbiah, Md. Rahel, A Sravika, R. Ambika, A. Srujana, E. Navya,Materials Today: Proceedings, 18, 2265-2269 (2019).
14. B.Chaitanyakumar, P. SriCharan, Kanishkar Jayakumar, D.Alankrutha, G.Sindhu, Ra m Subbiah, Materials Today: Proceedings, 27, 1541-1544 (2020).
15. T. Lakshmi Deepak, G. Ananda Mithra, K. Lokesh, B. Sai Chandra, Ram Subbiah, Materials Today: Proceedings, 27, 1681-1684 (2020).
16. A. Rohit Sai Krishna, B. Vamshi Krishna, T. Sashank, D. Harshith, Ram Subbiah, Materials Today: Proceedings, 27, 1555-1558 (2020).
17. J. Anix Joel Singh, T. Vishnu Vardhan, J. Vairamuthu, B. Stalin, Ram Subbiah, Materials Today: Proceedings, 33, 4893-4896 (2020).
18. K. ManjithSrinivas, S. Bharath, P.N.V. KrishnaChaitanya, M. Pramod, Ram Subbiah, Materials Today: Proceedings, 27, 1575-1578 (2020).
19. S. Sathish, K. Kesavaraj, L. Girisha, A. DanielDas, Pradeep Johnson, Ram Subbiah, Materials Today: Proceedings, 47, 4235-4238 (2021).
20. M.Mamatha Gandhi, Animesh Bain, P Rohith, R. Srilatha, Ram Subbiah, E3S Web of Conferences, 184, 01002, (2020)
21. K. Ramya Sree, G. Keerthi Reddy, K. Aishwarya, E. Nirmala Devi, Ram. Subbiah, E3S Web of Conferences 184, 01003 (2020)
22. A Rohit Sai Krishna, B Vamshi Krishna, D Harshith, T Sashank, Ram Subbiah, E3S Web of Conferences 184, 01018 (2020)
23. Shivani Koppula, Aakula Rajkumar, Siram Hari Krishna, Reddi Sai Prudhvi, S. Aparna,Ram Subbiah, E3S Web of Conferences 184, 01019 (2020)
24. Lakshmi Deepak Tadepalli, Ananda Mithra Gosala, Lokesh Kondamuru, Sai Chandra Bairi, A. Anitha Lakshmi, Ram Subbiah, E3S Web of Conferences 184, 01020 (2020)
25. Gandla Lakshmi Prasanna, G. Keerthi Reddy, Ram Subbiah, E3S Web of Conferences 184, 01021 (2020)
26. Gandla Lakshmi Prasanna, J Saranya, Ram Subbiah, E3S Web of Conferences 184, 01022 (2020)
27. Manne Vamshi, J. Saranya, Ram Subbiah, E3S Web of Conferences 184, 01023 (2020)
28. ManneVamshi, AnimeshBain, M. Sreekanth, Ram Subbiah, E3S Web of Conferences 184, 01024 (2020)
29. M. Mamatha Gandhi, J. Saranya, G. Keerthi Reddy, S. Srikanth, Ch. Keshav, M. Niranjan, S. Someshwar Rao, Ram Subbiah, E3S Web of Conferences, 309, 01066 (2021).

30. D.Prathusha, J.Venkatesh, K.K.Arun, KulkarniSanjay Kumar, S. Prabhu, Ram Subbia h, Materials Today: Proceedings, 47, 4312-4315 (2021).
31. Animesh Bain, B.RamakrishnaReddy, PrasadRamchandra,Baviskar, M Patil Milind, J. Saranya, P. Geethasree, R. Shruthi, Ram Subbiah, E3S Web of Conferences, 309, 01125 (2021).
32. K. Ramya Sree, D. Raguraman, J. Saranya, Animesh Bain, V.SrinivasViswanth, S. Ap arna, Ch. Dhanush, Ram Subbiah, E3S Web of Conferences, 309, 01181 (2021).
33. B Divyasri, Ch.PhaniRamaKrishna, Pradeep Jayappa, G. Keerthi Reddy, V. Vinay Ku mar, B. Shankarachary, M. Surya and Ram Subbiah, E3S Web of Conferences, 309, 01182, (2021).
34. Ram Subbiah, V. Vinod Kumar, G. Lakshmi Prasanna, Materials Today: Proceedings, 26, 2946-2952 (2020).
35. Ram Subbiah, Anand Poras, K. Ratna Babu, M. Mamatha Gandhi, K. Ramya sree, Ch. Naveen, Materials Today: Proceedings, 26, 2977-2982 (2020).
36. A Kumar, H Majumder, K Vivekananda, KP Maity, Materials Today: Proceedings, 4 (2), 2194-2202 (2017).
37. Anshuman Kumar, Chandramani Upadhyay, Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 236(3), 1645-1665, (2022).
38. A Kumar, K Abhishek, K Vivekananda, KP Maity, Materials Today: Proceedings 5 (5), 12641-12648 (2018).
39. S Kumari, A Kumar, RK Yadav, K Vivekananda, Materials Today: Proceedings 5 (5), 12750-12756 (2018).
40. A Kumar, H Mishra, K Vivekananda, KP Maity, Materials Today: Proceedings 4 (2), 2137-2146 (2017).
41. Aravind Deshini, S Sathish, S Krishnaraj, Anshuman Kumar, J Saranya, V Srinivas Viswanth, Ram Subbiah, Materials Today: Proceedings 82, 47-52 (2023)
42. A Kumar, K Abhishek, International Journal of Industrial and Systems Engineering 30 (3), 298-315 (2018).
43. Anshuman Kumar, Ram Subbiah, Vivekananda Kukkala, Dusanapudi Siva Nagaraju, Chandramani Upadhyay, R Karthikeyan, Journal of Advanced Manufacturing Systems, 1-23(2023).
44. S. Kolappan, T. Arunkumar, V. Mohanavel, K. Subramani, C. Kailasanathan, P. Kum aran, Ram Subbiah, S. Suresh Kumar, Materials Today: Proceedings, 62(8), 5540-5545 (2022).
45. K. Subramani, T. Arunkumar, V. Mohanavel, S. Kolappan, C. Kailasanathan, B. Boop athi Rathinam, Ram Subbiah, S. Suresh kumar, Materials Today: Proceedings, 62(8), 5514-5518 (2022).
46. Mohanavel V, Suresh Kumar S, Ravichandran M, Rajkumar Sivanraju, Palanivel Velmurugan, Ram Subbiah, ECS Transactions,107(1), 12513–12524 (2022).
47. Mohanavel.V, Priyadharshan R, Ravichandran M, Rajkumar Sivanraju, Palanivel Velmurugan, Ram Subbiah, ECS Transactions,107(1), 12001–12010 (2022).
48. S. Rajkumar, K. Arul, K. Mageshkumar, T. Maridurai, Ram Subbiah, V. Mohanavel, M. Ravichandran, Materials Today: Proceedings, 59(2), 1429-1433 (2022).
49. T. Raja, V. Mohanavel, S. SureshKumar, S. Rajkumar, M. Ravichandran, Ram Subbia h, Materials Today: Proceedings, 59(2), 1345-1348 (2022).
50. Rajesh, M., Sri, M.N.S., Jeyakrishnan, S. *et al.* Optimization parameters for electro discharge machining on Nimonic 80A alloy using grey relational analysis. *Int J Interact Des Manuf* 18, 1429–1442 (2024)

51. Karumuri, S., Haldar, B., Pradeep, A. *et al.* Multi-objective optimization using Taguchi based grey relational analysis in friction stir welding for dissimilar aluminium alloy. *Int J Interact Des Manuf* 18, 1627–1644 (2024).
52. Srividya, K., Ravichandran, S., Thirunavukkarasu, M. et al. Examination of electrochemical machining parameters for AA6082/$ZrSiO_4$/SiC composite using Taguchi-ANN approach. Int J Interact Des Manuf 18, 1459–1473 (2024).
53. Veeranjaneyulu, I., Haripriya, V., Saminathan, R. et al. Friction and wear optimization of SiC/graphite reinforced AZ31 hybrid composite using Taguchi method. Int J Interact Des Manuf 18, 1373–1386 (2024).