Wear assessment on AISI 410 steel by tempering process for constant load and speed sustainable applications

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Abstract. Stainless steels are readily available and inexpensively priced on the market. The reasonable corrosion resistance of AISI 410 martensitic stainless steel has made it a popular choice. Although it is not very ductile, AISI 410 martensitic stainless steel is very strong, robust, and resistant to wear. Due to their exceptional hardness and resistance to wear, martensitic stainless steels were favored for certain limited applications. Therefore tempering was chosen to improve the ductility by keeping stability in brittleness and hardness. The samples were underwent with tempering at 230°C, 430°C, 630°C and designated as T1, T2,T3 respectively. The samples were made cylindrical in shape with 12 mm diameter, length of 42 mm. A pin-on disc wear test instrument was used to assess the material's resistance to wear for all the samples. A sample that has not been treated is set aside for results comparison. All the samples were undergone with hardness measurement and Scanning electron microscope to examine the microstructure and the resulting data were compared.

Keywords: Tempering, hardness, Microstructure, Wear, stainless steels.

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1 Introduction

Stainless steel is a remarkable metal that has facilitated numerous technological advancements across industries. Its adaptability has enabled the creation of an extensive range of alloys and therefore it is also considerably more economical than the majority of alternative materials, particularly in relation to the performance it offers [1-3]. Stainless steels are facilitated by the extensive variety of treatment procedures to enhance the mechanical properties of the material [4-6]. Martensitic stainless steel is a variety of stainless steel distinguished by its resistance to corrosion, hardness, and strength. Martensitic stainless steels have a special place in the world of engineering materials because of their exceptional qualities, which includes good corrosion resistance, toughness, ductility, and high strength [7-10]. These steels are widely used in chemical plants, power generation components like gas turbines blades and discs, aircraft engine parts and fittings, marine parts. In addition to austenitic, ferritic and duplex stainless steels, it is classified as one of the four primary varieties of stainless steel [11-14].

Martensitic stainless steels are distinguished by their microstructure, which is predominantly composed of the brittle and rigid crystalline material martensite. Hardness and strength are the two characteristics that are commonly associated with martensitic stainless steels [15-19]. Because of this, they are suited for applications in which wear resistance and durability are of utmost important such as, cutting tools, knives, bearings, and sustainable applications like solar power plant components. The constituent elements of martensitic stainless steel are carbon 0.15%, chromium (10.5-18%), and iron [20-23]. These stainless steels can undergo thermal treatment similar to traditional steels, to yield a variety of mechanical properties and have minimal formability, undergo an impact transition at low temperatures as they are ferromagnetic in nature [24-27].

2 Experimental Work

2.1 Material Specification

Chosen for this research work, AISI 410 material were undergone with tempering process. Prior to the heat treatment, the samples were chopped to 42 mm in length, diameter of 12 mm as shown in Fig.1. The material composition were noted to be Chromium 13.6%, Phosphorus 0.05 %, Nickel 0.78 %, sulphur 0.04 %, carbon 0.15 %, silicon 1.1 %, manganese 1.1% and rest of the content Iron.

Fig. 1. AISI 410 Samples

2.2 Wear Test

Before the wear test, the samples were carefully rinsed, cleaned with acetone and the surface of the samples were polished. Among the many tribo-testers in use today, the pin-on-disk tester stands out and commonly used. A pin on disc machine was used to conduct wear test on treated samples. The load is applied such that the stationary pin gets pressed against the rotating disc under the dead weight [28-32]. Although any shape of pin can be used, the most common ones are cylindrical or spherical because they get mated with the disc easier. During the test, the wear and frictional force are monitored. 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 [33-37]. 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 [38-40].

Fig. 2. Wear tribo-tester

3 Discussion of Results

3.1 Hardness Measurements

Tempered samples were undergone for hardness measurements with the help of Rockwell hardness tester. 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]. The hardness for AISI 410 is noted as 30 HRC and for tempered samples T1 – 29 HRC, T2 – 27 HRC, T3 – 25 HRC.

3.2 Microstructure analysis

The microstructures were obtained from scanning electron microscope and the results were compared. 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.

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 [44-46]. Low volume wear loss was achieved because the material hardened due to the existence of residual austenite and cementite, which also ensures that the microstructure remains unchanged as shown in Fig.4.

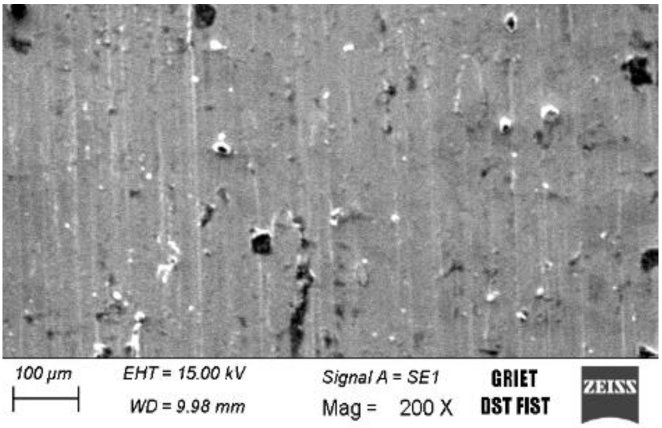

Fig. 4. AISI 410 Microstructure

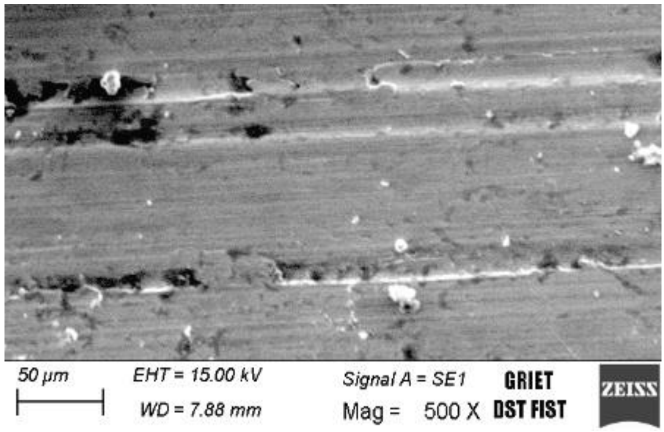

Fig. 5. Microstructure of tempered sample at 230°C

Tempering the sample at 230 ℃ resulted in a small improvement in ductility and negligible wear loss. Because at low temperature tempering, no major changes takes place in the material and martensitic phase remains same as shown in Fig 5. After being tempered at 430℃, the microstructure shows fewer cracks, leading to better ductility compared to samples tempered at 230°C. An increase in ductility is indicated by an increase in wear loss [47-49]. It was identified that ductility, wear resistance increased as the time of tempering is increased to 430°C.

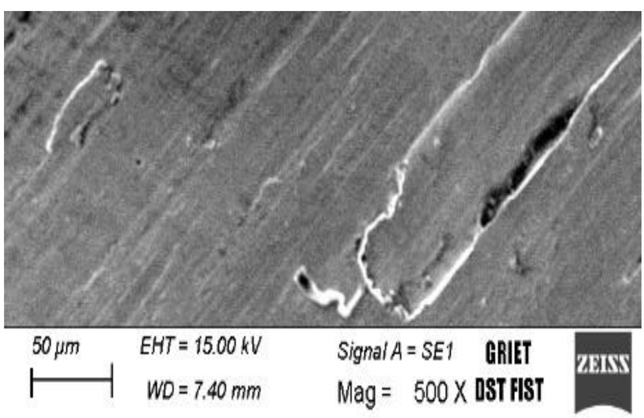

Fig. 6. Microstructure of tempered sample at 430°C

The time delayed due to cooling process makes the cementite content separated, results in formation of austenite phase near the surface. The hardness of the material gets stabilized. The refined structure of martensitic steel results in coarse grain structure, which increases toughness and ductility.The material, had a high peel and substantial to losses due to its coarse ferrite and carbide microstructure. The martensitic transformation of the coarse-grained structure favors the fine-grained structure and promotes the ductility of the material [50-53]. The diffusion zone were characterized and found to have small micro-etches in the inter connect layer as shown in Fig.6. The material ductility is enhanced and the microstructure in the martensitic phase slightly transforms to coarse grain structure making the material soft. Wear of stainless steel materials decreases as the temperature range for heat treatment expands.

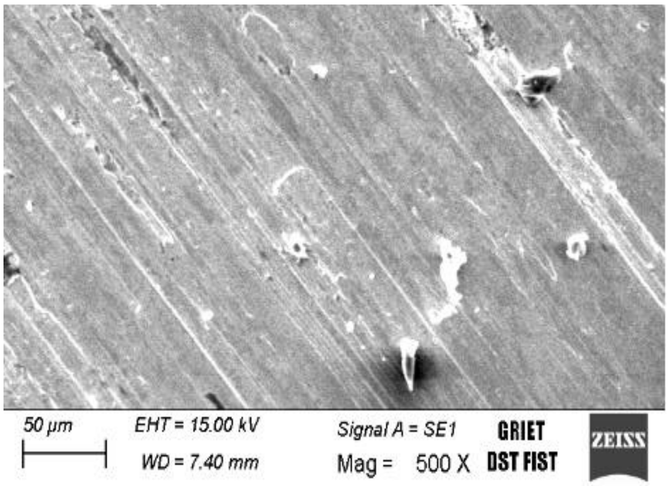

Fig. 7. Microstructure of tempered sample at 630°C

As martensite underwent a gradual transformation to high temperature tempering process, the fine grain structure became coarse, enhancing the material's ductility. As the mixture of ferrite and carbide was separated, it was discovered that there was a significant loss of material volume. The ductility of the specimen and the stabilization of the material with hardness were found to increase in direct proportion to the time and temperature of tempering as shown in Fig.7. Stabilized hardness and ductility is obtained improving the wear resistance of the material.

4 Conclusions

From the above research work, the involvements of tempering process upon AISI410 were assessed. Very few research scholars have made work on AISI 410 stainless steel material and the major findings from this work are:

1. As determined by the wear test, the samples that underwent tempering at 630°C exhibited a more reduction in wear loss compared with untreated sample. According to the findings, tempered sample is more effective than sample which is untreated, as the material is stabilized with dutility and hardness.
2. Compared to the untreated samples, the treated samples revealed a higher amount of material loss. The materials changed from martensitic to austenitic phase were noted and tempering revealed carbides in stabilization of hardness and ductility.
3. The treated samples revealed the hardness and were found to be lesser than untreated samples. It was found to be 30 HRC for AISI 410 and 25 HRC for the Sample tempered at 630°C.

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).