Analysis of Wear Behaviour on AISI 431 Martensitic Stainless Steel by Vacuum Annealing Process

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Abstract. In the research work, AISI 431 grade stainless steel were chosen to investigate the effects of vacuum annealing processes on reducing hardness and enhancing ductility. Although stainless steel of martensitic type are well known for their high hardness, wear resistance and they have limited applications due to high hardness properties. Chosen for this research work, vacuum annealing were carried out to temperatures of 740°C, 840°C and 940°C. The samples were prepared cylindrically to a dimension of 40 mm length and 10 mm diameter. An untreated material was kept aside for comparison.Vacuum annealing involves heating the material in a controlled environment to eliminate impurities and relieve internal stresses, resulting in reduced hardness and improved ductility. To evaluate the effect of wear on annealed material, a pin-on-disc wear test apparatus were used. The wear behavior of the annealed specimens were compared to the untreated material. It includes both the treated and untreated samples, were examined by using a scanning electron microscope (SEM) to obtain images of microstructure. The results of this research work contribute to the understanding of the annealing effects on martensitic stainless steels and provide insights into optimizing their properties for specific applications.

Keywords : Martensitic stainless steel, Annealing, wear test, Hardness test, scanning electron microscope.

1 Introduction

Stainless steels were indeed into iron-based alloys that contain a minimum value of 12% Cr, in some cases it is compulsory to prevent rust formation in a simple environment [1-3]. Certain stainless steels were having 35% more Cr content and 52% of iron less contents.

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In presence of oxygen it allows the formation and self-repairs of the protective chromium oxide layer on the surface of stainless steel [4-6]. Stainless steel with three major types such as austenitic, ferritic, martensitic type and they were having its own unique characteristics and it were designed to meet some specific requirements in terms of hardness, strength, wear resistance and corrosion resistance [7-10]. Martensitic Stainless steels are well-known to hardness, strength, wear resistance and poor in ductility. To make use of these steels for commercial applications, hardness and ductility has to be stabilized [11-14]. Annealing involves in heating process of AISI 431 stainless steel to a range of 740°C to 940°C. The steels were slowly cooled in the furnace to allow for the desired transformation and structural changes occurs when the temperature is kept on holds [15-18].

Annealing is a heat treatment process used to alter the microstructure of a hardened material, in order to achieve specific mechanical, electrical, or other material properties. In the case of AISI 431 stainless steel, which is a martensitic stainless steel often used in applications where corrosion resistance and moderate strength are required, annealing plays a significant role in tailoring its properties [19-22]. To achieve maximum softness and ductility, the steel is heated to a temperature above its critical temperature around 723-840°C, held several hours and cooled in furnace. This allows for the complete transformation of the microstructure from martensite (a hard, brittle phase) to a softer, more ductile phase. The cooling rate can be relatively slow, such as air cooling or furnace cooling, to avoid introducing excessive hardness [23-26].

2 Experiment Work

2.1 Materials Used

The composition of AISI431 were found to be Carbon 0.190%, Silicon 0.486%, Chromium13.555%, Manganese 0.750%, Phosphorus 0.050%, Sulfur 0.050%, Nickel 0.300%, Remaining Iron, was selected for this research study. As displayed in Fig.1, the specimens were prepared to the dimensions of 40 mm length and 10 mm diameter [27-30].

Fig.1. AISI431 samples

2.2 Material processing and testing

In this research, the samples were under gone with vacuum annealing treated to temperatures of 740^{0}C, 840^{0}C, and 940^{0}C. After the heat treatment, the samples were subjected to wear test by using wear tribometer. The wear test was conducted by applying load of 20N, rotational speed of 1000 rpm for a duration of 3 minutes. An untreated sample was also included in this experiment for comparison purpose. By comparing the results of the treated samples with the untreated sample, the effects of the heat treatment processes on wear behavior and characteristics could be assessed [31-34].

Fig.2. Pin on Disc Equipment used

Wear tribometer are widely used in tribology, which involves in placing a small pin against rotating disc as shown in Fig 2. This setup allows for the evaluation of friction, wear, and other tribological properties of materials under controlled conditions. The wear characterization of the materials in this experiment would involve analyzing the wear behavior of the treated samples based on factors such as wear rate, coefficient of friction, and surface damage [35-39]. The results obtained from the wear test would provide insights into the effectiveness of the heat treatment processes in improving the wear resistance of the material.

3 Discussion of Results

3.1Hardness Measurements

The hardness tests were measured by Rockwell hardness method. AISI 431 samples were identified with hardness of 32 HRC. The samples treated by annealing process to a temperature of 740^{0}C, 840^{0}C, 940^{0}C were having the hardness of 29HRC, 27.5HRC and 26 HRC.

3.2 Microstructure from Scanning Electron Microscope

In this experiment, by using scanning electron microscope (SEM), the surface morphology on each pin samples was examined. Fig.3 it shows the surface morphology of AISI 431 sample. The combined carbon in the martensitic stainless steel was hard and

brittle. As a result, the material peel is very less and the the sample volume wear loss were identified to around 7 $mm^{3.}$

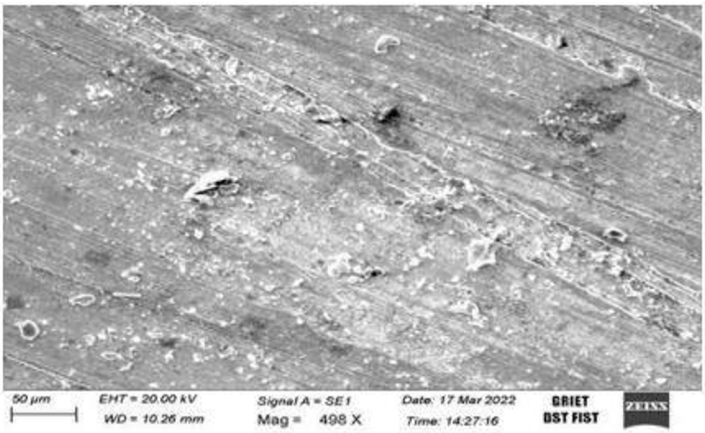

Fig.3. AISI431 Untreated Sample Microstructure

Fig.4 revealed out the surface morphology of annealed sample treated to a temperature of 740^0C. At this temperature it were observed that both ductility and wear resistance were observed [40-42]. Both ferrite and carbide got diffused and the volume wear loss was determined as 12 mm^3. The ductility were promoted and cracks were identified in the microstructure.

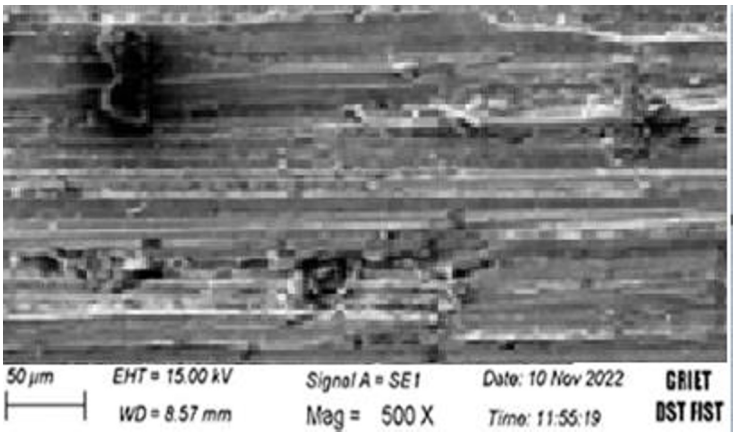

Fig.4. Microstructure of Annealed specimen at 740°C

Fig.5 revealed out on annealed sample treated to a temperature of 840°C. From the microstructure it has been observed that, the softness of the material were increased that were led to recrystallization of the material and grain growth of the material. More cracks were identified with more material peel [43-45]. As the material has undergone against the load, the volume wear loss were identified as 22 mm^3. The specimen's ductility grows and its wear property starts to rise. The components of cementite completely disintegrate as

cooling time increases, changing the phase structure to retained austenite from martensite. As a result, a structure of coarse pearlite in the microstructure, this causes the material's hardness, ductility to be in stable state as shown in Fig 6.

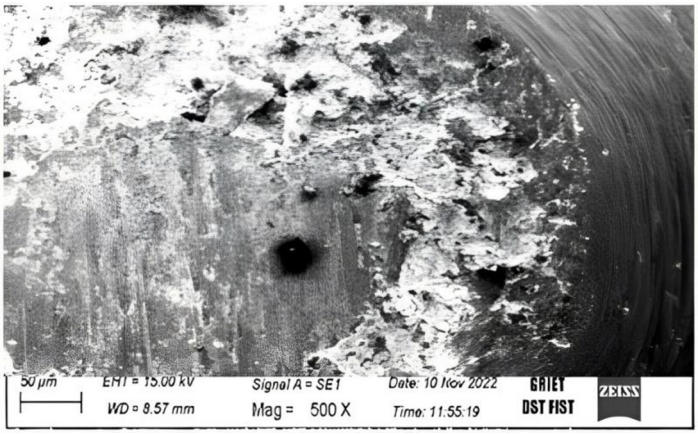

Fig.5. Microstructure of Annealed specimen at 840°C

Fig.6 displays the annealed sample treated to 940°C microstructure. The ductility of the specimen increases and thereby wear begins to increase. The time of cooling process increases and therefore the cementite components decomposes. The material phase shifts to austenite in retained condition from martensite. Pearlite structure is obtained, resulting in stable hardness, ductility. The volume wear loss were identified as 24 mm^3

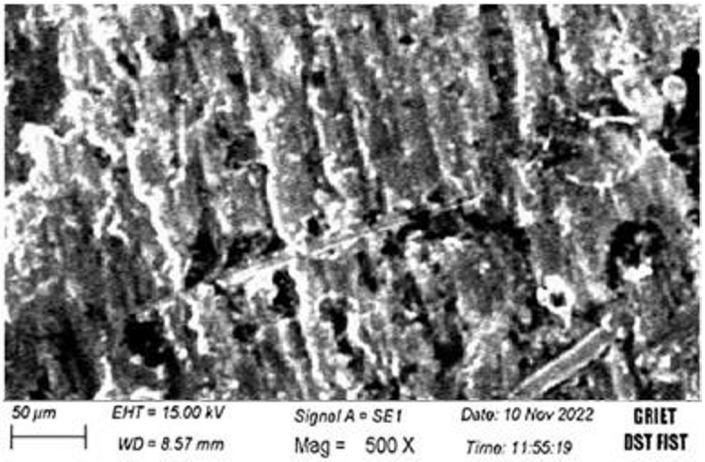

Fig.6. Microstructure of Annealed specimen at 940°C

4 Conclusion

From this work, annealing process were treated on the sample AISI 431. The hardness test of the annealed sample was identified as 29 HRC, 27.5HRC and 26 HRC respectively.

AISI 431 stainless steel samples subjected to annealing process were applicable commercially for applications such as cutlery, kitchen utensils, surgical equipments, dental instruments, pumps, valves, pipes, manifolds and exhaust systems, automotive components.Very few works were performed on AISI 431 stainless steel material towards annealing process.

1. The annealed samples volume wear loss was identified to be as 12 mm^3, 22 mm^3, 24 mm^3 respectively. Whereas the wear loss of untreated specimen is determined as 7 mm^3. More peel of material were obtained to the sample treated to 940^0C..

2. The wear resistances of martensitic stainless steel were improved stabilized with hardness and ductility.

3. The martensitic material's wear resistance can be increased through annealing. The material can be used to commercially manufacture products because of its stable ductility and hardness. It is crucial to remember that the speed and load were kept constant in order to get these results in this research work. By changing the speed and load to achieve better outcomes, the job can be continued in the future.

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 Subb iah, 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, Materia ls 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, Ram 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 Subbia h, 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 Sub biah, Materials Today: Proceedings, 47, 4312-4315 (2021).
31. Animesh Bain, B.RamakrishnaReddy, PrasadRamchandra,Baviskar, M Patil Milin d, 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. Aparna, Ch. Dhanush, Ram Subbiah, E3S Web of Conferences, 309, 01181 (2021).
33. B Divyasri, Ch.PhaniRamaKrishna, Pradeep Jayappa, G. Keerthi Reddy, V. Vinay Kumar, 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. M. Mamatha Gandhi, Sanjay Kumar, Ramaswamy Subbiah, K. Ramya Sree, D.S. Naga Malleswara Rao, J. Venkata Suresh and Ram Subbiah, E3S Web of Conferences, 391, 01091 (2023).
37. G. Saravanan, V. Rahul, Upendra Mahatme, G. Keerthi Reddy, T. Sharon, G. Suresh, R. Karthikeyan and Ram Subbiah, E3S Web of Conferences, 391, 01108 (2023).
38. Santosh Madeva Naik, Upendra Mahatme, M. Iyyappan, J. Ramesh Babu, M. Bala Gopala Krishna Reddy, D.S. Naga Malleswara Rao and Ram Subbiah, E3S Web of Conferences, 391, 01109 (2023).
39. P. Ravi Kumar, K. Manivardhan Reddy, Upendra Mahatme, T. Karthik, M. Saravanakumar, J. Venkata Suresh and Ram Subbiah, E3S Web of Conferences, 391, 01110 (2023).
40. Boopathi.S, Jeyakumar.M, Singh.G.R, King.F.L, Pandian.M, Subbiah.R, Haribalaji.V, Materials Today: Proceedings, 59,1094-1099 (2022).
41. Balaji.M, Dinesh.S.N, Raja.S, Subbiah.R, Manoj Kumar, Materials Today: Proceedings, 62, 1722-1728 (2022).
42. Boopathi.S, Thillaivanan.A, Pandian.M, Subbiah.R, Shanmugam.P, Materials Today: Proceedings, 50, 2430-2435 (2021).
43. Balasubramanian.M, Stalin.B, Marichamy.S, Anandan.K, Subbiah.R, Materials Today: Proceedings, 33, 4677-4680 (2020).
44. Balaji, M, Dinesh.S.N, Vikram Vetrivel.S, Manoj Kumar.P, Subbiah.R, Materials Today: Proceedings, 47, 5308-5312 (2021).
45. Dinesh.S.N, Ravi.S, Manoj Kumar.P, Subbiah.R, Karthick.A, Saravanakumar.P.T, Aravinth Pranav.R, 47, 5228-5232 (2021).