A REVIEW ON WEAR ANALYSIS AND OPTICAL MICROSCOPY OF SUPER DUPLEX STAINLESS STEELS

Mr. Shridharmurthy H.N.[1], Dr. Arulmani L[2]., Mr. Sachin Kumar N, Mr. Gnanendra K[4], Mr.Virupaksha Reddy[5]

[1] Assistant Professor: Dept. of Mechanical Engineering, RRIT (VTU), Bengaluru, India

[2]Associate Professor: Dept. of Mechanical Engineering, RRIT (VTU), Bengaluru, India

[345]B.E Students: Dept. of Mechanical Engineering, RRIT (VTU), Bengaluru, India

ABSTRACT

Super duplex stainless steels (SDSS) have high corrosion resistance because of their high contents of chromium, nickel, molybdenum and nitrogen but low wear resistance. To improve the wear resistance of these steels without affecting their corrosion resistance, samples of SDSS were treated by plasma ion nitriding at temperatures ranging from 350 °C to 570 °C for two hours. This thermochemical treatment resulted in the formation of different types of nitrides that affected the microhardness, the microwear behaviour and the corrosion resistance of the metal surface. The microwear resistance decreased at 400 °C because different nitrides formed on the surface, thereby increasing the hardness and volume wear resistance of the steel. The test results showed that the alloys that were nitrided at 400 °C and 450 °C exhibited the highest corrosion resistance to a solution medium containing chlorideions.

The aim of the present work is to focus on the characterization of materials in situ by using a modified near- field scanning optical microscope (NSOM) with a home- built tuning fork head that allowed us to obtain optical imaging concurrently with topography of some systems. The first example is related to finding precursor sites for pitting corrosion on duplex stainless steels (DSS). Precursor sites for pitting on DSS were found to be inclusions that are complex in structure and where metastable pits develop at temperatures below the critical pitting temperature (CPT), but where stable pits, with large corrosion current, occur at the CPT. These inclusions were analyzed and found to be inhomogeneous in nature and consisting of a mixture of various elements (Si, Al, Mg, Ca, Ti, Mn, and S). After analysis of the particles, in situ observation of the particles in 3.5% NaCl and HCl solutions showed that they developed metastable pits. The pits and corrosion products developed in both particles present in the austenite grains and in particles contained within the ferritematrix.

Keywords: Corrosion, Expanded austenite, Microwear, Tribological, Optical microscope, Austenite.

1. INTRODUCTION

The demand for wear- and corrosion-resistant components has stimulated growing interest in surface engineering as a means of enhancing the tribological and tribochemical properties of surfaces. Surface and

ISBN : 978-93-87793-87-3

thermochemical treatments are used to improve the wear resistance of metals. Plasma ionic nitriding, which was initially developed for ferrous alloys, is widely used for this purpose. In this treatment, nitrogen atoms are dissociated, ionised and transported at high velocities up to the surface of the metal part. A characteristic layer is created via the diffusion of nitrogen on the metal surface, and the properties of this surface layer can be modified by varying the process parameters. Plasma ion nitriding produces hard and wear-resistant surfaces via the formation of precipitates on the metal surface. Manfrinato has reported that this technique does not affect the metallic structure of the material and is efficient and not harmful to the environment because gases that are usually present in the atmosphere are used in the process. The plasma ion nitriding process is generally used to improve the surface hardness and wear resistance of a material. This process improves the corrosion resistance of a metal, as has been verified for SDSS ASTM A182. However, Liang has reported that relatively high temperatures increase the surface hardness and reduce the corrosion resistance of a metal because of the formation of chromium nitride (CrN). CrN is a phase that is fairly stable, brittle and less resistant to corrosion than the substrate. Super duplex stainless steel ASTM A182 has an austenitic/ferritic structure with phases that are formed in exact proportion due to their chemical composition and thermal treatment. In addition to a high %Cr content, these alloys are characterised by a low carbon content "< 0.03% in weight" and contain alloy elements such as molybdenum, tungsten, copper and nitrogen[5]. These steels are called special alloys and are used in locations with aggressive atmospheres that require high corrosion resistance, in oil platforms, for offshore activities, such as oil exploration, in piping systems, in evaporators, in distillers, and in storage tanks, among others.The objective of this study was to investigate the wear and corrosion resistance of SDSS ASTM A182 with and without surface treatment. The surface treatment that was used in the study was plasma ion nit riding at different temperatures.

Duplex stainless steels have a microstructure consisting of approximately equal amounts of austenite and ferrite which is obtained by thermomechanical processing of an alloy with alfa or gamma stabilizers elements in balance.This microstructure can be considered intermediary between austenitic and ferritic stainless steels. Duplex stainless steels have higher strength than austenitic stainless steels, higher toughness than ferritic stainless steels and good weldability. Furthermore, due to the high Cr content and the presence of alloyingelements in the material, the duplex stainless steels present superior corrosion resistance in different environments when compared to other types of similar stainless steels, together with a yield point that is superior to the one of austenitic stainless steels. This behavior allows thickness and weight reduction of a component or equipment produced with this type of steel.Changes in microstructure of duplex stainless steels during fabrication depends on the characteristics of the processing used (welding, cold working, heat treatments, etc.) and their variations and may have a significant impact on the final microstructure. Hence, the knowledge of these changes is extremely important to guarantee the high quality of the products obtained with these steels, especially after heat treatment and welding. Duplex stainless steels weldability is considered inferior to that of austenitic stainless steels. In general most ofthe weldability problems on duplex steels result from the reduction of the amount of austenite particularly in fusion zone (FZ) and at the heat-affected zone (HAZ) and from the precipitation of nitrites and intermetallic compounds. Due to their chemical composition, on heating duplex stainless steels completely transform to ferrite at around 1300-1400oC and maintain this structure up to their melting temperature. Therefore, during welding, the high temperature HAZ completely transforms to ferrite and undergoes an intensive grain growth. During cooling, austenite is again formed, mainly at ferrite grain boundaries with platemorphology.

2. LITERATURE REVIEW

V. Muthupandi, P.B. Srinivasan, S. Seshadri, S. Sundaresan, et al. [2013] Effect of weld metal chemistry and heat input on the structure and properties of duplex stainless steel welds, Materials Science and Engineering. They concluded that the wear in the Super Duplex stainless steel is occurred layer by layer. They even did conduct experiments on effects of welding on SDSS. In these experiments they came to know that the welding held the metals together and there was no chemical change in composition. They also listed the changes occurred on the structure due to heat input. They even mentioned about the structure and properties of Super duplex stainless steel.

V. Shamanth, K. S. Ravishankar, K. Hemanth et al. [2019]. Duplex Stainless Steels: Effect of Reversion Heat Treatment. Stainless Steels and Alloys. In their work they mentioned various effects of Reversion heat treatment. They concluded that the structure of the Super Duplex stainless steel was layered type. In their study they conducted experiments on effects of heat treatment reversion on the Super duplex stainless steel and they even mentioned few other theories about other stainless steels and their alloys.

P. Chandramohan, S.S. Mohamed Nazirudeen, S.S. Ramakrishnan et al. [2008] Studies on Production and Thermo- Mechanical Treatment of 0.32% Nitrogen Alloyed Duplex Stainless Steel. Journal of Materials Engineering and Performance. In their study they had chosen a specifically separate composition of Super duplex stainless steel. The metal they chose were 0.32□ of Nitrogen alloyed duplex stainless steel subjected to Thermo-mechanical treatment. They even mentioned few of their study works on production and treatment of Super duplex stainless steel and even different alloy combination of them. Their journal had even studies related to theories of Metal engineering and performance.

J.W. Elmer, T.A. Palmer, E.D. Specht et al. [2007] In situ observations of sigma phase dissolution in 2205 duplex stainless steel using synchrotron X-ray diffraction. Materials Science and Engineering. In their combined study they worked and researched on the sigma phase caused in special 2205 Duplex stainless steel. In their study and experiments they used synchrotron X-ray diffraction method to reveal the observations made on sigma phase in 2205 Duplex stainless steel. They worked collectively and published their study on Material science of SDSS in their journal.

García-Junceda, M. Rincón, J. M. Torralba et al. [2018] Development of Duplex Stainless Steels by Field-Assisted Hot Pressing: Influence of the Particle Size and Morphology of the Powders on the Final Mechanical Properties. Metallurgical and Materials Transactions. In their work they concluded about the production, manufacturing and development of Duplex stainless steel by hot pressing field assistance. They even made observations about influence of the particle size of the powders on the final mechanical properties of super duplex stainless steel. They conducted experiments on morphology of the metal powders before hot pressing them. They all collectively combined their observations and research on metallurgical and material transactions of Super duplex stainless steels.

Tatiana resend alvarez conducted experiment on double loop electrochemical potentialdynamicinorder to detect and qualify the optical microscopic structure of super duplex stainless steel. Small amount of phases in all different conditions by non-destructive at room temperature. The potential use to characterize phases of super duplex stainless steel in situ by the portal cell. He confirms the grain size on kinetics of phases.

Edgard Silva conducted experiment to detect the sigma phase of a 2205 duplex stainless steel with the help of induced magnetic field. Basically sigma phases caused due to heat treatment process or by welding process. To validate the approach the induced magnetic field values are been compared with the charpy impact energy so that the sigma phase is obtained by the optical microscopy. There may form fractures and they are detected by X-ray diffraction. Later he proved that there is relation between impact energy and induced magneticfield.

Juan Manuel Pardal conducted experiment on influence of deleterious phases perception in the corrosion resistance measured by double loop electrochemical polarization reactivation test in sdss. This test can be used as portaltest for field analysis. Due to achieving the difficult temperature of 40c more and more electrodes are used to obtain the good results. All these was studied by means of DL-EPR test and the mainmicroscope.

3.CONCLUSION

The super-duplex stainless steel without thermochemical treatment showed lower wear resistance when compared to the super-duplex stainless steel with thermochemical treatment. In the 16 N normal load the wear volume is higher than 8.3 N due to strong interaction of surface contact promoted by increasing the severity of test. For the 8.3 N normal load condition, there was a formation of a thin oxide film which interfere drastically in the results, reducing the volume wear of material. The treatment carried out at 350 ^{0} C was unable to produce a thin layer of nitrogen with formation of S’ phase, α’ and iron nitride. For temperature of 400 ^{0} C iron, chromium nitride, S' and α' phases were formed and the formed layer provides better wear resistance. An increase at the nitriding temperature leads to high thickness and hardness, however, the wear resistance decreases due to chromium nitride formation. The chromium nitride promotes high surface hardness but low wearresistance.

Duplex stainless steels exhibit greater toughness and better weldability than ferritic stainless steel (Nilsson, 1992). They have higher strength and better corrosion resistance than austenitic stainless steel (Atamert and King, 1992). Their good engineering performance has led to an increasing number of applications, mainly in corrosive environments such as sour gas pipelines and chemical reaction vessels. The microstructure of duplex stainless steel consists of austenite grains dispersed in a ferritic matrix. The austenite and ferrite regions have different compositions as a consequence of the partitioning of the ferrite- and austenite-forming alloying elements during heat treatment.

Experience has shown that there is always a certain ‘incubation’ period from the time of market introduction of a new alloy to the general acceptance among end users. For DSS this is in part explained by the initial difficulties in welding the carbon rich DSS that were first introduced. However, the welding problem in modern DSS has now been overcome to the extent that welds can be produced that have corrosion and mechanical properties that are almost as good as those of the base material. This has been achieved by a combination of alloy design and development of welding procedures. When appropriately treated, the DSS are unrivalled in a large number of applications in the temperature range - 50 to 250° C where a combination of corrosion resistance and mechanical strength is required. However, the duplex microstructure, which is the key to the unique properties, also renders them inherently sensitive to phase transformations that may lead to reduced toughness and or corrosion properties. Correct heat treatment and welding requires a thorough knowledge of the relationship between micro structural phenomena and properties. It is therefore essential for steel producers to convey this knowledge to manufacturers and users. In this paper much attention has been paid to deleterious phenomena such as the precipitation of undesirable phases of various types. In conjunction with this, the conditions for avoiding these phase transformations are defined and it is therefore hoped that this review article provides a basis for the successful use of DSS.

The main conclusions of this research work are the following:

(1) The physical and chemical properties of duplex stainless steel are affected by the solution temperature significantly. It has poor plasticity and corrosion resistance at lower temperature (900~ 1000 ℃) for the largeamount ofσ-phase.

(2) Precipitation of Cr- and Mo -rich σ-phase, is closely related to the process of solution treatment. It would result in deterioration of plastic and corrosion resistant properties when there are a large amount of precipitation at low temperature (900 ℃). With the increase of temperature, the σ-phase is gradually dissolved, and the precipitation volume decreases. After the temperature is up to 1050 ℃, the plasticity and corrosion resistant properties of the duplex stainless steel are improved significantly for the dissolution ofσ-phase.

(3) The content of ferrite in duplex stainless steel increases with the increase of solution temperature, while the proportion of ferrite and austenite is less affected by the coolingrate.

4. REFERENCES

1. V. Muthupandi, P.B. Srinivasan, S. Seshadri, S. Sundaresan, Effect of weld metal chemistry and heat input on the structure and properties of duplex stainless steel welds, Materials Science and Engineering: A, 358 (2003) 9-16.

2. J. HILKES, K. BEKKERS, and H. MEELKER: Proc. Conf. 'Duplex stainless steels.L.COLOMBIER and J. HOCHMANN: 'Stainless and heat resisting steels'; 1968.
3. M. Snis, J. Olsson, Reduce costs for storage and distribution of desalted water—use duplex stainless steel, Desalination.
4. Handbook of stainless steel, Outokumpu Oyj, Finland,2013.
5. R. Cremisio, H. Butler, J. Radavich, Effect of thermomechanical history on the stability of Alloy 718, J Metals, 21 (1969)55-61.
6. N. Haghdadi, P. Cizek, P.D. Hodgson, H. Beladi. (2019) Microstructure dependence of impact toughness in duplex stainless steels. *Materials Science and Engineering: A* 745, pages369-378.
7. Christian Paulsen, Runar Broks, Morten Karlsen, Jarle Hjelen, Ida Westermann. (2018) Microstructure Evolution in Super Duplex Stainless Steels Containing σ-Phase Investigated at Low-Temperature Using In Situ SEM/EBSD Tensile Testing. *Metals* 8:7, pages 478.
8. Joanna Michalska, Maria Sozańska. (2006) Qualitative and quantitative analysis of σ and χ phases in 2205 duplex stainless steel. *Materials Characterization* 56:4-5, pages355-362.
9. Graziele Gianini Braga Maria, Carolina Arriel Dias Pedroso, Daniella Gomes Rodrigues, Dagoberto Brandão Santos. (2019) Strain-Induced Martensite and Reverse Transformation in 2304 Lean Duplex Stainless Steel and its Influence on Mechanical Behavior. *steel research international* 90:3, pages 1800437.
10. Wei Zhang, Jincheng Hu. (2013) Effect of annealing temperature on transformation induced plasticity effect of a lean duplex stainless steel. *Materials Characterization* 79, pages37-42.
11. J. Michael Shockley, Derek J. Horton, Kathryn J. Wahl. (2017) Effect of aging of 2507 super duplex stainless steel on sliding tribocorrosion in chloride solution. *Wear* 380-381, pages251-259.
12. Sten Wessman, Rachel Pettersson. (2015) Application of Computational Thermodynamics to Predict Growth of Intermetallic Phases in Superduplex Stainless Steels. *steel research international* 86:11, pages 1339-1349.
13. P. Ferro. (2013) A dissolution kinetics model and its application to duplex stainless steels. *Acta Materialia* 61:9, pages3141-3147.
14. T. Vigraman, R. Narayanasamy, D. Ravindran. (2012) Microstructure and mechanical property evaluation of diffusion-bonded joints made between SAE 2205 steel and AISI 1035 steel. *Materials & Design* 35, pages156-169.
15. A. PORTERand K. E.EASTERLING:'Phase transformations in metals and alloys',287 — 290; 1992, London,ChapmanandHall.
16. Muthupandi V, Srinivasan PB, Seshadri SK, Sundaresan S: 'Effect of weld metal chemistry and heatinput on the structure and properties of duplex stainless steels welds', *Mater. Sci. Eng. A*, 2003, A358,9–16.
17. Gunn RN: 'Duplex stainless steels – microstructure, propertiesand applications'; 2003, Cambridge, AbingtonPublishing.
18. Pardal JM, Tavares SSM, Cindra Fonseca MP, Souza JA, Loureiro A, Moura EP: 'Modeling ofdeleterious phase precipitation during isothermal treatments in superduplex stainless steel', *J. Mater. Sci.*,2010,

45, 616–623.

19. Nilsson JO, Kangas P, Karlsson T, Wilson A: 'Mechanical properties, microstructural stability andkinetics of σ phase formation in 29Cr–6Ni–2Mo–0·38N superduplex stainless steel', *Metall. Mater.Trans. A*, 2000, 31A, 35–45.
20. Nilsson JO: 'Overview super duplex stainless steels', *Mater. Sci. Technol.*, 1992, 8, 685–700.
21. J. HILKES, K. BEKKERS, and H. MEELKER: Proc. Conf. 'Duplex stainlesssteels.
22. L. COLOMBIER and J. HOCHMANN: 'Stainless and heat resisting steels'; 1968.
23. M. Snis, J. Olsson, Reduce costs for storage and distribution of desalted water—use duplex stainlesssteel, Desalination.
24. Handbook of stainless steel, OutokumpuOyj, Finland,2013.
25. R. Cremisio, H. Butler, J. Radavich, Effect of thermomechanical history on the stability of Alloy 718,J Metals, 21 (1969)55-61.
26. B. Zhang, F. Xue, S. Li, X. Wang, N. Liang, Y. Zhao, G. Sha, Non-uniform phase separation in ferrite ofa duplex stainless steel, Acta Materialia, 140 (2017)388-397.
27. Ramirez, S. Brandi, J. Lippold, Secondary austenite and chromium nitride precipitation in simulated heat affected zones of duplex stainless steels, Science and Technology of Welding and Joining, 9 (2004) 301-313.