Methods Of Improvement Of Mechanical And Tribological Properties Of The Surface Of Ss 316l: A Review

Mukhtiar Singh, Ravinder Kumar, Hitesh Vasudev, Vikas Gulati, Mandeep Singh

Abstract: Stainless steel 316 L is alloy carbon steel alloy which have been widely used in highly reactive atmospheric conditions for several applications such as food processing equipment, marine applications, architectural applications, medical implants owing to its excellent mechanical properties and corrosion inhibitors. However, low hardness and wear resistance properties of this grade of steel have greatly limited its applications. Extensive research has been going on over years to improve the wear resistant properties of the steel either by addition of any wear resistant alloying element or by other surface treatment methods. One economical solution to improve the surface properties of all types of austenitic steel is heat treatment. This paper has an attempt to review different methods of improving the properties such as hardness, wear and corrosion on austenitic stainless steel SS316L.

Index Terms: Wear, SS-316, Corrosion, Hardness.

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1. INTRODUCTION

The main aim for the development of SS-316 austenitic stainless steel is to use this steel in moderately corrosive environments having different applications in the field of power generation, marine industries, chemical industries, food processing units and refineries. To improve the further corrosion resistance and mechanical properties molybdenum is generally added into the composition of SS 316 steel [1,2,3]. This evaluation of steel is notable for their great erosion opposition and mechanical properties like quality and so on. Be that as it may, because of its less hardness and wear opposition, their applications are significantly restricted. With the addition of nitrogen into SS 316 L the mechanical properties of the steel get improved which enables the steel to work in corrosive, moderately oxidizing and reducing environments. It additionally has incredible protection from intergranular erosion in the as-welded condition [17]. The microstructure of the Austenitic steel is stable at ambient temperature owing to the presence of different alloying elements [13].

These steels are used in several harsh environmental conditions and at high as well as low temperatures. The performance of SS 316 L also in boiling with 20% phosphoric acid is satisfactory and resistance to pitting corrosion in phosphoric and acetic acid is remarkable [18]. More will be the percentage of molybdenum in SS316 L, the steel will be more resistance to pitting corrosion in certain conditions which generally involve chloride solutions, specifically in an oxidizing environment. However, in the conditions where the extent of intergranular corrosion of welds, and heat-affected zones was there, SS 316 L should be preferred due to low carbon content. Different researchers are trying to minimise the wear of SS 316 L either by using advanced wear resistant material or by using some surface treatment techniques [20]. Wear properties play an important role in determining the lifecycle of any machine element. Metallic parts often fail due to wearing most often than any other reasons. Metal wear generally occurs either by the plastic distortion of the surface and near-surface material or by the detachment of particles. Wear can be classified into different categories, but the most typical types are: abrasive, erosion, metal to metal, fretting, corrosion etc. There a combination of modes of wear which result in material failure. The material selected for this project is SS 316Lwhich is primary an iron-based alloys having a FCC structure. The SS316L has a general composition of Cr 16-18 % (Wt), Ni-2 %(Wt) and Mn 2 %(Wt), C0.03 %(Wt),with other alloying elements and remaining Fe element [14]. These types of low carbon austenitic steels are formulated to restrict the formation of chromium carbides, that results into the depletion of chromium from the matrix (Austenite) which results into the loss of corrosion resistant properties. These types of steels are generally malleable in nature and due to this reason, it may get many common forms of wear. Due to it slow wear resistance of the usage of these alloys application is limited [16]. So, to improve wear resistant and hardness of the material and without any change in the other desirable properties hardening the surface of stainless steels is the best and economical method. Surface Engineering is a process of altering a materials surface to improve surface properties or enhance a materials interaction with the surrounding environment [19]. The most common surface engineering technologies used for steel alloys includes transformation hardening, surface modification by melting, conventional carburization, conventional nitriding, coating, and plating. So, this article deals with reviews of few methods available to improve the mechanical and chemical properties of the austenitic stainlesssteel.

2.LITERATURE REVIEW

Suresh[1] studied the effect of increased hardness value on the wear and resistance to corrosion behavior of the material used for propeller shaft. As it is known that stainless steels usually deplete by the effect of sensitization during high temperature hardening methods. He further noted that the corrosion resistance and hardness of SS316L can be improved by the advancement of the microstructure from

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- *Mukhtiar Singh, Assistant Professor, LPU, Phagwara-144411-India*
- *Ravinder Kumar, Assistant Professor, LPU, Phagwara-144411-India.*
- *Hitesh Vasudev, Assistant Professor, LPU, Phagwara-144411-India*
- *Vikas Gulati, Assistant Professor, LPU, Phagwara-144411-India*
- *Mandeep Singh, Assistant Professor, LPU, Phagwara-144411-India*

austenite to martensite without variation in chemical properties and Cryogenic treatment. The material was first cooled in a Liquid Nitrogen chamber to a temperature of -185 C for the duration of 2-3 hours and then maintained at that temperature up to 24 hrs. Pin on Disk Test was used to measure the wear properties according to the (ASTM G 99) standard and the corrosion behavior was examined by performing Ferric Chloride test. The results outlined that the resistance to wear of AISI 316L samples improved by 24% after Cryogenic treatment. The resistance to corrosion in comparison to untreated samples improved by 37% and the hardness improvement was up to,16%.Natishan et al[2] experimented with a new technique called para equilibrium carburization at low-temperature (415-455) to avoid the formation of carbides while introducing carbon into stainless steel. Usually, the case hardening is not used in chromium-containing alloys due to the formation of chromium carbide that substantially degrades corrosion resistance. Owing to this fact, the applications of case-hardened alloys in corrosive environments was significantly narrowed. Author performed the technique called Low-Temperature Colossal Supersaturation (LTCSS). In Para equilibrium conditions the diffusion of interstitial solutes is faster than substitutional solutes. Normally, the diffusion of carbon atoms into the alloy is substantially deeper under LTCSS conditions, on the other hand Substitutional solutes remains immobile under the same condition. A new discipline of engineered materials has emerged out of these interstitially surfaces hardening approaches, by which increased resistance to corrosion is accomplished with increasing resistance to fatigue and wear. The impact of LTCSS on austenitic steel 316 increases surface hardening by means of residual stress on the surface. The larger interstitial carbon concentration induces an expansion of the lattice that leads to compressive surface stress of more than 2 GPa thus enhancing both material surface hardness and wear resistance. It is possible to generate 15 atomic percent carbon concentrations at the region near to the surface covering the treated component entirely. The pitting potential can be improved from +320 mill volts (mV) to +950 mV by using LTCSS treatment. The most critical electrochemical parameters used to compare and measure the pitting resistance of different materials in laboratory is called pitting potential and a positive pitting potential value is desirable. It has been found that LTCSS-treated 316 SS has possessed very high resistance to corrosion when worked under natural seawater environments due to drastic improvement in pitting corrosion resistance. Crevice corrosion test founds that LTCSS-treated 316L has significantly higher corrosion resistance relative to the untreated 316L and Ni alloy. Further to this, surfaces treated with LTCSS method tend to have greater hardness in comparison to hard chrome and thus provide a future alternative to this environmentally harmful and toxic, corrosion-resistantand wear-resistant coatingMuthukumaran et al[3] conducted the argon and oxygen ion implantation technique by manipulating hardness and corrosion properties on the surface SS316 L. This technique was performed by using a dose of 1x1017ions/cm2 and 100KeV ion energy level on AISI316L, temperature was maintained at 32°C. Polarization testing was done in a simulated natural setting to check the corrosion resistance of the implanted samples. The author noted that the SEM and XRD results were in accordance with the results obtained from corrosion testing in comparison to the untreated AISI 316L the general corrosion resistance improved considerably in the case of oxygen and argon implanted material. On the other hand, the pitting corrosion resistance improved 4% in case of argon implanted material and no such improvement found in case of oxygen implanted material. The hardness of the surface found to be 465% in case of argon implanted and 425% for oxygen implanted against the original material.The hardness of the oxygen and argon treated substrates improved by about 512% and 556 respectively against original substrate samples. The hardness and corrosion resistance performance also found to be improved in case Argon implanted samples in comparison tooxygen implantedones. Sudjatmoko et al [4] investigated the nitrogen ion implantation technique on 316 materials to improve the surface characteristics of the material. The author performed the nitrogen implantation on AISI 316L stainless steel plate with ion dose of 5 1016 ion/cm^2 at 60, 80 and 100 KeV variation in ion energy levels. Upon investigation the author outlined that the implantation of nitrogen ions can substantially enhance the resistance to corrosion and value of hardness of AISI 316L stainless steel. The EDX and SEM analytical technique revealed appearance of boundaries on the surface of implanted AISI 316L samples. The white region on boundaries was formed due to the presence of nitride phases. The hardness characteristics also improved due to the formation of nitride phases inside the implanted samples. Further investigation of the surface morphology by XRD diffraction patterns revealed that the peaks of Fe_2N, Fe_3N and Fe_4N were formed on the implanted AISI 316L surface. From the results it was noted that in the of nitrogen-iron binary system, the Iron nitride found to be the iron-richest stable phase. He further outlined that these iron nitride binary systems possessed distinctive characteristics such as hardness, wear and corrosion resistant properties on surface of steel and iron components. Through potentiostat PGS 201T investigation the author noted that the resistance to corrosion of the nitrogen implanted samples improved substantially. Fernandes et al [5] conducted the technique of Plasma Nitriding and nitro carburizing ofaustenitic stainless steels SS316L and concluded that it can induce layers of expanded austenite. This technique involves supersaturating the surface with nitrogen which results in increased wear resistance and hardness. In this investigation nitro carburizing and plasma Nitriding was performed on AISI 316L at a varying temperature of 410, 455 and 510°C. Nitro carburizing and Plasma Nitriding were conducted by using the dc method with the following gas mixtures: 3 vol. % CH_4, 20vol. % N_2 and 78 vol. % H_2 for nitro carburizing and 21vol. % N_2 and 82 vol. % H_2 for Nitriding. The experiment was conducted at a temperature range of 410, 450 and 500ºC under 500Pa pressurefor the duration of 5h..The examination of the AISI 316L steel samples treated with plasma was carried out with X-ray diffraction, optical microscopy, and corrosion tests. A solution of 3.5% NaCl was used in the potentiodynamic polarization technique to measure the corrosion behavior of the samples. The thickness of the layer found to be increased in case of plasma treated samples. The investigation also revealed the formation of precipitate-free S-phase and homogenous layers at 400 but X-ray diffraction revealed the presence of chromium and iron nitrides and/or C iron carbide 450 and 500°. The resistance to corrosion of treated samples at410°C found to be more than untreated samples according to curves of potentiodynamic polarization. Also, the mechanism of corrosion changed from pitting corrosion at localized area to general corrosion after nitro carburizing or nitriding treatment of the samples. The author also found substantial improvement in resistance to corrosion of samples in a solution of 3.5% NaCl for both nitro carburizing nitriding and at temperature of 410°C. Sun et al[6] investigated wear and corrosion effect on the behaviour of carburized steel. The author further investigated tribocorrosion behaviour of AISI 316L samples carburized with plasma at low temperature, in solution of 1 M H_2SO_4 with sliding along unidirectional and using a tribometer of pin-on-disk types connected with a potentiostat for control of electrochemical. Author conducted the Sliding wear tests using potentiation and potentiodynamic conditions at applied potentials range and noted that at anodic potentials the carburized layer has a far stronger resistance to tribocorrosion than the virgin specimens but at cathodic potential the resistance to wear did not improve. Due to differences in the mechanism of tribocorrosion it is further noted that the resistance to tribocorrosion of 316L ata anodic potentials after the carburizing treatment improved by up to 12 times. It is noted that during the process of sliding the re-growth and removal of the oxide layer by chemical corrosion dominates the removal of the materials from the carburized samples, while corrosion-accelerated by wear and wear-accelerated by corrosion effects the untreated sample at anodic potentials. Mechanical wear of the underside carburized layer reduced at anodic potentials under the current conditions of testing. The author observed that the mechanism of tribocorrosion of the carburized layer switches from mechanical to chemical wear and at open circuit the mechanical wear is predominate on the other hand it again witches from chemical to mechanical wear with chemical wear more dominate at anodic potentials. For carburized layer the much-improved resistance to tribocorrosion at anodic potentials is due to its good resistance to corrosion and high hardness so that both chemical and mechanical wear are minimized. Author further concluded that carburizing at low temperature and varying potential at anode can be useful to reduce the component of chemical wear by 3.5 times and the component of mechanical wear by 35 to 55 times under the current conditions of testing. Gomes et al [7] performed the technique of metal matrix composite to further enhance the density and hardness. The investigation was carried out on 316L SS water-atomized powder. Samples with added 3% of TaC and NbC each and pure samples were milled mechanically in a ball mill by conventional method upto 24 hours and then pressed axially in cold conditions at 700 MPa in a steel die of cylindrical shape. The process of sintering was performed in vacuumconditions. The heating of the samples was carried out at a rate of 20°C/min up to temperature of 1290°C and then kept for 30 and 60 minutes in isothermal state. Scanning microscopy, X-ray diffraction, and measurement of hardness and density were examined for sintered samples. The impact of nano-sized refractory carbides (TaC and NbC) particles on the hardness, denseness and sintering mechanism, of samples of stainless steel was evaluated. It reveals that the value of hardness of the specimens reinforced with carbides increased significantly by mechanisms of hardening due to particles size differences. The hardness of the nanosized reinforced samples increased from 76.0 HV to 140HV due fine carbides precipitation and dispersion into metallic. Author elaborated that the value of hardness of stainless steel samples increased significantly with the addition of carbides resulting in reduction of grain size of carbides in metallic matrix during the process of sintering. Further conclusion revealed that increase in the hardness mainly dependent on the segregation of nanosized particles on the grain boundaries in the microstructure of the sintered samples. Chuankrerkkul et al[8] performed the fabrication technique called Powder metallurgy for fabricating a matrix composite of tungsten carbide and stainless steel. This method used Tungsten carbide and AISI 316L material. In this technique the composite prepared by mixing 5%, 10% or 15% by weight of Tungsten Carbide with powder of stainless steel and then compacted at 300MPa.The samples was sintered at 200 °C, 1250 °C or 1300 °C with a holding time of 30, 45 or 60 minutes' duration. The author also fabricated 316L specimens with no Tungsten carbide addition by using same process. It revealed that value of Hardness and porosity improved with high WC contents when investigate at different temperatures but on the other hand the porosity and hardness value decreased at a higher temperature of sintering. The holding time found to have no effect on the value of hardness. The specimens with sintered at 1300 °C temperature and with 15 wt% of tungsten carbides found to, have the maximum hardness. Sulima et al[9] performed a technique known as high temperature-high pressure for the improvement of the mechanical properties of AISI 316L specimens. The Author used two samples of AISI 316L SS composites reinforced with 10% vol. and 20 %vol. of TiB_2. These composites powder was mixed in a Turbula mixer by up to 6 hours and then pressed in a matrix of steel for shaping into discs under 200 MPa pressure value. The materials densification was achieved by Bridgman type apparatus. The sintering was done at 7 ± 0.2 GPa pressure and 1200 ^{o}C temperature values for time period of 60 seconds. Author observed that value of hardness and Young's modulus value of the austenitic AISI 316L material can be improved with the addition of the TiB_2 particles. The investigation concludes that in caparison to unreinforced alloy the compression strength of the reinforced composite increased significantly. The value of coefficient of friction of composites also improved with the addition of TiB2 content. Author outlined that at 20 vol.% TiB_2 ceramics reinforced AISI 316L SS, properties were optimized. The material properties such as friction coefficient, compression strength, hardness and Young's modulus value for the respective composite are 0.37, 1350MPa, 460HV1 and 225GPa, respectively. Wang et al [10] evaluated the annealing effect on the nanostructured austenitic 316L SS specimens with twin bundles of nano-scale inserted into grains of nano-size which were synthesized by employing DPD (dynamic plastic deformation). The author used commercial grade SS316L material annealed to 1200^{o}C before DPD process to maintain the homogeneity of the coarse grains. Some DPD 316L samples annealed and some samples left as in the form of DPD316L. Further, the author utilized the scanning electron microscopy (SEM) at a 5-kV operating voltage on a FEI Nova Nano-SEM system for the characterisation of the annealed and without annealed DPD 316L SS specimen's microstructure. The material hardness was measured using Vickers hardness machine. Author observed that the under a load of 30 N the DPD 316L steel exhibits similar resistance to wear and a little improved wear resistance under a load of 10 N relative to that of the original. Author also inferenced that under a load of 30 N the resistance to wear decreases with an increase in hardness and on the other hand under a load of 10 N it follows the reverse trend after annealing. From the results it can be demonstrated that if the DPD samples annealed for 20-22 min at a 749-751 temperature range then highest resistance to wear canbe obtained. The wear resistance in this case more than 48% greater than CG steelspecimens. Subbiah et al[11] demonstrated that thorough case hardening methods such as surface hardening methods and nitriding the resistance to, corrosion resistance and hardness value can be improved to larger extent.The Authorinvestigated austenitic 316LN samples and found that the properties such as resistance to corrosion, hardness, resistance to wear can be improved with gas nitriding technique. The micro hardness tester was used to measure micro hardness value of the samples and bath nitriding was performed for different duration at a temperature of 5000^{o}C followed by a post oxidation method for a duration of 30 minutes and optical microscope used for the investigation of inter metallic phases. The Author noted a significant increase in micro hardness after gas nitriding treatment. With this technique upto 1410Hv hardness value can be obtained on the austenitic stainless-steel samples and e the presence of various alloying elements can be attributed to this phenomenon. Author found that there is an increase in hardness value at the surface level with the time of diffusion to a certain level and after that there is no change found in the hardness value. Author also found that hardness value remains same aftert post- oxidation but the resistance to corrosion increases substantially in comparison to non-oxidized samples Hassona et al [12] characterized austenitic AISI 316L to investigate the impacts of process parameters gas nitriding on the protection of erosion wear. Author utilized X-ray diffraction (XRD), techniques for measuring surface hardness and, Optical microscope to evaluate the properties of nitrided layers produced by gas nitriding at a temeparature range of 400– 600°C, time duration (10– 50 hr.) and ammonia flow rate of 100-600 L/hr. The results of the research revealed that gas nitriding produces nitrided layers on the surface of AISI 316L samples and variation in the hardness, thickness, and composition was due to varying conditions of nitriding. Due to the formation of nitride layer on the sample, the resistance to erosion after gas nitriding can also be improved. The variation in erosion protection behavior is a function of the impact angle a value of around 54% in the 90° test and 93% in the 30 ° test can be achieved. Chuankrerkkul et al [13] concluded that the method of Powder metallurgy can be useful for the manufacturing of composites of tungsten carbide and stainless steel. The research examined Tungsten carbide and AISI 316L composite. The Tungsten carbide with varying weight of 5%, 10% or 15% mixed within the powder of stainless steel and compacted at 300MPa. The sample was then sintered at varying temperature of 200 °C, 1250 °C or 1300 °C with a holding time of 32, 46 or 60 min. The author also worked on the 316L samples manufactured with same procedure but without any addition of Tungsten carbide. The author noted that the hardness and porosity of the composite samples increased with an increase in composition of WC at different temperatures. On the other hand, the porosity of the composite decreased at a higher temperature of sintering but he hardness increased at the same conditions. Upon further investigations it is inferenced that the there is no differences in the hardness value at different holding times. Balamurugan et al [14] investigated the corrosion behavior of the Titania coated 316L SS samples and noted an increase in resistance value. There are desired and beneficial effects of Gel Titania coating on the corrosion resistance of 316L SS. The coating is very useful to minimize current density of corrosion which provides an added advantage of prevention of ion release. The results of FTIR SEM and XRD, further confirmed the presence of uniform coating. The parameters of corrosion kinetic in relation to the pristine steel samples indicate corrosion behavior improvement of the coated steel specimens. Fathi et al [14] examined behavior of corrosion of titanium and hydroxyapatite coated 316L SS specimens. The coating of the specimens was done using physical vapor deposition and plasma s|praying techniques. The investigation of the morphology and microstructure of the coatings was done by using EDX, SEM and XRD, techniques. The corrosion behavior was determined using electrochemical potentiodynamic polarization technique. The corrosion behavior improved significantly due to the presence of double layer coating. In comparison to HA coatings and untreated 316L, the densities of the current were minimized for this coating of double layer. The SS-316 van be used in the high temperature applications like boilers and heat exchangers , when coated with superalloys [14-17]

3. CONCLUSION

a) The review contains numerous methods for improving the corrosion, hardness and wear behavior of the SS316L austenitic steel but there are very few methods available for metal matrix and metal composite that improve the corrosion, hardness, and wear behavior of the austenitic SS316L material
b) There is general acceptance that all these methods are very effective to improve surface properties of the stainless steel
c) Studies on various coating methods have proposed that electrolytic plasma methods, such as electrolytic plasma oxidation, could provide a variety of steels with potentially superior surfaces. However, further study is required to bring this study process to the application level.

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