

Wear Behavior Analysis of Aisi440 Martensitic Steel by Annealing and Tempering Process

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Abstract: Experiments on the wear behavior of AISI440 steel were conducted and the specimens were subjected to annealing process, followed by tempering. AISI440 is a martensitic stainless steel which is used in many applications due to their hardness and wear resistance. AISI440 is subjected to Annealing and Tempering processes at different temperatures like 500, 600 and 700°C. The result showed a lath of martensite and retained austenite. After tempering the microstructure consists of mixtures of tempered martensite, carbides and reversed austenite dispersed in the martensite matrix obtaining the strength and toughness in the steel. The metallographic studies were compared with scanning electron microscope results.

Keywords: AISI 440, martensitic steel, annealing, tempering, microstructure.

I. INTRODUCTION

Martensitic steels have excellent corrosion resistance and high hardness properties. Martensitic stainless steel grades are relative cheaper when compared to the austenitic stainless steel. Currently, the uses of martensitic stainless steel grades in several industrial applications have increased tremendously. Some of its applications include razor strip, blades and cutting tools, surgical instruments, gears, valves, pumps, shafts, offshore oil and gas components, bearings, mixers and stirrers, turbine parts and aerospace. Many of these applications are hidden to most of us which probably explains why martensitic stainless steels do not have a prominent public profile. The microstructure of martensitic stainless steel consists of martensite, carbide as well as retained austenite and the amount of carbide in the quenched microstructure influences the properties of this material such as hardness, strength, toughness and wears. A. Calik et al [1] conducted studies on annealed stainless steel 316LN austenitic stage reversed. The 316LN austenitic stainless steel was cooled to 90% reduction in thickness at room temperature and subsequently annealing is applied for 1–100 min in the temperature range of 600 to 1000 ° C. The findings show that 46% of α' -martensite and deformed untransformed austenite through the annealing process of nucleation and expansion.

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With enhanced annealing temperature and time, the average grain size raised continuously, resulting in decreased yield strength and reduced 22 elongations. In this research, it has been noted that X-ray diffraction has recognized and quantified the evolution of stages in chosen samples.

L.D. Barlow et al [2] Xiao hong Liu, Li Xiao, Chunhua Wei, Xiuxia Xu, and Minghuan Luo Weilin Yan explored the effect of multidirectional forging and annealing in medium carbon low alloy steel on abrasive wear behaviour. Multi-directional forging and annealing was used to process a medium carbon low alloy steel. The microstructure was refined after multi-directional forging. The ductility was dramatically improved without significantly compromising the tensile strength and hardness after subsequent controlled annealing. For further improvement, more ductility resulted in abrasive wear resistance. Higher hardness, ductility and hardness level of work have been found to be responsible for higher abrasive wear resistance of ultrafine-grained low-alloy carbon steel. Microstructural development is studied by optical and electron microscopy and abrasive wear resistance is researched.

I.Sudsakan et al [3] has researched modifications in the microstructure and mechanical characteristics of D2 tool steel. Improving the soaking time during the annealing phase allows the carbide morphology to convert from uneven form to almost round form and to be evenly dispersed in a pearlite matrix. Badaruddin et al [5] researched the impact of annealing temperature on a lean duplex stainless steel material's strain-hardening conduct. Tensile deformation investigated the persuasion that the annealing temperature varied from 1000 ° C to 1200 ° C on the stress-hardening

Table 1: Chemical Composition of AISI440 Martensitic Stainless Steel

C% Max.	Mn% Max.	S% Max.	P% Max.	Si% Max.	Ni % Max.	Cr %Max	Fe %Max
1.2	1	0.03	0.04	1	1	18	Bal

conduct of a lean duplex stainless steel with a metastable austenite stage. The findings provide the data that the test steel's tensile characteristics were susceptible to the temperature of the annealing. Due to the 23 plasticity or / and the twinning-induced plasticity effects, the test steel showed enhanced ultimate tensile strength and elongation. The finest combination of ultimate tensile strength and ductility with approximately 60 GPa% was obtained at an annealing temperature of 1050 °C. The profile of the strain hardening curve could be divided into two types for the selected annealing temperature range: I a typical three-stage strain hardening from 1000 to 1050 ° C and (ii) a two-stage strain hardening from 1100 to 1200 ° C temperature.

Zhong hua Jiang et al [13] had Experimental work on martensitic stainless steel alloyed nitrogen. In warm

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forged, hardened and tempered conditions, they researched the behavior of tensile, tensile, impact, wear and corrosion behavior on conventionally melted nitrogen alloyed martensitic stainless steel. To study the impact of nitrogen, 6 distinct alloyed materials of nitrogen structure have been selected here. here they are applied the heat treatment services like hardening, tempering and forging is carried out in hot condition. Tensile tests are done to find out the deformation level, impact tests are done to calculate the toughness. By using pin on disc machine they found the wear in the material, corrosion tests are done to conclude the corrosion resistance. In this research we can observe that strength is enhanced by adding nitrogen to the material but toughness of effect, wear resistance, corrosion resistance improved to a certain point but eventually reduced in relation to nitrogen. SEM assessment disclosed the fracture morphology, showing ductile and quasi-cleavage fractures on the surfaces.

Chang weng et al [12] studied that the redistribution of C and N occurs when the martensitic stainless steel comprising X4CrNiMo16-5-1 (0.034 wt percent C and 0.032 wt percent N) is treated. In this research we can observe a continuous decrease in the unit cell quantity of martensite during tempering. Atomic probe topography has shown that this volume decrease is entirely due to interstitial atom separation. Atomic probe topography disclosed that this volume reduction is completely accounted for by interstitial atom separation, suggesting that in small interstitial martensitic stainless steel stress relaxation only results in negligible modifications in the quantity of the martensite unit cell. By using metallographic studies such as X-ray diffraction (XRD) insitu synchrotron and redistribution atomic tomography (APT).

Pradip Kumar et al [14] investigated changes in Ti- Micro alloyed low carbon steel by applying quenching, partitioning, and tempering. The Quenching-partitioning-tempering method was used after cold rolling to treat a low-carbon Ti-micro alloyed stainless steel. In addition to martensite, ferrite and maintained austenite formation, after the Quenching Portioning-Tempering therapy, TiN, coarse TiC, fine TiC, (Fe, Cr)₃C and ultra-fine TiC precipitates were created. By using an electron microscope for emission scanning (FESEM) and transmission Observations, thermodynamic, crystallographic and statistical analysis were used to reveal these particles ' rainfall habits. The impacts of temperature and moment partitioning-tempering (P-T) on the microstructure and mechanical characteristics of samples treated with Q-P-T have been researched in particular. The coarsening and spheroidization of (Fe, Cr)₃C particles during Portioning-Tempering stage were obviously retarded by large Cr addition. Regain of austenite was obtained significantly. The precipitation of ultra-fine TiC particles in the martensite during the P-T stage at 500 °C induced a secondary hardening.

S.A.Tukur et al [15] investigated that martensitic stainless steel materials are not used in big amounts compared to austenitic and ferritic grades, owing to their mixture of strength, toughness and mild corrosion resistance, they play an enormous and often invisible role in our modern world. However, they tend to lose their mechanical / microstructural integrity after welding the martensitic stainless steel. In this study, after various heat treatments, the microstructures and mechanical properties of a welded AISI 410 martensitic stainless steel were studied with the aim of restoring the

hardness and improving the material grain refinement. The results show that the steel structures are of lath martensite mixed with a small amount of retained austenite. In addition to the TP2 specimen in which the martensite phase has been transformed into a ferrite structure, the tempered steel structures are mixtures of tempered martensite, carbides and reversed austenite dispersed in the martensite matrix. The result showed that the tempering regimens (500, 600 and 700 ° C) improved the hardness and refinement of the grain resulting in a finely finished existence. The TP3 specimen has experienced secondary hardening phenomenon, displays the best mechanical properties and has the highest hardness value of 370.7 HV near the parent metal after tempering at 700 ° C.

Zhinan Yang et al investigates to evaluate the cyclic deformation mechanism, the cyclic hardening / softening conduct and the evolution of microstructure of high-carbon nano-bainitic steel were studied in this research. Results showed that the optimum temperature at low temperature was determined. The retained austenite is converted into martensite during cyclic deformation. After low temperature tempering, the cyclic deformation of high-carbon steels at complete strain amplitude of 0.6% shows no apparent cyclic softening conduct, primarily due to the high density of dislocation tangle around martensite and cyclic deformation twins.

M Preethi et al investigated a portion of the car suspension scheme is the anti-roll bar, swing or stabilizer bar. It connects the vehicle's right and left and resists the vehicle's swinging in sharp curves or street irregularities. During service, this tubular component experiences fatigue failure. The impact of temperature and temperature moment on the fatigue characteristics of 26MnB5 steel is discussed in the present document. In a closed quench oven, the electrical resistance welded pipes produced of 26MnB5 were hardened above Ac3 temperature. The tempering is performed for 15, 30 and 60 minutes at 400 ° C, 450 ° C, 500 ° C. The microstructure and the mechanical properties have been analyzed by means of optical microscopy, hardness testing and tensile tests. The tubes were then bent to shape and tested for fatigue. Then the pipes were bent to form and fatigue tested. In this document, the impact on microstructure and mechanical characteristics of tempering temperature and tempering time is discussed and contrasted with the component's fatigue characteristics.

Dianz hong Li et al The characteristics of RA decomposition and its effects on the steel's mechanical properties are investigated in this study. The results show that during standard tempering at 700 ° C, RA decomposes into a cluster of coarse M23C6 carbides and ferrite. These coarse carbides decorate the cluster's border, worsening the steel's effect toughness. Accordingly, these carbides are tentatively modified in size and distribution by introducing pre-tempering at different temperatures ranging from 180 ° C to 650 ° C before the standard tempering at 700 ° C. That's because during pre tempering, RA first decomposes into various transitional microstructures such as martensite, bainite or pearlite, which further transform during the subsequent 700 ° C tempering into M23C6 carbide clusters. The experimental results show that after the tempering of 700 ° C, 455 ° C is the optimum pre-tempering temperature to enhance the steel effect toughness. Microstructural observations reveal that during the pre tempering stage of 455 ° C, the RA completely

decomposes into bainite consisting of fine bainitic packets and a high density of M₃C carbides, providing additional nucleation sites for M₂₃C₆ carbides within the carbide clusters during the subsequent tempering stage of 700 ° C, thus preventing the formation of coarse M₂₃C₆ distributed along the carbide cluster.

II. EXPERIMENTAL WORK

The material used is AISI440 steel and its chemical composition is shown in Table 1. Polished cylindrical pins measuring length of 40 mm, diameter of 12mm were used. The specimens were ultrasonically cleaned, rinsed dried and were applied suitable etching agents. Three cylindrical pins were used and the specimens were annealed at different temperatures to 700⁰ C and cooled slowly. After that tempering was done in muffle furnace at different temperatures (500, 600 and 700⁰ C), soaked for 1 hr and air cooled. Using Pin on Disc apparatus, as shown in figure 2.2 with the disc rotated at 500 rpm with load 30N was applied for 5 minutes under the dry sliding conditions. The weight loss is determined before after the test and wear loss is calculated. Microscopic observations are made using scanning electron microscope as shown in figure 2.1.



Fig.1 Scanning Electron Microscope



Fig 2 Pin-On-Disc Apparatus

Ch.Vijay Krishna et al [4] Microstructural observations showed that the typical three-stage hardening was primarily linked to a martensitic transformation caused by strain. Microstructural observations revealed that the typical three-stage hardening was primarily associated with a strain-induced martensitic transformation with a sequence of the TRIP impact, i.e. In addition to the martensites induced by the strain, mechanical twins were noticed at temperatures above 1100 ° C in the deformed austenite of the specimens annealed. This result got that TRIP and TWIP occurred simultaneously in the austenite at higher annealing

temperatures. The synergy and common competition from the coexistence of TRIP and TWIP caused the two stage strain-hardening.

Yang peng Zhang et al [6] investigated the use of annealing heat treatment services on Fe-19Cr-2Mo-Nb-Ti ferritic stainless steel. They explored the behavior of the Effect of precipitates on annealed mechanical characteristics between 850⁰C and 1050⁰C. In this study we can observe that the low-angle grain boundaries are transformed into high-angle grain boundaries with increasing annealing temperatures, while the finer phases of Laves are transformed into coarsened (Nb, Ti)(C, N) precipitates, thus weakening the pinning grain boundaries effect of precipitates on inhibiting grain growth deteriorating the solid solution strengthening effects of Nb in the matrix, and then the values of tensile strength decreased from 829 MPa to 478 MPa.

Hang Liu et al [8] explored the corrosion behavior of medium carbon steel using a 3.5% w.t. NaCl Solution quenching method. In this experiment, different surface analysis methods investigated the corrosion features of a quenched and partitioned medium carbon steel in a 3.5 percent NaCl solution. And evaluated with those of the same structure of quenched and tempered steel. Both steels showed almost identical patterns in variations in corrosion. However, a lower corrosion rate was verified by the quenched and partitioned specimen. The development of preserved austenite in the carbon-rich state increases the corrosion capacity of the carbon-depleted martensitic matrix and reduces the residual tensile stress on the quenched and partitioned surface, thus enhancing its corrosion resistance.

Actual metal melting happens only in cases where the impact of dry wear generated heat can in several respects decrease wear resistance. It can temper hardened constructions as phase changes boost hardness and fragility and decrease mechanical characteristics and accelerate resistance to corrosion. Atoms of identical or crystallographically similar metals have a very powerful cohesive force.

When two smooth surfaces of the same metal actually touch each other, due to nuclear appeal, if adequate pressure is applied by friction to break through any remaining separating material such as oil, dirt or adsorbed moisture and the surfaces are in adequate contact to cause elastic or plastic deformation, then seizure takes place. Seizure can cause full stoppage. Impact is a wear factor, as plastic flow and shape change can be caused by the sudden load applied. Proper design should provide compressive surface yield strength above impact-generated compressive stresses and sufficient support to prevent surface flow.

Fatigue failure is included in a discussion of wear since it is a gradual deterioration due to use proper design to eliminate stress concentration at notches and sharp angles will increase, fatigue strength compressive stress at the surface will provide additional protection. This may be obtained by case hardening like carburizing, and by shot peening.

III. RESULTS AND DISCUSSIONS

A. Microstructure Analysis

AISI440 stainless steel microstructure is seen under the Scanning Electron Microscope. Martensite steel with high content of carbon, ferrite substance, combined format of iron and carbon were

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formed. AISI 440 when subjected to the annealing process at different temperatures like 500, 600 and 700⁰ C are shown in figure 3.1(a, b, c). The microstructure of specimens observed is of mixture of martensite and retained austenite is shown in figure 3.1(c). To alter phase composition, tempering treatment is done at different temperatures like 500, 600 and 700⁰ C to improve the toughness in AISI440 steel. The microstructure of tempered samples is shown in figure 3.1(d, e, f). The micrograph of the tempered sample revealed retained austenite within the tempered martensite and carbide precipitate as shown in figure 3.1(f).

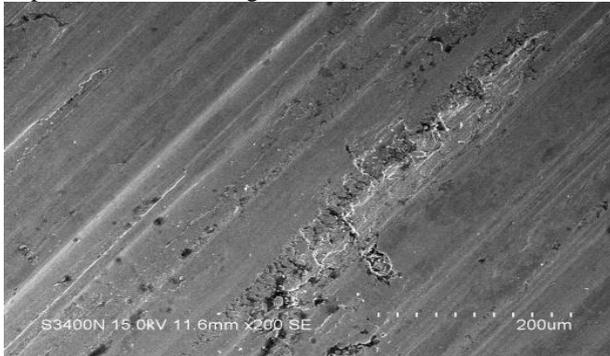


Fig 3.1(a) Annealed Sample at 500⁰ C



Fig 3.1(b) Annealed Sample at 600⁰ C

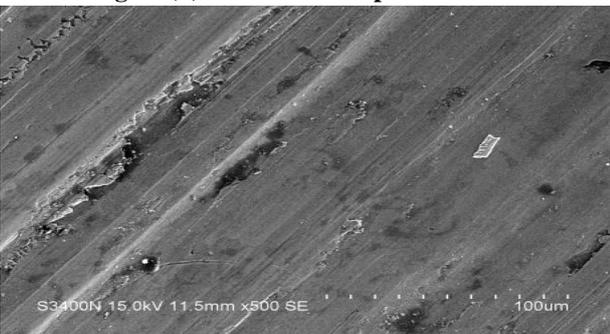


Fig 3.1(c) Annealed Sample at 700⁰ C

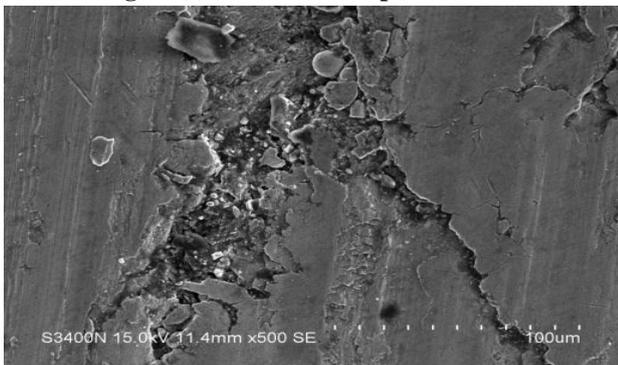


Fig 3.1(d) Tempered Sample at 500⁰ C

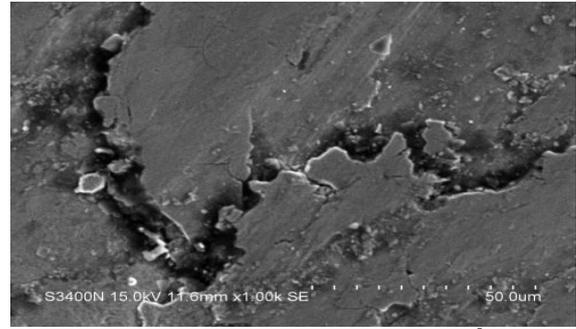


Fig 3.1(e) Tempered Sample at 600⁰ C

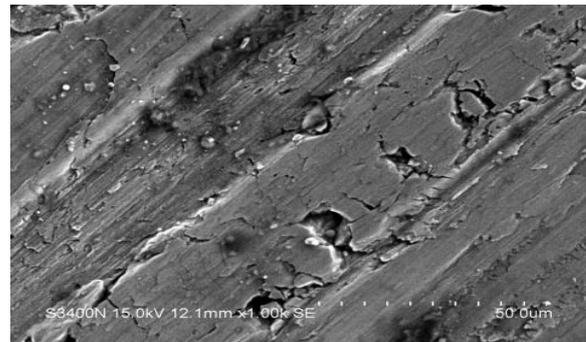


Fig 3.1(f) Tempered Sample at 700⁰ C

Xiaojie Zhao et al [9] have involved in studies on the comparison of impact-abrasive wear features and immediate quenched and partitioned steel performance. With variable quantities of silicon, aluminum and chromium, two medium-carbon chemical compositions of 0.3% were chosen. The direct quenching and partitioning processing route involved intermittent water quenching with two different quench stop temperatures (TQ) (1750 and 2250⁰C). For the comparison of both mechanical properties and wear features, direct quenched versions were also developed. With the disastrous, enhanced effect toughness and elongation to fracture were accomplished compared to the direct quenched therapy. Treatment quenched and partitioned with decreased original strength and hardness. The effect abrasive wear efficiency rate of the distinct experimental microstructures was measured using an impeller tumbler testing machine compared to that of a 500 HB commercial reference steel. There is no advantage from the enhanced ductility of the steels that have been directly lifted and parted.

Le Xu et al [10] researched that the embrittlement of martensitic stainless steel as-normalized AISI 410 is high when exposed to tempering therapy at a temperature range of 823K. They found that, when applied at low temperatures around 723 K, mostly iron-rich carbides are present in steel, but precipitation is dominated by chromium-rich carbides under elevated temperature circumstances. The temperature range from 773 to 823 K is the temperature of change for the precipitates, with carbides coexisting in both Fe₂C and M₂₃C₆ types in the material. During low temperature tempering, the nucleation of Fe₂C within the martensite lath has a definite position in the embrittlement of this steel. High brittleness is not observed at high temperature tempering because of precipitation of M₂₃C₆Carbohydrates preferably along the lath and previous austenite limits instead of Fe₂C. Even through Auger electron, separation of S and P, which is commonly reported as one of the causes of hair embrittlement, could not be

identified in the fabric. The toughness of the material founded using charpy impact test, and extraction of precipitated carbides during tempering identified by x-ray diffraction.

S.Usharani et al [11] researched on martensitic stainless steel has been conducted using tempering therapy. Nano-sized M3C carbides at 300 ° C, nano-sized Cr-rich M23C6 carbides at 550 ° C and sub-micron-sized Cr-rich M23C6 carbides at 700 ° C led in a tempering of 13 wt. percent. Late martensite with un dissolved M23C6 carbides is noted due to austenitization. In this study that the pitting resistance for tempered condition was lower than the austenitized condition at 550 ° C with the least resistance. The study was attributed to a Fe-rich surface movie and massive carbide precipitation with a Cr depletion zone of 7–9 nm at a carbide interface for temperature 550°C as resisted to a Cr-enriched passive film Metallurgical tests were done by using Transmission electron microscopy, X-ray photo electron spectroscopy.

B. Hardness Behaviour

Hardness of Untreated AISI440 sample was found to be 428 Hv. After annealing at 500⁰ C, the sample showed hardness of 335.25 Hv and case depth was found to be 12µm. Further annealing at 600⁰ C sample showed the hardness of 264 Hv and the case depth was found to be 14µm. When annealing is done further to 700⁰ C sample showed low hardness of 234 Hv and the case depth was found to be 16µm. This confirms the softness of sample which indicates retained austenite. After tempering at 500, 600 and 700⁰ C showed hardness of 352 Hv and the case depth was found to be 13µm. Tempered sample at 600⁰ C showed hardness of 280 Hv and case depth was found to be as 15µm. Tempered sample at 700⁰ C showed the hardness of 387 Hv and the case depth was found to be 18µm. Tempering at 700⁰ C sample exhibited high hardness and also the toughness which confirms the martensite matrix with low level of austenite.

C. Wear Behavior

Wear loss was found by using pin on disc apparatus under the dry sliding conditions by applying the load of 30N, speed at 500 rpm the sliding distance of 80mm. The wear loss in the sample was calculated by determining the difference between the weights before and weight after testing. The density of stainless steel material was found to be 0.0078 g/mm³. For an untreated sample, the wear loss was found to be as 0.012 grams and the volume loss was found to be as 1.54 mm³. For the annealed sample treated at 500⁰ C, the wear loss was found to be as 0.025 grams and the volume loss was found to be as 3.225 mm³.

For the annealed sample treated at 600⁰ C, the wear loss was found to be as 0.027 grams and the volume loss was found to be as 3.48 mm³. For the annealed sample treated at 700⁰ C, the wear loss was found to be as 0.029 grams and the volume loss was found to be as 3.74 mm³. For the tempered sample treated at 500⁰ C, the wear loss was found to be as 0.022 grams and the volume loss was found to be as 2.83 mm³. For the tempered sample treated at 600⁰ C, the wear loss was found to be as 0.019 grams and the volume loss was found to be as 2.45 mm³.

For the tempered sample treated at 700⁰ C, the wear loss was found to be as 0.016 grams and the volume loss was found to be as 2.06 mm³. It was noted that more hardness on untreated martensitic stainless steel. By performing the annealing and tempering process, the hardness, brittleness and strength of

martensitic stainless steel were slightly reduced. Ductility was promoted to the martensited material.

IV. CONCLUSIONS

AISI440 stainless steel were subjected to annealing and tempering process at 500, 600 and 700⁰ C. The conclusions are drawn.

- I. Results of annealing samples microstructure gives the presence of retained austenite along with the martensite after tempered showed carbide precipitates along with retained austenite.
- II. Annealed sample at 700⁰ C showed minimum hardness of 234Hv compared to the annealed specimens treated at 500⁰ C, 600⁰ C.
- III. Tempered sample at 700⁰ C showed high hardness of 387 Hv compared to all other samples.
- IV. Wear loss of tempered specimen at 700⁰ C is 0.016 grams as it is minimum as it maintain the hardness and also the toughness.

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