Effect of shot peening on hardening and surface roughness of nitrogen austenitic stainless steel

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Abstract

Austenitic stainless steel cannot be hardened by heat treatment. It is usually annealed, followed by cold working for improving hardness. Nitrogen is a strong austenitic forming and stabilizing element and is a strong solid solution strengthener. The amount of nitrogen contained in an austenitic stainless steel affects its properties significantly. The fatigue strength and corrosion resistance are improved by inducing nitrogen in the austenitic stainless steel. In this paper, shot peening of nitrogen austenitic stainless steel (RS561) has been done to study its effects on hardness, fatigue strength, compressive residual stress and surface roughness. The emphasis in this paper is focused on the change in hardness, fatigue strength and surface roughness of nitrogen austenitic stainless steel by primary shot peening and double shot peening.

Key Words: Nitrogen austenitic stainless steel, Fatigue, Shot peening.

Introduction

Stainless Steel is a highly corrosion resistant material due to the presence of chromium along with the other alloying elements like nickel and molybdenum. From the classification on the basis of the predominant phase constituent of the microstructure, the austenitic stainless steel is most corrosion resistant. This makes its wide application in chemical and food processing equipments, medical equipments, cryogenic vessels, etc. Hence, it is better to have hardenability, fatigue strength and tensile strength, along with the corrosion resistant in various applications.

The main constituents for stainless steel are chromium, nickel, molybdenum, and aluminium. Chromium makes the surface passive by forming a surface oxide film, which protects the underlying metal from corrosion. Nickel added to stainless steel improves corrosion resistance in neutral or weak oxidizing environments. It also improves ductility and formability by enabling the face centered cubic (FCC) crystal structure to be retained at normal temperatures. Aluminium improves high temperature scaling resistance. More specific alloy like molybdenum (Mo) and nitrogen (N) are used to enhance pitting and corrosion resistance [1]. Nitrogen increases the yield and tensile strength of austenitic stainless steels without decreasing the ductility and toughness. The RS561 is the Mo and N based austenitic steel. Many of the currently available duplex grades contain additions of both Mo and N. Duplex stainless steel has good mechanical and corrosion resistance properties [2]. Duplex stainless steels are the new trend towards the improvement of austenitic stainless steel. Duplex grades possess the same, or even better, corrosion resistance as present in austenitic counterparts along with weight reduction.

K. Ram Mohan Rao et al. [3] induced nitrogen on AISI 316L austenitic stainless steel and noticed that the material developed the rich corrosion resistive layer. Examination was done by X-ray diffraction and subjected to a potentiodynamic polarization tests in 1 wt% NaCl solution, and found significant and optimum improvement in corrosion resistance. Barbosa L.P. et al. [4] studied the corrosion resistance of 316 stainless steels filters sintered in nitrogen–hydrogen atmosphere. The austenitic stainless steel alloyed with nitrogen enhances the metallic component of inter atomic bonds. They provide more homogeneous distribution of substitution solutes through short range ordering of nitrogen atoms and strong chemical interaction between nitrogen and alloying elements. This results in the high thermo-dynamical stability of nitrogen austenitic steels.

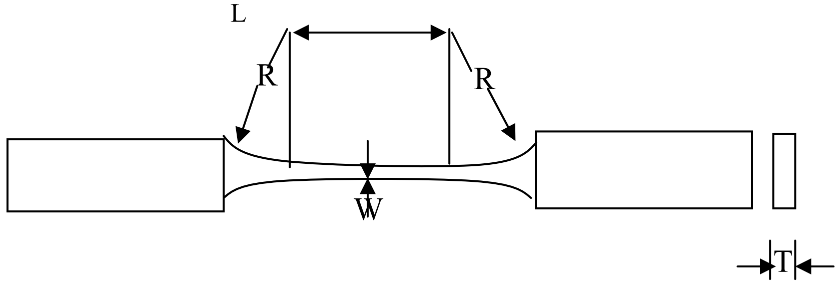
Cold working is often used to increase strength, especially in higher alloyed austenitic stainless steels [5]. Shot peening is one of the most versatile tool to strengthen the metal parts against fatigue failure and corrosion. The improvement in mechanical properties is due to the induction of compressive residual stress in the metal parts. The residual compressive stress induced by shot peening is the function of material and mechanical conditions. Different materials have different patterns of residual stress for same shot peening condition. Bombarding of small spherical shots is done in shot peening [6]. Each shot strikes the metal surface and imparts the stress in the form of compression. The induction of compressive residual stress is limited to a very small depth from the surface.

Shot peening produces residual compressive stress [7]. This is beneficial for improving fatigue strength. The better results should be obtained by controlling the different shot peening parameters. Surface finish has a considerable effect on fatigue strength of the component [8]. Surface finish of a component can be improved by different processes like chemical polishing, electrochemical polishing, double shot peening etc. Out of these double shot peening is simple and low cost process.

On the basis of predominant phase constituent of the microstructure has three main classes of the stainless steel i.e. martensitic, ferritic and austenitic [9]. Out of these three stainless steels, martensitic is capable of heat treatment. This is because in martensite, the prime micro constituent and the other alloying constituents produce dramatically change in iron-iron carbide phase diagram. In austenitic stainless steel, the austenite phase field is extended to room temperature. However, ferritic stainless steel has α ferrite body centered cubic (BCC) phase. Hence ferritic and austenitic stainless steels are not heat treated [10].
High carbon content in the austenitic stainless steel may cause chromium rich carbide precipitation and form intergranular boundaries, then deplete the grain edges of chromium and causes intergranular corrosion cracking in the corrosive environments. If the carbon content is reduced then, this problem decreases significantly. However lower carbon content in nitrogen induced austenitic stainless steel reduces the yield strength and consequently limit their applications. For improving mechanical properties such as hardness, fatigue strength and surface roughness, the nitrogen induced austenitic stainless steel can be shot peened. In the present paper mechanical properties such as hardness, fatigue strength, compressive residual stress, depth of deform layer and surface roughness of the shot peened and double shot peened nitrogen austenitic stainless steel are experimentally studied.

Experimental Procedure

The chemical composition of high nitrogen austenitic steel (RS561) is shown in Table1. The material was used to manufacture different specimens as per ASTM standards for various mechanical properties tests. The ASTM specimen used for fatigue testing is shown in Fig.1. The specimens were put in different categories. The shot peened specimens were marked as SP and un-shot peened as USP. Shot peening was done by centrifugal wheel system.



T = 5mm W = 2.6T L = 3.23W R= 117mm

Fig. 1: ASTM Flat Specimen

$$\frac{W}{T} = 2 \text{ to } 6$$

$$L \geq 3W$$

$$R \geq 8\,W \quad \text{to minimize } K_t \text{ of specimens}$$

Taking, $T = 5\text{mm}$

$$W = 13\text{mm}$$

$$L = 42\text{mm}$$

$$R = 117\text{mm}$$

Table 1 Chemical composition of RS561 steel

Steel	C	Si	Mn	P	S	Ni	Cr	Mo	V	N
RS561	0.02	0.15	6.0	-	-	10.0	23.0	2.0	0.14	0.48

The mechanical properties of the steel in solution treated condition were: yield strength of 748 MPa, ultimate tensile strength of 836 MPa and fatigue limit of 193 MPa. For the purpose of comparing the peening effect, an A-type Almen strip, 76 x 19 x 1.3mm thick was used. The arc height was measured using Almen scale. 0.1mm of A was designated as 4A. The glass shots of spherical shapes were used for shot peening. The shots had diameter 0.05mm to 0.15mm with coverage of 200%. The different intensities 1A, 3A, 4.5A and 6A were employed. Then fatigue testing was carried out in axial loading fatigue testing system at room temperature. To draw S-N curve, the specimen was used to fail at different stress levels. Stress ratio (R) equal to 0.1 was used during fatigue testing.

Micro-shots of zirconium were used for double shot peening. The specimens were marked as DSP for double shot peening. The DSP were again subjected to fatigue testing. Almen intensities were obtained by changing shot flow rate. Surface irregularities were measured by 'Talysurf' in which a stylus with a diamond tip was drawn across the surface.

The micro hardness of surface changes with peening intensity. Vickers hardness tests were carried on the surface of both SP and USP. Hardness measurements were carried out from surface towards the core of the steels. The residual stress induced by shot peening was measured by X-ray diffraction method. A Cr tube operated at 30 KV and 8 mA was used for projecting $K\alpha 1$ X-rays.

Results and Discussion

Hardness

The average value of hardness for base material (USP) was 250 VHN. Depending on the shot peening intensity, the hardness varied from 332 VHN to 396 VHN for shot peened samples. It is evident from the results that the hardness increases with the intensity of shot peening (Table 2).

Table 2: Variation of hardness and depth of deformed layer with shot peening

S.No.	Shot peening intensity (Almen A scale)	Hardness (VHN)	Depth of deformed layer (mm)
1	1A	332	0.23
2	3A	358	0.35
3	4.5A	380	0.44
4	6A	396	0.50

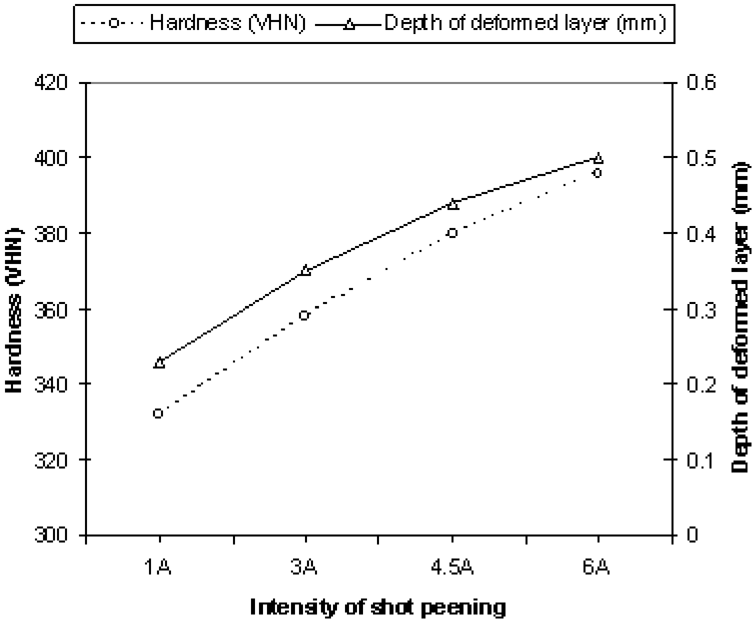


Fig. 2: Hardness distribution of RS561.

The variation in hardness was found because of the plastic deformation of metals on the metal surface [11]. The effect of shot peening is limited to a very small depth of deformed layer. The depth of deformed layer and hardness were found to vary with shot peening intensity (Fig. 2).

S/N Curves

The slippage in the surface during shot peening is homogeneous, thus it minimize the tendency of crack propagation [12]. Shot peening repairs micro cracks and hence, the initiation of fatigue crack over the surface can be delayed by cold working of the surface with the shots [8].

Cyclic-stress curves for the base material and for the shot peening intensity of specimens at 5A were determined using an axial fatigue-testing machine. The four stress levels (Table3) were not all of the level tested; more tests were conducted near the endurance limit. Fifteen specimens [13] were tested in order to plot an S/N curve. Only the average points were presented for each level (Fig.3). Shot peening influence for stress levels: 265MPa, 240MPa, 225MPa and 210MPa, the fatigue strength gain in relation to base material at endurance limit was expressive (193MPa to 209 MPa). The test stress levels were reviewed for base material and peened specimens, and increase in endurance strength was observed from the shot peening treatment. The effect of shot peening was negligible if the magnitude of the applied stress is above the endurance limit.

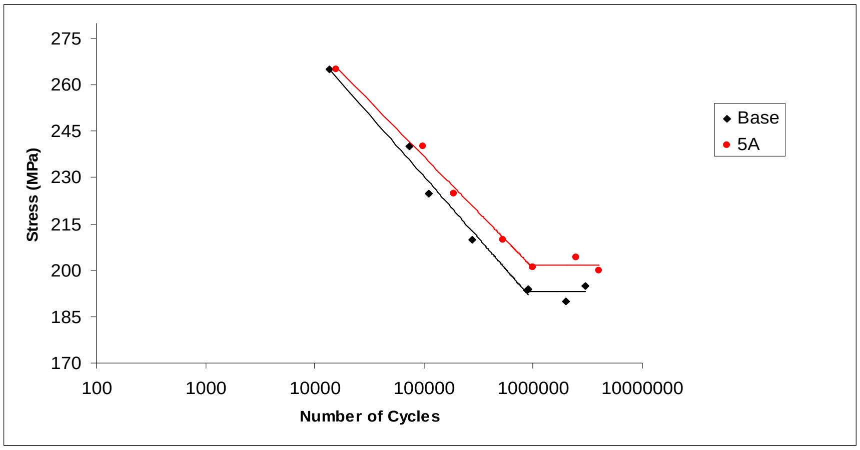


Fig. 3: S/N comparative curves.

Table 3: Fatigue life of shot peened and base material samples.

S.No.	Stress (MPa)	Fatigue life (cycles) of base materials	Fatigue life(cycles) of primary shot peened material at 5A
1	265	12855 13124 14909 Av.13629	14941 17262 15253 Av.15819
2	240	74602 72835 72576 Av.73338	99869 95348 98531 Av.97916
3	225	105338 106164 123751 Av.111751	170824 192964 199286 Av.187692
4	210	290528 256442 282356 Av.276442	4750270 4965354 4880438 Av. 4865354

Microstructure

In carbon steel, shot peening causes plastic deformation of surfaces and brings austenite to martensite transformation and results in two phase structure [14]. The martensitie phase has higher yield point than that of the austenitic phase. Austenitic stainless steel is an iron-chromium-nickel alloy. It retains the austenitic structure at ambient temperature. The grain boundaries are well defined for austenitic stainless steel (Fig. 4). After shot peening the austenite phase is partially converted into martensite phase (Fig. 5) and also introduces compressive residual stress (Fig. 6). The microstrcture of unpeened austenitic stainless steel (austenite phase) and microstructure of shot peened austenitic stainless steel (martensite + austenite phase) resemble with available microstructures [15, 16].

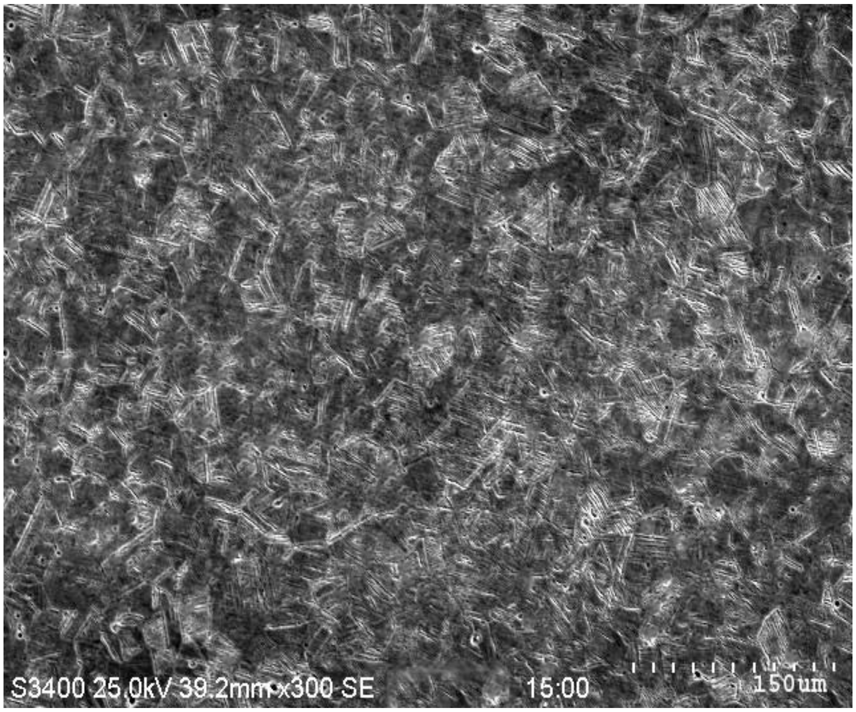


Fig 4: Microstructure of austenitic stainless steel without shot peening.

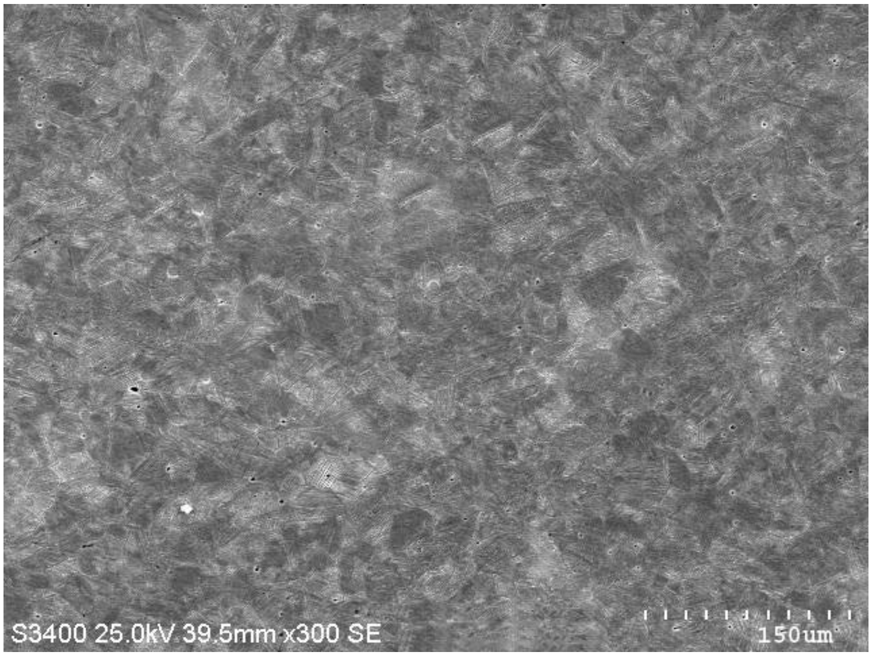


Fig. 5: Microstructure of Austenitic Stainless Steel with shot peening.

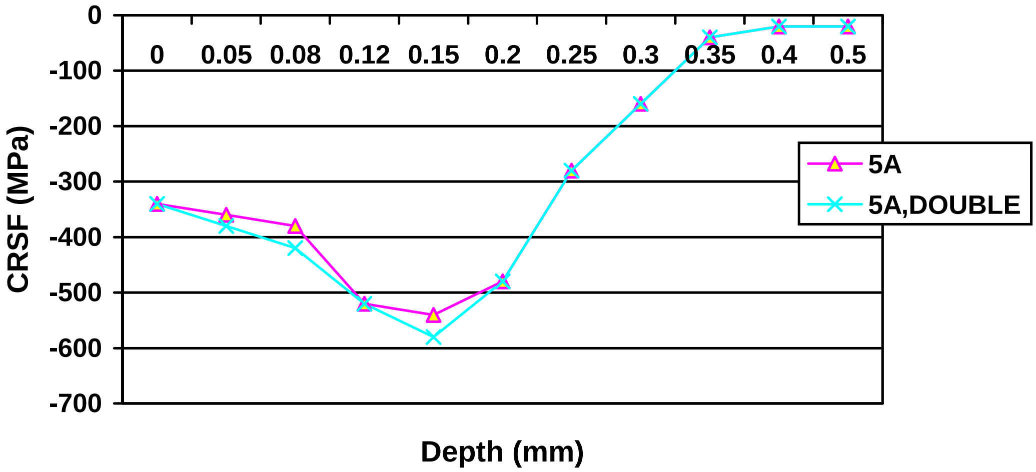


Fig. 6: CRSF and depth of deformed layer at 5A.

The formation of martensite phase and plastic deformation on the surfaces helps in improving tensile strength, hardness, residual stress, depth of deform layer and fatigue strength.

Double shot peening

The surface of a part is its exterior boundary and the surface irregularities consist of numerous wedges and valleys that deviate from a hypothetical nominal surface. Surface roughness increases with the increase in peening intensity (Table 4). Average surface roughness of base material (USP) was 2.9µm. Surface roughness of base material samples was found to be less as compared with the shot peened samples.

Table 4: Surface roughness variation

S.No.	Shot peening intensity (Almen scale)	Average surface roughness (µm)	
		Primary shot peening	Double shot peening
1	3A	3.28	2.88
2	4.5A	3.32	2.96
3	6A	3.37	3.02

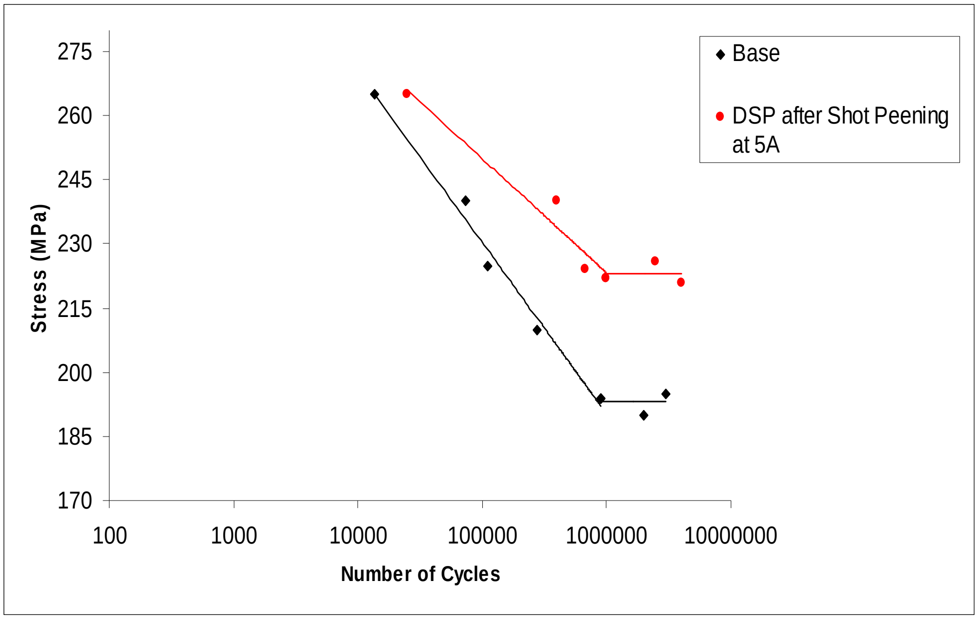


Fig. 7: S/N comparative curves of double shot peened samples and base material samples.

Table 5: Fatigue life of double shot peened and base material samples

S.No.	Stress (MPa)	Fatigue life (cycles) of base materials	Fatigue life (cycles) of double(primary+secondary) shot peened material at 5A
1	265	12855 13124 14909 Av.13629	22400 28117 23940 Av.24819
2	240	74602 72835 72576 Av.73338	380290 410254 409204 Av.399916
3	225	105338 106164 123751 Av.111751	670606 681825 680645 Av.677692
4	210	290528 256442 282356 Av.276442	5466678 5388602 5140229 Av.5331836

It was found that the improvement in surface finish of shot peened samples increases the fatigue life. Fatigue life was further improved by decreasing the surface roughness. Surface roughness was reduced by double shot peening. In double shot peening, primary shot peening (5A) is followed by micro-ball shot peening. For double shot peening zirconium shots of 1-6 microns were used. Double shot peening reduced the surface roughness by approximately 0.4 microns. The decrease in surface roughness was equivalent to the surface roughness of base metal. The S-N curve is again plotted for DSP and base material (Fig.7). It was observed that endurance strength due to double shot peening increased to 221 MPa which is about 15% higher as compared with base metal. The fatigue strength also increases above endurance limit due to double shot peening (Table5). The effect of double shot peening on the residual stress is negligible (Fig.6). The increase in fatigue strength is mainly due to improvement in surface finish.

Conclusions

The paper has accomplished the following for RS561 nitrogen induced austenitic stainless steel:

1. Shot peening of nitrogen austenitic stainless steel increases its hardness. The hardness can be controlled by adjusting the intensity of the shot peening. Hardness increases with peening intensity.
2. Endurance limit of RS561 steel improves with shot peening. However the fatigue life is unchanged for stress level higher than endurance limit. Double shot peening reduces the surface roughness without significant change in residual stress. Further, increase in the fatigue strength of the material is noted with primary and secondary shot peening.

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