

Influence of shot peening on surface quality of austenitic and duplex stainless steel

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Abstract: In the present investigation, an attempt has been made to enhance the surface quality of austenitic stainless steel 316L and duplex stainless steel 2205 through shot peening process. The study mainly focuses the surface morphology, microstructural changes, surface roughness and microhardness of the peened layers. Metallography analysis was carried out and compared with the unpeened surface characteristics. As result of peening process, surface recrystallization was achieved on the layers of the peened samples. It was found that shot peening plays significant role in enhancing the surface properties of 316L and 2205. Particularly it has greater influence on the work hardening of austenitic stainless steel than the duplex stainless steel due to its more ductility nature under the investigated shot peening parameters. The findings of the present study will be useful with regard to the enhancement of surface texture achieved through peening.

1. Introduction

Stainless steel grades are well known for their excellent corrosion resistance and high strength nature due to their various combinations of Fe – Cr – Ni – N system [1]. Corrosion resistance is an essential requirement for them in the marine applications, particularly in the high chloride environment. For the past few decades, Duplex Stainless Steel (DSS) grades such as AISI 2205 and 2507 are playing crucial role in the marine applications by replacing Austenitic Stainless Steel (ASS) grades such as 304L and 316L in minimizing the weight of a structure by reducing the thickness of the structural members and maintaining the same strength. DSS grades are having 2 to 3 time's greater strength than the ASS grades [2]. However, the metallurgy of DSS is quite complex when compared to ASS due to the mixture of ferrite and austenite in a dual proportion. Because of which the cost of the DSS grades is significantly higher than the ASS grades. In most of the situations, failure starts from the metal surface and it is very important to protect the surface from any kind of destructions like corrosion attack and fatigue failure. Surface topography plays the major role in delaying these failures. Shot peening is a cold working process and providing the high quality surface which is widely used to enhance the surface properties such as hardness, fatigue life and corrosion resistance [3 – 6]. Life of a material is increased by inducing compressive residual stresses on the surface layers with a better topography. Under low cyclic stresses during the service, shot peening plays the major role in increasing the life span of materials. Implementation of peening technique on the stainless steel grades is definitely a fruitful one due to the better surface quality ending [6, 8, 9]. In general, DSS has excellent resistance to Stress Corrosion Cracking (SCC) with less formability, while ASS has excellent formability with



lesser resistance to SCC than DSS [7, 8]. It is desirable to study the improved surface quality of ASS and DSS grades through shot peening in order to understand the use ability of these materials in proper service applications. ASS grades are more prone to the formation of strain-induced martensite during peening in particularly ASS 304L [10]. Thus, peening of ASS 304L is not recommended for corrosion environment due to the detrimental microstructure formed on the surface layer. However, ASS 316L is more suitable for peening which has the least susceptibility for strain induced martensite transformation [11]. The present work aims to compare the effect of shot peening on the surface quality of ASS 316L and DSS 2205 with special reference to their surface properties.

2. Experimental

The chemical compositions of the ASS 316L and DSS 2205 taken for the study were confirmed using the optical emission spectroscopy test. Initially, the samples were cut in the dimensions of $80 \times 15 \times 8$ mm from the rolled plate. Since, presurface condition influences the post peening surface roughness, the samples were polished using a grinding process to a surface roughness of around $0.5 - 0.7 \mu\text{m}$. Centrifugal type tumbling shot peening machinery was used for the present study. Cast steel spherical shots (S 390) of diameter 1mm and hardness 40 to 42 HRC were used as a peening medium. The shots for the peening process were delivered from the blades rotate at 2800 rpm from which they gain centrifugal force. The samples used for peening were kept inside the peening chamber in such a way that the shots were forced from the top side. The cast steel shots contain brittle iron oxide skin on its surface which gives higher hardness to the peening medium. Peening was carried out in 15 min, 30 min, and 45 min durations. 100% of coverage was achieved after 10 min of peening. Long durations of peening were considered to analyze the effect of peening on ductility limit, weight loss and surface hardenability. After peening, the mass of the peened samples was measured to ensure that the peening causes any metal removal on the surface due to the attainment of the ductility limit. Surface roughness analysis on the peened and unpeened samples was carried out using non-contact surface profilometer and contact surface roughness tester to analyze the morphology of the surface. Surface roughness values were measured for the length of 4 mm with a cutoff length of 0.8mm. Vickers micro hardness test was conducted using 0.1 kg load with a dwell time of 10 sec. Microstructural analysis was carried out in the peened and unpeened samples. Samples taken for metallography analysis were subjected to mirror polishing and electrolytic etching to study the grain refinement and severe plastic deformation on the peened surface layers.

3. Results and discussions

The kinetic energy of the cast steel shots used for peening induces significant changes in the surface of the two stainless steel grades such as DSS 2205 and ASS 316L. The detailed discussion of the results obtained from the experiments is given below.

3.1. Weight measurement

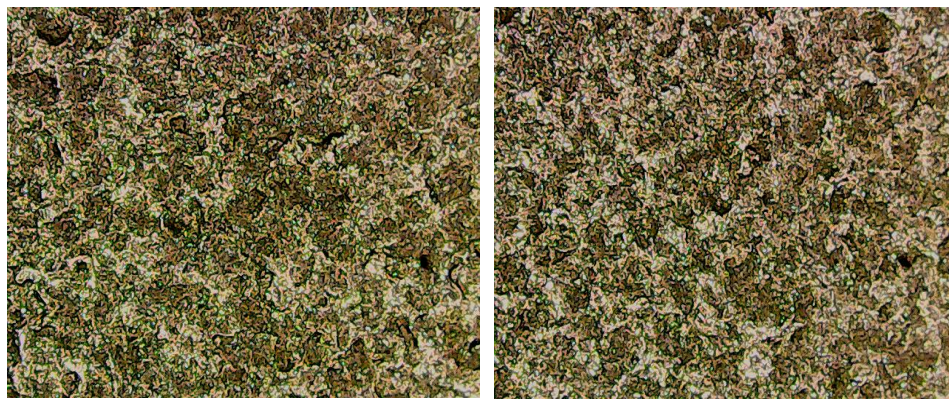
Some times over peening causes the removal of material from the surface due to the attainment of ductility limit of the material which has been peened. Also, over peening causes reduction in the material hardness [3]. If the material used for peening has high ductility, then it is more capable of high intensified peening. The measured values of masses in grams before and after peening are given in Table.1. It shows very negligible amount of material loss in all the peened samples at a milligrams level. This is mainly due to the removal of sharp corners and dust particles accumulated in the grooved profile of the ground surface before peening. Maintaining almost the same amount of masses before and after peening shows the strain hardening capability of both the materials used for peening.

Table 1. Weight measurement before and after peening

Sample No's	Peening duration	Before peening Weight in grams	After peening Weight in grams	Loss in weight in grams
ASS 1	15 min	197.347	197.297	0.05
ASS 2	30 min	196.948	196.840	0.108
ASS 3	45 min	197.420	197.022	0.398
DSS 1	15 min	195.207	195.106	0.101
DSS 2	30 min	195.217	195.101	0.116
DSS 3	45 min	192.144	191.983	0.161

3.2. Morphology of peened surfaces

Surface topography plays the major role in the life of the metallic components. Shot peening provides trough profiles which induces roughly spherical dents contains peaks and valleys on the surface of both materials used for peening [13, 16]. The macro observations of the magnified peened surfaces are given in Figure. 1 (a) and (b).



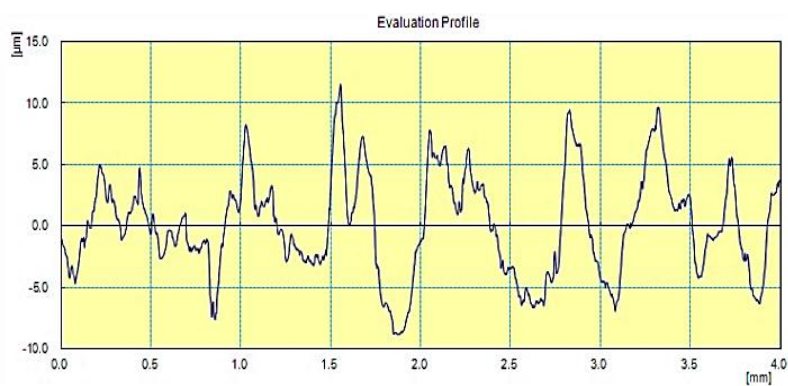
(a) ASS 316L

(b) DSS 2205

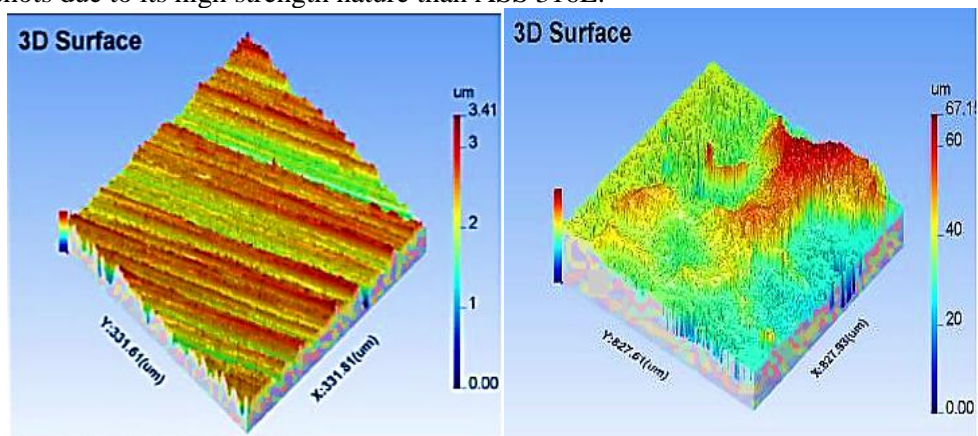
Figure 1. Macro image of peened surfaces

Large size dents were observed in the ASS 316L as compared to DSS 2205. This is mainly due to the higher capability of plastic deformation in 316L due to the presence of ductile nature face centered cubic austenitic structure. It shows that the work hardening of ASS316L is more when compared to DSS 2205 which causes larger size indentations on the peened surface during elastoplastic impact. There was no notable change in the surfaces peened for various durations like 15 min, 30 min, and 45 min. It is proving that repeatedly hitting the surface using the shots with the same velocity for the prolonged duration of time does not cause much improvement on the surface properties. However, as the peening time increases, the surface microcracks exist before peening were getting smoothed by the formation of spherical dents.

3.3. Surface roughness

(a) Roughness profile of ASS 316L ($R_a = 5.584\mu\text{m}$)(b) Roughness profile of DSS 2205 ($R_a = 3.359\mu\text{m}$)**Figure 2.** Peened surface profile

The surface profiles of the peened surfaces were measured using Mitutoyo surface tester and the topographies are given in Figure.2. (a) and (b). The roughness average (R_a) value of ASS 316L is around two times higher than the DSS 2205. This was identified by the depth of valleys observed in the peened surfaces. Maximum depth of valleys was observed in the ASS 316L due to its higher percentage of elongation than DSS 2205. To get more intensity of peening, DSS 2205 requires high velocity shots due to its high strength nature than ASS 316L.



(a) Ground surface

(b) Peened surface

Figure 3. 3D surface topography of ASS 316L

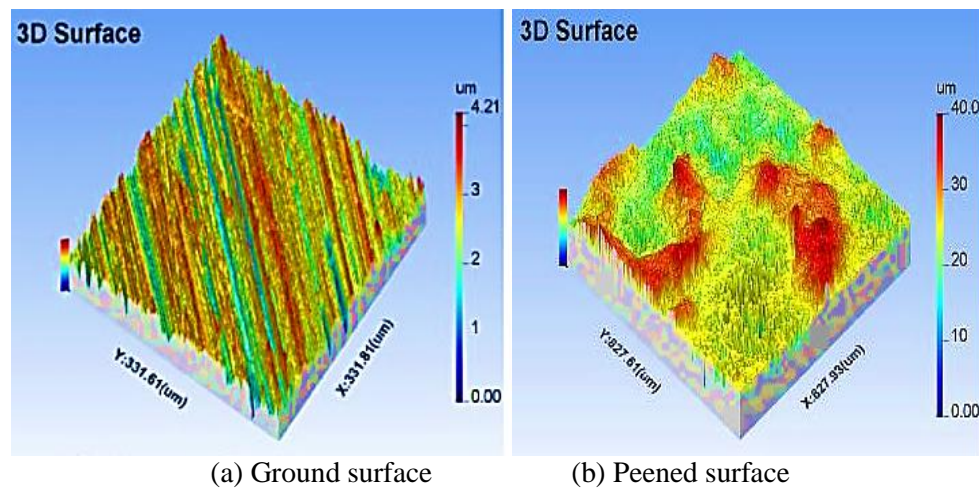


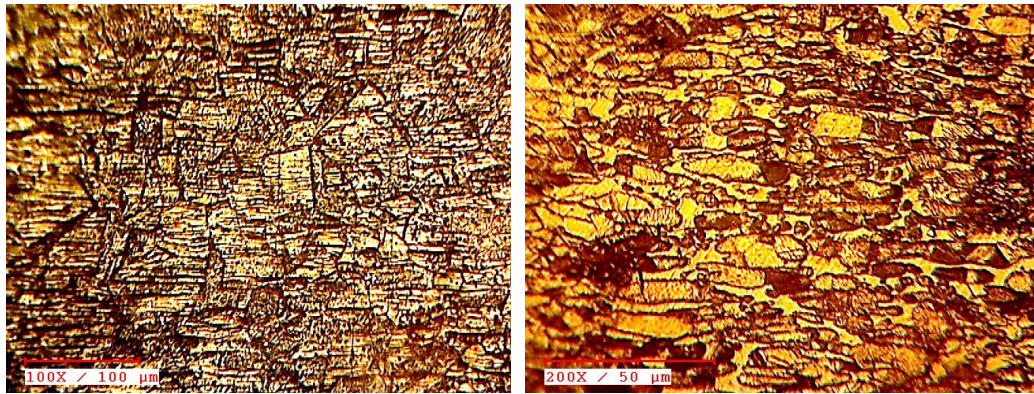
Figure 4. 3D surface topography of DSS 2205

Three-dimensional surface profiles before and after peening were taken using Taylurf non-contact surface roughness tester are given in Figure 3 and 4 (a), (b). It shows grooved profile before peening and trough profile after peening on both the samples taken for the investigation. Grooved profile on the ground surface was formed due to the shear fracture occurred during the tool-chip interaction on the machining process [16]. Almost all kinds of machining processes are giving the similar kind of grooved profiles during machining which is generally not recommended for a long life span of metals. These grooves are acting as a stress raisers in the real-time applications. Plastic flow on the metal surface is maximum for ASS than for DSS. The dents formed on the ASS 316L give more depth of peening which is identified by having the amplitude between the peak and valley as $67.1\mu\text{m}$ for ASS and $40.0\mu\text{m}$ for DSS in the investigated locations. The surface roughness induced during peening is far higher than the grinding process. However, the residual compressive stresses induced by peening plays crucial role in enhancing the surface behavior [6, 15]. Also, higher R_a values can be reduced by means of repeening technique. The study related to dual shot peening or triple shot peening techniques is essential in bringing the surface roughness almost to the minimum level after peening. Further, the morphology of peened surface plays the major role in the reduction of friction coefficient during the stick-slip phenomenon between the sliding surfaces [17]. Thus, peening has more beneficial effects on the tribological applications too. But, the present analysis was not intended to study towards the particular direction.

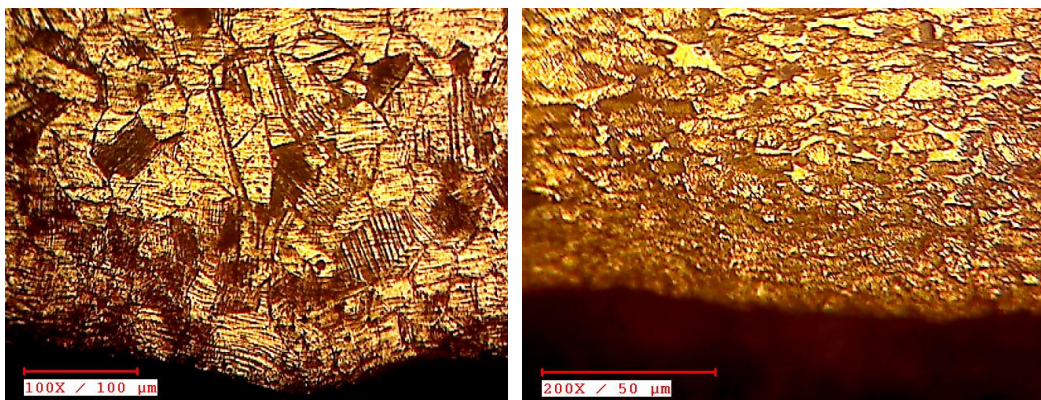
3.4. Microstructural analysis

The microstructure of the unpeened ASS 316L shows equiaxed grains with fully austenite phases and the unpeened DSS 2205 shows the dual phase ferritic-austenitic structure which is given in Figure 5 (a) and (b). The elongated austenite phases were observed in the DSS microstructure which indicates the rolling direction. Peening induces grain refinement and severe plastic deformation on the surfaces of both metals which are given in Figure 6 (a) and (b). Bombarding of shots causes recrystallization of DSS microstructure on the top surface layer which was observed by the broken austenite grains on the surface. Austenite phases of DSS were mainly deformed during peening. This is mainly due to the nature of tensile residual stresses present in it before peening [12]. Also, the surface grains of DSS were severely packed in the lateral direction. In ASS 316L, more quantities of twin bands were formed due to the distortion of austenitic phases on the peened surface layer of ASS 316L. Simple magnetic test on the peened surface confirms that there is no formation of strain-induced martensite phases on ASS 316L during the severe plastic deformation induced by peening. This has been proved in an earlier research work, which shows 316L has less susceptibility to the martensite

formation [11]. The chemical composition of ASS 316L plays a major role in the stabilization of austenitic microstructure even after peening treatment.



(a) ASS 316L (b) DSS 2205
Figure 5. Parent metal microstructure (unpeened)



(a) ASS 316L (b) DSS 2205
Figure 6. Shot peened layer

3.5. Hardness Vs. Shot peening

Peening has its effect approximately for 0.5mm thick layer from the top surface as shown in Figure 7. Both the metals taken for investigation maintain their parent metal hardness below the depth of 0.5 mm. Peening causes improvement in the surface hardness of both metals due to the hard layer introduced by the grain refinement and severe plastic deformation. One of the most essential needs of shot peening is to improve the surface hardness to induce the barrier against the corrosion attack particularly SCC and fatigue failure in service [4, 9]. In the present work, a surface hardness of ASS 316L reaches close to the surface hardness of DSS 2205 in most of the measured locations. The surface layer was attained maximum hardness which shows the elongation capability of ASS 316L. More intensity of peening is required for DSS to induced significant effect on DSS. The nano-sized surface layer was formed on the peened surface plays the crucial role in enhancing the mechanical properties of the materials [10, 14]. Nano crystallization on stainless steel grades due to peening needs to be addressed more in the future research scenario with special reference to corrosion resistance and mechanical behavior. Also, the surface strength of ASS approaching the strength of DSS is a good sign to use this material in a marine exposure with peened condition.

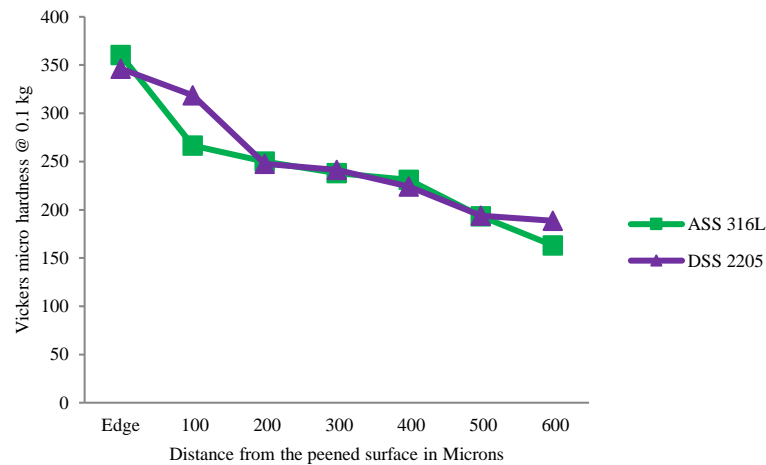


Figure 7. Surface hardness Vs. Peening

4. Conclusion

In the present study, the effect of shot peening on the surface texture of ASS 316L and DSS 2205 is addressed. The following conclusions are arrived within the formulated objectives. Shot peening induces beneficial trough profiles i.e. roughly spherical dents on the surface layers of both metals used for peening. More amount of severe plastic deformation on the surface due to peening was observed in ASS 316L than DSS 2205. Roughness average (Ra) values of ASS and DSS were significantly higher than the unpeened ground surfaces. Also, Ra value of ASS 316L is significantly higher than DSS 2205 due to the peening induced large sized dents. Surface hardness was increased significantly on the peened layers. Austenite phases were broken and severely packed in the lateral thickness direction during peening of DSS. Mechanical twinning was observed in the surface grains of ASS 316L. Peening does not cause any kind of noticeable weight loss on both the samples which proves that the parameters used for peening are suitable for bringing the advantageous effects on the surface properties. However, to get more intensity of peening than ASS 316L, DSS 2205 requires a high velocity of shots.

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References

1. J C Lippold and D J Kotecki 2005 Welding metallurgy and weldability of stainless steels *Wiley publications* 20 – 22
2. R N Gunn 1997 Duplex stainless steels microstructure, properties and applications *Woodhead publishing Ltd.*
3. David Kirk 2007 Review of shot peened surface properties *The shot peener, Fall 2007* 24-30

4. W H Friske and J P Page 1981 Shot peening to prevent the corrosion cracking of austenitic stainless steel *Proceedings of International conference on shot peening (ICSP-1)* 485-492
5. Lakhwinder Singh, R A Khan and M L Aggarwal 2010 Effect of shot peening on hardening and surface roughness of nitrogen austenitic stainless steel *International Journal of Engineering Science and Technology* **2(5)** 818-826
6. P Sanjurjo, C Rodriguez, I F Pariente, F J Belzunce and A F Canteli 2010 The influence of shot peening on the fatigue behaviour of duplex stainless steels *Procedia Engineering* **2** 1539 – 1546
7. Practical Guidelines for the Fabrication of Duplex Stainless Steel 2005 2nded. London: *International Molybdenum Association* **5**
8. J Kritzler 1999 Effect of shot peening on stress corrosion cracking on austenitic stainless steel 7th *International conference on shot peening, ICSP – 7*, Poland 199 – 208
9. V Azar, B Hashemi and Mahboobeh Rezaee Yazdi 2010 The effect of shot peening on fatigue and corrosion behavior of 316L stainless steel in Ringer's solution *Surface and Coatings technology* **204** 3546 – 3551
10. Okan Unal and Remzi Varol 2015 Surface severe plastic deformation of AISI 304 via conventional shot peening, severe shot peening and repeening *Applied Surface Science* **351** 289–295
11. D Kirk and N J Payne 1999 Transformations induced in austenitic stainless steels by shot peening 7th *International conference on shot peening, ICSP – 7*, Poland **15 – 22**
12. Q Feng, C Jiang, Z Xu, L Xie and V Ji 2013 Effect of shot peening on the residual stress and microstructure of duplex stainless steel *Surface and Coating Technology* **226** 140–144
13. R Clausen and J Stangenberg 1999 Roughness of shot peened surfaces – Definition and measurement 7th *International conference on shot peening, ICSP – 7*, Poland
14. Sara Bagherifard, Sebastian Slawik, Ins Fernández-pariente, Cristoph Pauly, Frank Mücklich and Mario Guagliano 2016 Nanoscale surface modification of AISI 316L stainless steel by severe shot peening *Materials and Design* **102** 68 – 77
15. Qiang Feng, Chuanhai Jiang and Zhou Xu 2013 Surface layer investigation of duplex stainless steel S32205 after stress peening utilizing X – ray diffraction *Materials and Design* **47** 68 – 73
16. D Kirk 2008 External characteristics of shot peened surfaces *The Shot peener, Fall 2008* 24 – 32
17. Xiaobin Lu 2011 Shot peening – A tribological approach 11th *International conference on shot peening, Indiana, ICSP – 11* 435 – 439