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Effect of shot Peening on surface characteristics of Austenitic Stainless steel (AISI 304) and Numerical Validation

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Abstract— ***Nanocrystallization enhances surface mechanical properties such as hardness, wear resistance, fatigue life, corrosion resistance for stainless steel. Severe plastic deformation by shot peening for AISI 304 stainless steel to increase nanocrystallized surface layer above 50μm thickness and grain size as low as possible in nanometers.Nanosurface layer also reduces friction of surface. Nanocrystallized layer can be examined by X-ray powder diffraction, Transmission electron microscopy methods. Experimental data verification using Finite element method. Explicit analysis software is used.***

Index Terms— **Grain refinement, Ls-Dyna simulation, Mechanical properties, shot peening, Surface mechanical attrition treatment (SMAT), Surface nanocrystallization.**

1. INTRODUCTION

In most cases, material failures occur on surfaces such as fatigue fracture, fretting fatigue, wear and corrosion, etc. These failures are very sensitive to the structure and properties of the material surface. The surface nanocrystalline treatment that induces forming nanostructure on the surface of metals can obviously improve the surface and combination property of materials .As the size reduces into the nanometer range, the materials exhibit peculiar and interesting mechanical and physical properties, e.g. increased mechanical strength, enhanced diffusivity, and electrical resistivity compared to conventional coarse-grained counterparts. The grain refinement of ductile materials by means of plastic deformation has initiated extensive research in the past decade. Some processes such as high pressure torsion, sliding wear, ball milling, ball drop and shot Peening have the potential to produce nanostructures with a scale of 5–100nm on surface layers.

In terms of the grain refinement mechanism induced by plastic straining, surface mechanical attrition treatment (SMAT) was developed for producing a nanostructure surface layer on metallic materials.

The definition of severe plastic deformation (SPD) describes it as a process in which high strain is applied without any significant change in the dimensions of the work piece. The principles behind SPD have been used to develop surface treatments that create a Nano-crystalline layer on the surface of a material. Large number of collisions between the balls and the surface, creating a strain rate on the order of 10^2–10^3 s^{-1}. A gradient grain size distribution from a few nanometers (in the top surface layer) to several micrometers is developed in the SMAT sample that provides a unique opportunity to examine the microstructure characteristics at different levels of strain and strain rate. Plastic deformation behaviors and dislocation activities in metals depend strongly on the lattice structure and the stacking fault energy (SFE) [2].

Shot Peening is a cold working process used to produce a compressive residual stress layer and modify mechanical properties of metals. It entails impacting a surface with shot (round metallic, glass, or ceramic particles) with force sufficient to create plastic deformation. Shot Peening is used for SMAT [5]. It is similar to sandblasting, except that it operates by the mechanism of plasticity rather than abrasion each particle functions as a ball-peen hammer. In practice, this means that less material is removed by the process, and less dust created. Peening a surface spreads it plastically, causing changes in the mechanical properties of the surface. Its main application is to avoid the propagation of micro cracks from a surface. Such cracks do not propagate in a material that is under a compressive stress; shot Peening can create such a stress in the surface along with tensile stress in the interior [5].

Shot peening is one of the most important and widely used surface treatments that is used as a post manufacturing process in order to increase fatigue life and fatigue limit of components, to superimpose tensile RS (arising from machining, welding etc.) with beneficial compressive RS, to form locally the component in order to correct distortions and achieve tight tolerances and last but not least, to form thin sheets made of soft material [6].

Due to shot peening mechanical properties added to metal surface such as significant increment of hardness and strength in the surface layer with nanostructures after the SMAT. The friction and wear properties of the low-carbon steel can be improved by means of formation of the nanostructure surface layer. While the ultimate tensile stress is increased about 13% To the real value after SMAT. To enhance the surface mechanical, tribological, chemical and corrosion properties of bulk materials. Flexibility and low-cost procedures of the SMAT will greatly facilitate the widespread application of this technique to various industry areas. The process is also feasible to obtain a localized nanostructured surface layer in bulk materials and to realize surface nanocrystallization of components with complex shapes [2].

Majzoobi and Azizi [1] presented three numerical models Simulating shot peening. The first is a quarter-symmetry numerical model comprising a single shot impacting on a strain rate sensitive steel target. The second numerical model includes multiple shot impacts of 4, 6, 8, 9, 13 and 25 impacts at specified locations, in order to reproduce high coverage percentage. The method followed by the authors can be characterized as controversial as shot peening is stochastic by nature. The RS computed for the 25 subsequent impacts was compared with available experimental results and the differences between the two curves have shown a small difference.

G.I. Mylonas, G. Labeas [7] An investigation of the effects of controlled shot peening (CSP) process parameters on the treated material is presented. For this purpose, a three dimensional numerical model is developed, comprising the target plate and a number of shot impacts. The numerical model is verified by comparing the predicted residual stress (RS) fields to experimental. The main advantages of the present numerical model are is the relatively high number of shots introduced in the simulation compared to other publications that use only one shot, the high-strain rate material behaviour used for the target plate, the capability to calculate CSP effects on the target plate as function of coverage, the computed data which include RS field, surface roughness, cold work and geometrical stress concentration factor (Kt) and finally the computed results which are validated by experimental measurements.

Therefore objective of project is shot Peening of AISI 304 Stainless steel. To produce small grain size in nanometers. Produce Nano-surface layer thickness above 50µm from surface. Check grain size and Nano-surface layer using X-ray powder Diffraction (XRD), Transmission electron microscopy (TEM) methods. Modeling and simulation for shot peening of stainless steel. Verification of results using Finite element method (FEM) using LS-DYNA code. Enhance surface properties for AISI 304 stainless steel.

2. EXPERIMENTATION

After literature study experimental set-up is developed as shown in figure 1. Due to use of compressor air natural cooling of plate is done to get deeper nano-crystallized layer.

Fig. 1.Experimental set-up


Fig.2 Peening plate (60mm*60mm*5mm)

2.1 Materials and method

Material used for shot peening is AISI 304L having hardness 220HV of size 60*60*5 (All dimension in mm)as shown in figure 2 . Before shot peening sample was solution annealed at 1080^{0}c for 8 hours and then water quenched to to dissolve complete austenitic phase. And the annealing is done at 400^{0}c for 4 hours for stress relieve from surface.Before shot peening sample is mirror finished.

2.2 shot peening

Shot peening is done by 60 small shots of dia. 5mm of material EN31 of Hardness 180 HV for 60 minute at different flow rate of air as shown in figure 3.


Fig.3. Shots

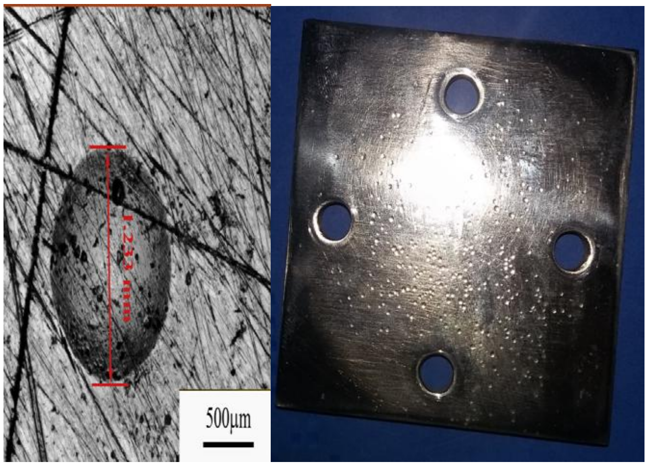

Fig 4 . a] Microscopic image of shot impact
b]Real plate image after few shot

Different flow rate used for shot peening is 780LPM, 840LPM, 900LPM, 960LPM, 1020LPM for 60 miniute at 6bar compressor pressure.

2.2.1 Velocity deteminatin of shot impact

Shot velocity is detemined by using impact diameter of shots on plate by running set-up for few second[7].Figure 4 gives impact images .Table 1 gives impact dia. At different flow rate and calculated velocity.

FLOW RATE (LPM)	MAX DIA (μm)	MIN DIA (μm)	AVG. DIA (μm)	VELOCIY OF BALL IMPACT (m/sec)
780	727.68	574.03	589.736	4.88
840	734.69	644.45	704.052	5.3
900	847.91	650.4	746.630	5.65
960	880.96	720.73	788.306	6.24
1020	944.8	709.8	825.338	6.75

Table 1. Velocity at different flow rate

Mass flow rate of ball through area=ρ A V= 6400gm/sec

Where A=10*10mm^2

V=Velocity of ball 8000mm/sec

ρ = density of ball =0.008g/mm^3

Weight of 1 ball is =0.5gm

Number of ball impacting on plate in 1 sec

$\frac{\text{Mass flow rate}}{\text{Weight of 1 ball}}$ =10000 no.

Due to some loss and motion against gravity total number of balls impacting on plate in 1sec is 900.

3. RESULT AND DISCUSSION

DEPTH FROM PEENED SURFACE (μm)	HARDNESS(HV) FOR DIFFERENT FLOW RATE (LPM)				
	780	840	900	960	1020
10	445.3	452.7	468.5	470.8	475.4
20	434.9	442.3	442.7	429.4	470.4
30	380.3	440.2	428.5	436.5	446.3
40	395.4	421.1	430.1	451	466.2
50	405.6	399.9	465.3	455.3	422.9
60	407.2	436.8	468.2	442	410.7
70	370.5	389.8	422.9	421.1	449.3
80	368.3	396.2	465.2	468.4	431.9
90	384.4	376.2	439.7	458.5	400.4
100	382.8	388.8	451.3	411	414.9

Table 2. Hardness after shot peening

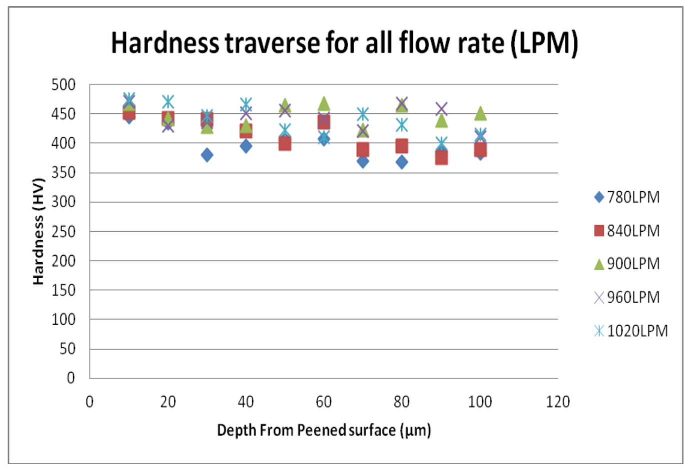

Fig.5 Hardness traverse for different flow rate

SHOT VELOCITY (m/sec)	SURFACE HARDNESS (HV)	DEPTH OF DIFORMATION (μm)	NANO-CRYSTALLIZATION DEPTH (μm)
4.88	445.3	440	140
5.3	452.7	490	210
5.65	468.5	510	290
6.24	470.8	540	370
6.75	475.4	650	400

Table 3. Nano-crystallization with depth

Hardness readings for sample after shot peening up to depth 100μm given in table2 .Measures on Vickers hardness machine. This gives as flow rate increases surface hardness and depth of nano-crystallization increases as shown in figure 5.

Table 3 gives hardness values for different velocities and depth of deformation .For AISI 304L steel 354HV is hardness value up to which Nano-crystallization occurs [2].In table 3 observed that as velocity of shot increases Nano-crystallization depth increases.

4. NUMERICAL ANALYSIS

Numerical analysis of shot peening is Non-Linear explicit dynamic analysis. Ls-dyna software is used for shot peening simulation. For meshing Hypermesh 12 is used.figure6 shows mesh model with boundary condition .

Material model used for plate in LS-dyna is *MAT_PIECEWISE_LINEAR_PLACTICITY [7] .For Non-Linear analysis true stress and true strain values are calculate by using engineering Stress and engineering strain values which is calculated from UTM test of sample.

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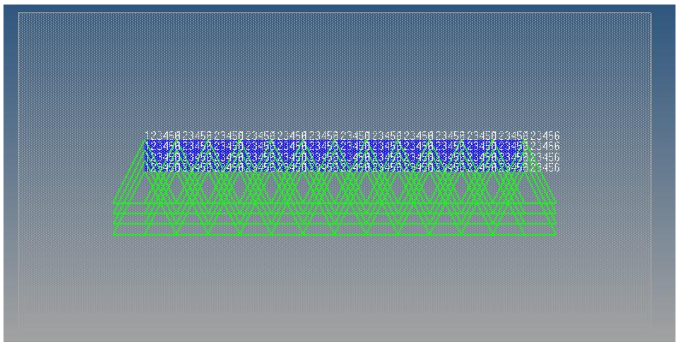

Fig.6. Mesh model with boundary condition

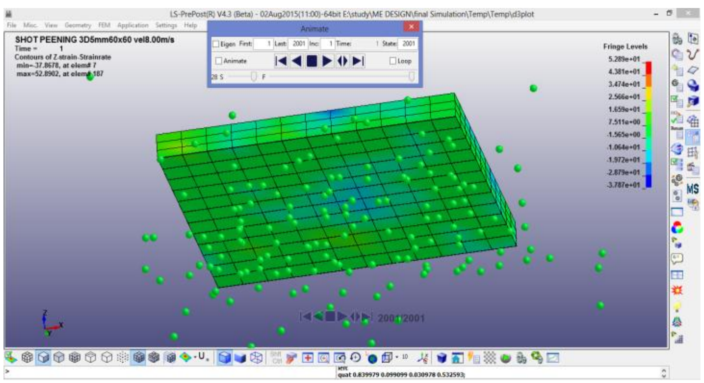

Fig. 7. Result Model

Figure 7 shows strain rate at the surface of plate after impact.

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