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Numerical Simulation of Residual Stress Distribution Using LS-DYNA on Shot Peening Process

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Abstract: In the following mini-project, we studied the measurement of compressive residual stress in the material, Al 2024, produced due to the shot peening process and also did the literature review for the optimization of process parameters of shot peening and compressive residual stress formation. The numerical simulation and modelling were done using the software, LS DYNA. We, first, carried out the literature review to learn about the work done in the area. To determine the compressive residual stress, we used LS DYNA to create model. We set the parameters of the model according to the properties obtained by the Johnson Cook Material Model for Al 2024 and used the properties of Stainless Steel for the shot. We carried out the experiment for three different velocities of 50m/s, 100m/s and 150m/s. Thus, we carried out the numerical simulation based on these conditions in LS DYNA. The LS DYNA PrePost was used to obtain the results.

Keywords*:* shot peening, residual stress, Fatigue Life

1. INTRODUCTION

1.1 Introduction to Shot Peening Process

Shot peening is a cold working process used to produce a compressive residual stress layer and modify the mechanical properties of metals and composites. It involves striking a surface with shot (round metallic, glass, or ceramic particles) with force sufficient to create plastic deformation. In machining, shot peening is used to strengthen and relieve stress in components like steel automobile crankshafts and connecting rods. In architecture it provides a muted finish to metal. Shot peening is similar mechanically to sandblasting, though its purpose is not to remove material. Rather, it employs the mechanism of plasticity to achieve its goal, with each particle functioning as a ball-peen hammer[1].

Shot peening works by striking a surface with a shot (round metallic, glass or ceramic particle) with enough force to generate plastic deformation. When a group of shots impact the surface they generate multiple indentations, resulting in the component being encased by a compressive stressed layer on the metal surface[2].

1.2 Residual Stresses and Compressive Residual Stresses

Residual stresses are stresses that remain in a solid material after the original cause of the stresses has been removed. Residual stress may be desirable or undesirable. For example, laser peening imparts deep beneficial compressive residual stresses into metal components such as turbine engine fan blades, and it is used in toughened glass to allow for large, thin, crackand scratch-resistant glass displays on smartphones. However, unintended residual stress in a designed structure may cause it to fail prematurely [3].

1.3 LS-DYNA

LS-DYNA is a general-purpose finite element program capable of simulating complex real world problems. It is used by the automobile, aerospace, construction, military, manufacturing, and bioengineering industries. The code's origins lie in highly nonlinear, transient dynamic finite element analysis using explicit time integration. "Nonlinear" means at least one (and sometimes all) of the following complications:

- Changing boundary conditions (such as contact between parts that changes over time)
- Large deformations (for example the crumpling of sheet metal parts)
- Nonlinear materials that do not exhibit ideally elastic behaviour (for example thermoplastic polymers) "Transient dynamic" means analysing high speed, short duration events where inertial forces are important. Typical uses include:
- Automotive crash (deformation of chassis, airbag inflation, seatbelt tensioning)
- Explosions (underwater Naval mine, shaped charges)
- Manufacturing (sheet metal stamping) LS-DYNA's potential applications are numerous and can be tailored to many fields. In a given simulation, any of LS-DYNA's many features can be combined to model a wide range of physical events. An example of a simulation, which involves a unique combination of features, is the NASA JPL Mars Pathfinder landing simulation which simulated the space probe's use of airbags to aid in its landing[4]. LS-DYNA is one of the most flexible finite element analysis software packages available.

2. Experimentation Analysis:

2.1 Model Description

Finite element analysis has been carried out on thin-plate of dimensions 10 mm × 10 mm × 5 mm by impacting a rigid sphere at various impact speeds from 50 m/s -150 m/s at every 50 m/s interval and at an angle of incidence 0^{o} .

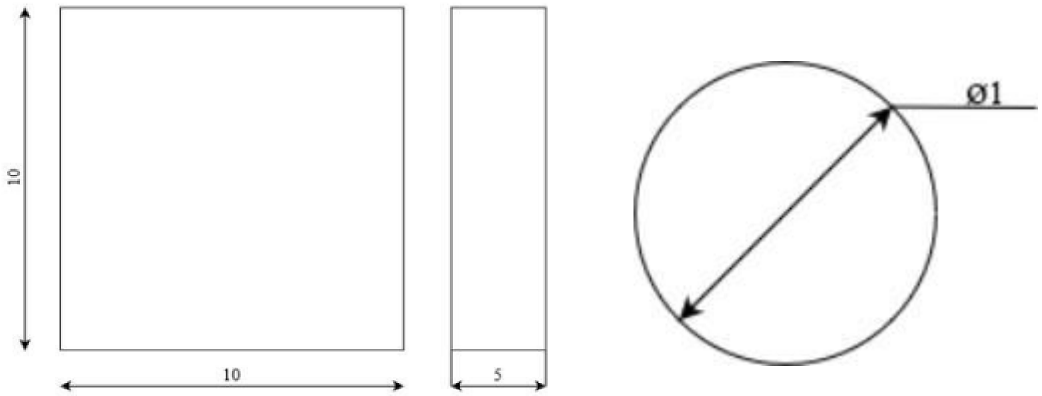


Figure 1 Model Dimensions in mm.

LS-Dyna pre-processor module was used to create finite element model of rectangular plate with very fine mesh. The very fine mesh was created at the location of impact to get the accurate results. Eight noded brick elements were used to discretize the test specimen and projectile[5,6,7]. The number of nodes created are 19,57,327 and the number of elements is 18,98,625.

Figure 2 Meshed sphere

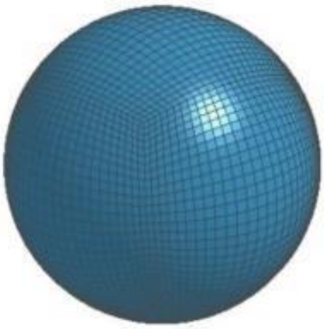
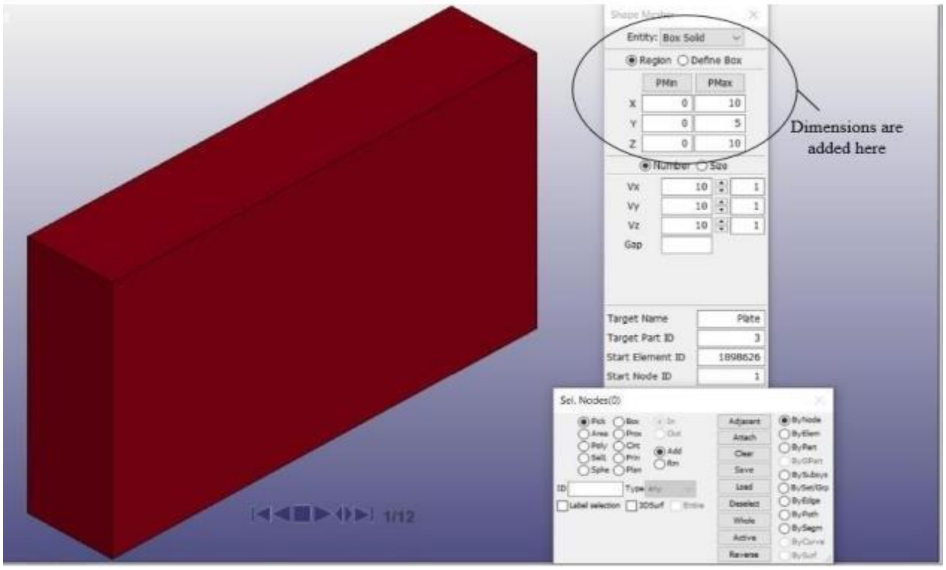


Figure 3 Meshed plate



Entity: Box Solid

● Region ○ Define Box

	PMin	PMax
X	0	10
Y	0	5
Z	0	10

● Number ○ Size

Vx	10	1
Vy	10	1
Vz	10	1

Target Name: Plate
Target Part ID: 3
Start Element ID: 1898626
Start Node ID: 1

Dimensions are added here

Figure 4 Creation of meshed plate

3. Material Properties of Model

3.1. Material Properties of Sphere Here, the material chosen is GCr15 Stainless Steel. Stainless Steel Media is often in the form of stainless-steel shot, stainless steel peening balls or cut stainless steel wire. Stainless steel is an alloy of iron with a minimum of 10.5 percent chromium. Chromium produces a thin layer of oxide on the surface of the steel, the passive layer, that prevents surface corrosion. When shot peening with a steel media, the carbon steel media used embeds contaminants into the stainless steel. Unprotected carbon steel rusts when exposed to air and moisture. This iron oxide film (rust) is active and accelerates corrosion by making it easier for more iron oxide to form. One way to eliminate this issue, is to peen the parts with stainless steel media.

Material Properties of Plate In this numerical investigation, Al 2024 alloy material was used as a rectangular plate like specimen. Due to its high strength and fatigue resistance, 2024 is widely used in aircraft, especially wing and fuselage structures under tension.

2024 is commonly extruded, and also available in alclad sheet and plate forms.

4. Results

The results are obtained in the form of graphs showing maximum compressive residual stress. This stress is maximum at the point of impact and then, decreases with time to become stable. The graphs for different velocities along with the impact it causes on the plate is shown.

The impact caused and the graph for 50m/s velocity of the sphere are shown in Figures

4.1 and 4.2. The maximum residual stress produced by the sphere in this case is -2.029e+03 N/mm^2 .

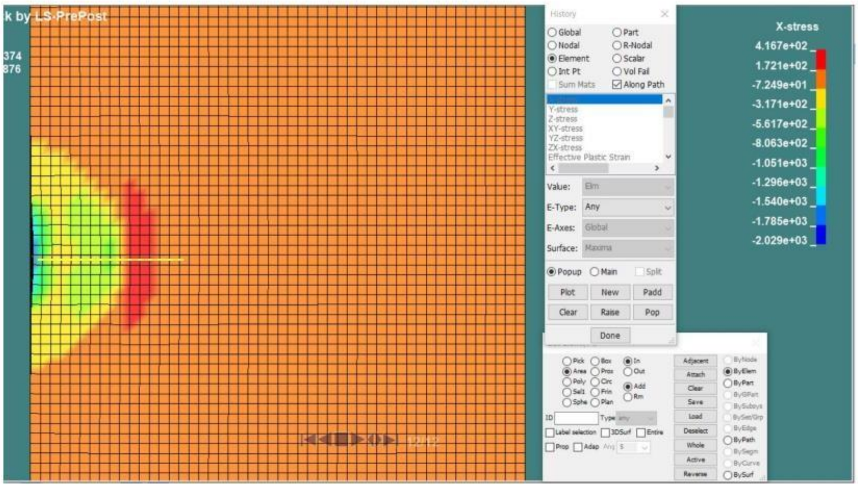


Figure 5 Stress analysis at Impact of 50m/s

Here, you can see a yellow line in the stress profile. That yellow line is used to pick those points that are desired to be plotted on the graph along the x-axis. The graph is plotted when the Plot function is clicked on in the window as seen. This process is repeated for the other two velocities as well [8,9].

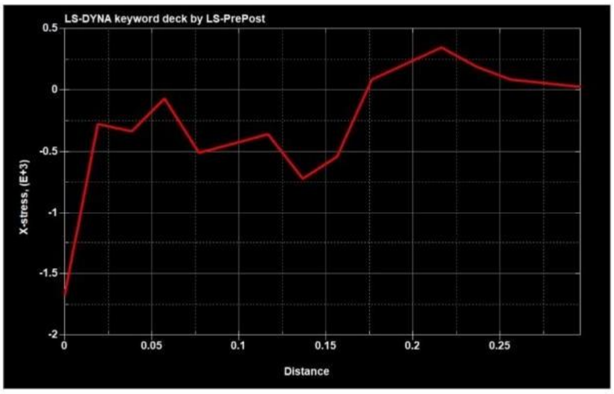


Figure 6 Plot for 50m/s

5. Conclusion

The compressive residual stress profile is significantly influenced by the impact velocity. Up to a certain point, increasing velocity improves the residual stress distribution. An increase in velocity may reduce the maximum residual stress even further. This was studied in the work carried out by G.H. Majzoobi et al. The work carried out by us is in promising agreement with their work. As the impact velocity is increased, in our case study, the compressive residual stress has been seen to be increasing as well. The maximum compressive residual stress for each of the velocities is as follows: • For 50m/s: -2.029e+03 N/mm2 • For 100m/s: -2.612e+03 N/mm2 • For 150m/s: -2.818e+03 N/mm2 This shows the increasing trend that has been studied and seen in the literature review. Hence, we can conclude that the compressive residual stress profile is significantly influenced by the impact velocity.

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