ANALYSIS TO IMPROVE FATIGUE LIFE BY SHOT PEENING PROCESS

A project report submitted in partial fulfilment of the requirement for the award of the degree of

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ABSTRACT

The present work was to determine the effect of residual stresses produced during shot peening operation. In order to basically understand the influence of various shot peening process parameters on the mechanism of residual stress generation, there is a need to develop numerical models that are capable of accurately predicting residual stresses produced during shot peening. Towards this goal, the finite element package ABAQUS 6.9 software package has been employed to clarify and for better understanding of the effect of several key parameters such as shot velocity, shot size, shot material to determine optimum peening process parameters for fatigue life enhancement. The geometry of the target plate is assumed to be a deformable plate with 8.5×5 mm dimensions. Also, for simplicity, shot is assumed to be fully spherical, discrete and deformable with a mass positioned at its centre. The material models used was an aeronautical-based Aluminium 6061 alloys as deformable plate and Alumina (Al_2O_3), Cast steel as shot materials. Situations of single shot impacts were studied; specifically of interest was the magnitude of the residual stress on the surface, as well as the magnitude of the maximum compressive residual stress developed beneath the surface of the target. Other values of interest included the depth of the compressive layer and the magnitude of the maximum tensile residual stress. The model is first validated by comparison of residual stress profiles obtained by various simulation techniques published in the literature. The present work also indicates that the proposed finite element analysis is capable for investigating the influence of various parameters on the shot peening process and this process can successfully be simulated by the finite element package ABAQUS.

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CHAPTER 1 – INTRODUCTION

1.1 SHOT PEENING

Shot peening is used in numerous engineering applications. It is a cold-workprocess in which a stream of spherical shot is blasted against an engineering component. Each shot impacts on the target surface, causing plastic deformation. After contact between the shot and the component ceased, a high compressive residual stress is generated at the surface of the component. Compressive residual stress in the surface layers of the component greatly improves the fatigue strength. It is therefore very useful to be able to predict the pattern and magnitude of the residual stress distribution near the surface after shot peening. Shot peening is a very complex process to model numerically, involving dynamic analysis of fast moving shot impacting on a metallic component which can often has complex geometry. There are a significant number of parameters involved in shot peening which need to be controlled and regulated in order to produce a more beneficial compressive residual stress distribution within the component. These parameters can be categorized into three groups relating to the shot, the component and the process. The shot parameters include size, density, shape, impact velocity, rotary inertia, incident angle and hardness. The component parameters include geometry, initial yield stress, work-hardening characteristics and hardness. The process parameters include mass flow rate, air pressure, angle of attack, distance between nozzle and component and percentage coverage. In order to control the resulting residual stress pattern in peened components, it would be highly beneficial to establish quantitative relationship between these parameters and residual stresscharacteristics.

This section provides a brief description of the shot peening operation including the many parameters that are involved. Information is also provided regarding the measurement of peening intensities, as well as, the role that shot peening plays in the formation of residual stresses in the penned component. Shot peening is a surface strain hardening process that is used mainly in the manufacture of mechanical components. Strain hardening can be described as a process in which a ductile metal will become harder and stronger as it is plastically deformed. This process is also referred to as work hardening or cold working since the temperature at which is usually takes place is well below the absolute melting temperature of the material being worked on. In order to explain the fundamental principle behind strain hardening one must look at the dislocation-dislocation strain field interactions. Cold working causes the dislocation density in the material to increase resulting in a decrease in the average distance between the dislocations. The movement of a dislocation is hampered by the presence of other dislocations because of the repulsive interaction that occurs between them. As a result the stress required to further deform the ductile metal increases. Overall, shot peening has been proven to markedly improve the fatigue life of a component. This is accomplished by impinging the surface of the component with many small spherical shots. Typical shot materials include hardened cast-steel, conditioned cut- wire, glass, or ceramic beads. Shot velocities can range from 30m/s to 125m/s. The size of the beads can vary from 0.1mm to 2mm in diameter. "After contact between the shot and the target material has ceased, the elastically stressed region tends to recover to the fully unloaded state, while the plastically deformed region sustains some permanent deformation".

1.2 RESIDUAL STRESS

The primary focus of this research is to estimate the residual stresses resulting from shot peening Aluminium6061. It is necessary to first present a brief background on such subjects as residual stress, shot peening, and fatigue. In this section a brief description of what residual stresses are and how they are introduced will be presented. 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, crack- and scratch- resistant glass displays on smart phones. However, unintended residual stress in a designed structure may cause it to fail prematurely. "Residual stresses are one of the most important parameters that characterize the near surface layer of any mechanical component, which plays a crucial role in controlling its performance. A residual stress is one that remains in a body even when all external loads have been removed and is the result of a non-uniform plastic deformation. Such stresses are generally the result of a previous thermal or mechanical load applied to the body or of a phase transformation that occurs within the body itself. An example of a thermal load would be one that is applied during a heat treatment process, while mechanical loading can occur during finish machining, bending, or shot peening operations.

1.3 FATIGUE

According to Callister, fatigue can be defined as "failure, at relatively low stress levels, of structures that are subjected to fluctuating and cyclic stresses." Under such cyclical loading conditions components have a tendency to fail at stress magnitudes that are well below the material's understood tensile or yield strength for static loading conditions. As the name itself implies fatigue failures tend to occur over a rather lengthy period of time. As the driving factor behind approximately 90% of all metallic failures, fatigue is the single largest cause of failure in metals. Because very little plastic deformation is associated with fatigue failure it tends to be brittle by nature and is brought on by the generation and propagation of cracks through the material. At the present time "controversy exists in the shot peening and fatigue community as to whether the major benefits of shot peening should be described to the compressive residual stresses or to the micro structural changes and/or deformation which occur over the same region and influence crack initiation". Niku-Lari found that for materials which posses "low characteristics" the resulting increase in the endurance limit due to the shot peening operation is primarily caused by the "superficial strain hardening and the residual stresses" while for high strength materials the increase in fatigue life has been found to be caused by the residual stresses. It is widely accepted that compressive residual stresses improve the overall fatigue life of a component, however, what is not known is the exact impact that these stresses have. Amongst researchers there seems to be an increased interest in developing models capable of incorporating residual stress values into fatigue life calculations.

"The difficulties in controlling the parameters of the strain hardening operation by shot peening very often lead its users to treat it only as an extra safety factor, without taking the residual stresses due to the shot peening into account when calculating the required dimensions of the part". In the United States and France component developers tend to follow the previously stated approach, however, in England, Germany, China, and Japan engineers take residual stresses due to shot peening, in the stabilized condition, into account in their fatigue life calculations.

Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit.

Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), and grain interfaces. Eventually a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure.

1.4 TARGET MATERIAL

1.4.1 ALUMINIUM 6061

Aluminium has become a prominent material in aerospace, nuclear industries have developed a large range of super alloy and heat resistance materials mnemonics like ceramics and composite materials. With the vast and rapid progress in science and technology, modern industry has introduced a new generation of composite materials having low density and very light weight with high strength, hardness and stiffness to meet the current needs of modern technology and the challenges against liberalization and global competitiveness in market .it has numerous benefits like formability, weld ability, corrosion resistance and low cost. Aluminium 6061 is used as matrix material for the fabrication of Al-e-glass-fly ash hybrid composite material. Some of the mechanical properties have been evaluated and compared with Al6061 alloy. Significant improvement in tensile properties, compressive strength and hardness are noticeable as the wt % of the fly ash increases. The microstructures of the composites were studied to know the dispersion of the fly ash and e-glass fiber in matrix. It has been observed that addition of fly ash significantly improves ultimate tensile strength along with compressive strength and hardness properties as compared with that of unreinforcedmatrix.

Annealed 6061 (6061-O temper) has maximum tensile strength no more than 18,000 psi (125 MPa), and maximum yield strength no more than 8,000 psi (55 MPa). The material has elongation (stretch before ultimate failure) of 25–30%. T4 temper 6061 has an ultimate tensile strength of at least 30,000 psi (207 MPa) and yield strength of at least 16,000 psi (110MPa). It has elongation of 16%. T6 temper 6061 has an ultimate tensile strength of at least 42,000 psi (300MPa) and yield strength of at least 35,000 psi (241MPa). More typical values are 45,000 psi (310MPa) and 40,000 psi (275MPa), respectively. In thicknesses of 0.250 inch (6.35 mm) or less, it has elongation of 8% or more; in thicker sections, it has elongation of 10%. T651 temper has similar mechanical properties. The typical value for thermal conductivity for 6061-T6 at 77°F is around 152 W/m K. A material data sheet defines the fatigue limit under cyclic load as 14,000 psi (100MPa) for 500,000,000 completely reversed cycles using a standard RR Moore test machine and specimen. Note that aluminium does not exhibit a well defined "knee" on its S-n graph, so there is some debate as to how many cycles equates to "infinite life". Also note the actual value of fatigue limit for an application can be dramatically affected by the conventional de-rating factors of loading, gradient, and surface finish.

1.5 SHOT MATERIAL

1.5.1 ALUMINIUM OXIDE

Aluminium is very strong, light, and durable.Aluminium Oxide is a form of aluminium. Aluminium is an extremely reactive substance so it is scarcely found in nature. Therefore, it is usually found in the form of Alumina. Alumina is formed in nature when aluminium reacts with oxygen in moist air to form a thin, whitish coating on Aluminium metal of Bauxite .Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium(III) oxide. It is commonly called alumina, and may also be called al oxide, Alluminiumoxite, or alundum depending on particular forms or applications. It commonly occurs in its crystalline polymorphic phase α-Al_2O_3, in which it composes the mineral corundum, varieties of which form the precious gemstones ruby and sapphire. Al_2O_3 is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point.

The most common form of crystalline aluminium oxide is known as corundum, which is the thermodynamically stable form. The oxygen ions nearly form a hexagonal closepacked structure with aluminium ions filling two-thirds of the octahedral interstices. Each Al^{3+} centre is octahedral. In terms of its crystallography, corundum adopts a trigonal Bravias lattice with a space group of R-3c (number 167 in the International Tables). The primitive cell contains two formula units of aluminium oxide.

Aluminium oxide also exists in other phases, including the cubic γ and η phases, the monoclinic θ phase, the hexagonal χ phase, the orthorhombic κ phase and the δ phase that can be tetragonal or orthorhombic. Each has a unique crystal structure and properties. Cubic γ-Al_2O_3 has important technical applications. The so-called β-Al_2O_3 proved to be $NaAl_{11}O_{17}$.Molten aluminium oxide near the melting temperature is roughly 2/3 tetrahedral (i.e.2/3 of the Al are surrounded by 4 oxygen neighbours), and 1/3 5-coordinated, very little (<5%) octahedral Al-O is present. Around 80% of the oxygen atoms are shared among three or more Al-O polyhedral, and the majority of inter-polyhedral connections are corner-sharing, with the remaining 10–20% being edge-sharing. The breakdown of octahedral upon melting is accompanied by a relatively large volume increase (~20%), the density of the liquid close to its melting point is 2.93 g/cm^3.

1.5.2 CAST STEEL

Cast steel is a type of metal created by heating iron using a crucible container. Its creation was due to a revolutionary process invented by an Englishman, Benjamin Huntsman, the 1751. Cast steel allowed for a more uniform composition of, and fewer impurities in, steel than any previous manufacturing process. Since it is made in a crucible, cast steel is often called crucible steel. Steel is made by combining iron with carbon or other alloys. Iron is a soft metal, so not ideal for many construction purposes. The creation of steel removes many of the impurities in iron, which allows steel to be harder and more durable. The better the steel, the more iron impurities that are removed. Early steel was made by adding small amounts of carbon to iron. For example, blister steel was made by repeatedly heating wrought iron and charcoal together in a kiln the charcoal's carbon transferred to the steel by the process of diffusion. Cast steel was the first type of steel that allowed alloys to be added to the iron. Prior to this method, manufacturers had not been able to get steel hot enough to melt. By heating blister steel in a clay crucible placed directly into a fire, Huntsma allowed the metal to reach up to 2900°F (1600°C). Melting allowed other elements, such as nickel, to be mixed into the metal, thus strengthening the steel. Over the centuries, improvements in the crucible process have been made, though the steel is still heated by fire and inside clay, pot-shaped crucible that can be sealed. Modern cast steel is use in engines and machines, as well as ship building. It tends to be more expensive than other types ofmetals used for similar projects. Cast steel has a rough finish. It often has surface holes created by gas bubbling during the heating process. An elastic metal, this typeof steel is very tough, having four times the tensile strength of cast iron. Tensile strength is how much pressure, created by pulling, an object can withstand before it breaks. One concern when using cast steel is whether the surface holes extend into the interior of the metal. If so, these holes could create weaknesses that affect the soundness of the steel. Measuring the volume of water that can be poured into the holes will give a good indication of whether the holes extend far into the metal.

1.6 ABAQUS

- Abaqus FEA **(**formerly **ABAQUS**) is a software suite for finite element analysis and computer-aided engineering, originally released in 1978. The name and logo of this software are based on the abacus calculation tool. The Abaqus product suite consists of five core software products:
- Abaqus/CAE or "**C**omplete **A**baqus **E**nvironment" (a backronym with an obvious root in **C**omputer-**A**ided **E**ngineering). It is a software application used for both the modelling and analysis of mechanical components and assemblies (pre-processing) and visualizing the finite element analysis result. A subset of Abaqus/CAE including only the post-processing module can be launched independently in the Abaqus/Viewer product.
- Abaqus/Standard, a general-purpose Finite-Element analyzer that employs implicit integration scheme (traditional).
- Abaqus/Explicit, a special-purpose Finite-Element analyzer that employs explicit integration scheme to solve highly nonlinear systems with many complex contacts under transient loads.
- Abaqus/CFD, a **C**omputational **F**luid **D**ynamics software application which provides advanced computational fluid dynamics capabilities with extensive support for pre-processing and post processing provided in Abaqus/CAE.

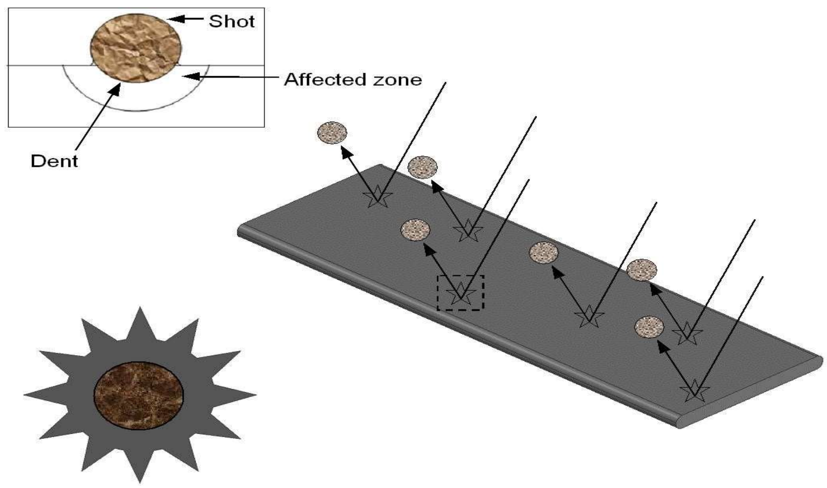

Figure1.1: Schematic representation of short peening

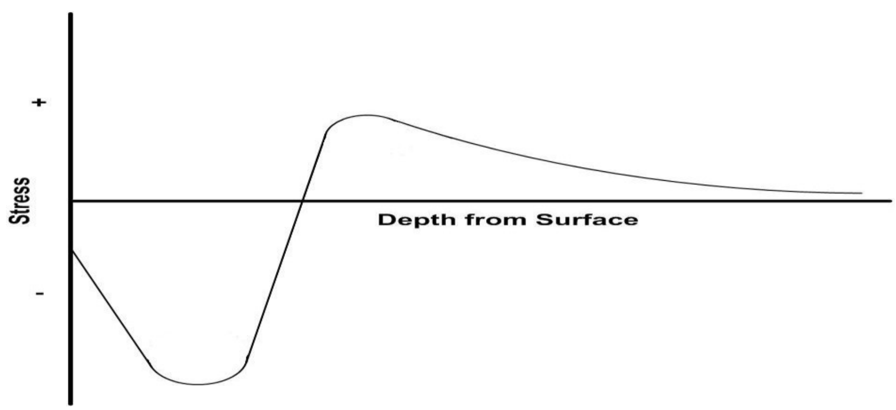

Figure 1.2: Shown here is a typical residual stress profile that would result from a peening operation.

CHAPTER 2 – LITERATURE REVIEW

Details of work conducted by various authors,

The shot peening process is significantly complex the system is dynamic and includes contact mechanics. Study of contact problems of the elastic and elastic-plastic materials resulting from the loading of circular contact area of a sphere with a plane (or more generally between two spheres) was presented by **Hertz** [1]. **Li, et al**. proposed a simplified analytical model for calculating the compressive residual stress field due to the shot peening process which cannot take the velocity of the shot into account and, in addition, depends on empirical parameters to develop a theoretical model.

Hardy al. [2] was the first to solve the contact problem of a rigid sphere indenting an elastic–perfect plastic half-space using the FE method. The first FE analysis of shot peening using the commercial FE program was presented by **Edberg**.

Meguid. [3] used the ANASYS computer program and developed a three-dimensional finite element model of dynamic elasto-plastic analysis, single and twin spherical indentations using rigid spherical shots and metallic targets. He examined the effects of shot velocity, size and shape, and target characteristics on residual stress distribution in the target. Their results indicated that the effects of shot parameters were more profound than the strain-hardening rate of the target.

M. Frija. [4] published a numerical simulation of the shot peening process using a finite element method and obtained the residual stress, the plastic deformation profiles and the surface damage. In their model, the shot was supposed to be a rigid sphere. The mechanical behavior of the subjected material was assumed to be elastic plastic coupled with damage, using an integrated form of the **Lemaitre and Chaboche** model. The shot peening loading was simulated by a static indentation, obtained by an energetic equivalence with the dynamic impact.

Al-Hassam [5] presented a numerical simulation of single shot impact on a component and examined single shot impacting with an oblique angle but very limited results were presented and their results verified the significant role played by non-linear work hardening and strain rate dependency of the target on residual stress profile and extent of surface hardening.

Majzoobi [6] have investigated multiple shot impacts and the effect of the shot velocity on the residual stress profile by using LS-DYNA code. Their results showed that, residual stress distribution was highly dependent on impact velocity and multiplicity.

M.A.S. Torres, **H.J.C. Voorwald b** [7], Shot peening is a method widely used to improve the fatigue strength of materials, through the creation of a compressive residual stress field (CRSF) in their surface layers. In the present research the gain in fatigue life of AISI 4340 steel, used in landing gear, is evaluated under four shot peening conditions. Rotating bending fatigue tests were conducted and the CRSF was measured by an X-ray tensometry prior and during fatigue tests. It was observed that relaxation of the CRSF occurred due to the fatigue process. In addition, the fractured fatigue specimens were investigated using a scanning electron microscope in order to obtain information about the crack initiation points. The evaluation of fatigue life, relaxation of CRSF and crack sources are discussed.

Midori Yoshikawa Pitanga Costaa, Herman Jacobus Cornelis Voorwalda, Walter Luis Pigatinb , Valdir Alves Guimarãesa , Maria Odila Hilário Cioffic [8] The aim of this research is to analyze the fatigue behavior of anodized Ti-6Al-4V alloy and the influence of shot peening pre-treatment on the experimental data. Axial fatigue tests (R = 0.1) were performed, and a significant reduction in the fatigue strength of anodized Ti-6Al-4V was observed. Shot peening pre-treatment proved to be an efficient process to improve the fatigue strength of anodized Ti-6Al-4V base metal The extend to which anodic coatings can reduce the fatigue strength of Ti-6Al-4V alloy, is illustrated in Figure 2. The effect of anodic coatings was to decrease the fatigue strength for Ti-6Al-4V alloy. At stress levels 986 MPa and 955 MPa, reduction in number of cycles to failure due to the anodic coatings, and increase in fatigue life after shot peening process were, respectively, 10.50%/219.9% and 9.98%/247.1%.

Baskaran Bhuvaraghana, Sivakumar M.Srinivasanb, Bob Maffeoc [9], Imparting residual compressive stresses in the surface layers of metallic components is one of the ways to improve their fatigue strength characteristics. Shot peening is employed for imparting residual stresses by means of cold work. Shot peening is a complex random process with many input variables. To obtain the maximum fatigue strength, the designer needs to consider both favorable and detrimental aspects of these responses together. The prediction of the responses from the input parameters involves many methods spanning across multiple-disciplines such as plasticity, fracture, optimization etc. Using probabilistic optimization techniques, the fatigue life can be optimized. In the long run, employing multi-scale models linking dislocations and microstructure of the material to continuum will help in reducing experimental studies.

Ahmed N. Al-Khazraji [10], This paper is experimentally studied to optimize shot peening time of aluminium alloy 6061 as well as using analysis of variance (ANOVA). Two types of fatigue test specimens configuration were used, one without notch and the other with a notch radius(1.25mm), each type was shot peened at different time. The (O.S.T) was experimentally estimated to be 8minutes reaching the surface stresses at maximum peak of -184.94 MPa. The same optimum S.P.T which was 8min experimentally obtained for the two cases specimens which gave a 56.24% gain for notched peened. A 26.6% improvement by RSM method in fatigue life compared with experimental results for this work.

CHAPTER 3 – SIMULATION PROCEDURE

We are going to study the compressive residual stress generated due to shot peening by using simulation procedure. The simulation procedure we have adopted is ABAQUS. Here we are going to compare the different parameters like velocity, size and compressive residual stress generated by taking Aluminium 6061 as target material and Cast steel, Aluminium oxide as shot materials. The simulation procedure consists of the number of steps which are discussed below. For the Explanation of the procedure we have considered Aluminum6061 as target material and Cast steel as the shot material.

3.1 CREATING THE MODEL GEOMETRY

- Go to the Start Menu and open Abaqus CAE. Here you will observe a model tree on the left side of the home screen. Model tree consists of steps involved in the analysis like Part, Materials, assembly step, job etc. ABAQUS home screen is shown in figure 3.1
- As our analysis is shot peening the geometric model of part consists of the two parts Target and Shot material. For this select the part in the model tree.
- Enter the new name as the target, under the modelling space select axis-symmetric, under the type select the Deformable and under the base feature select the shell then press continue then draw a rectangle with required dimensions. Thus target part has been completed
- The same procedure has been adopted for the design of the shot. Initially the selected size of the shot is 212.5µm as shown in figure 3.2

3.2 DEFINING MATERIAL PROPERTIES

- Next step in the procedure is defining the material properties for this select the materials in the model tree. As shown in the figure 3.3 assign the required properties for the materials here we had taken Aluminium 6061 as target material and cast steel as shot material.
- Plasticity parameters here we have taken are Johnson-Cook parameters. The Johnson-Cook parameters and mechanical properties we have taken are given in the below table 3.1 and table 3.2

- Next we have to give the material properties of the cast steel. Elasticity and plasticity properties of cast steel are given in the below table 3.3 and table 3.4.

3.3 CREATING SECTIONS AND SECTION ASSIGNMENT

- In this step the sections must be created and the materials to the section are assigned. For this select the section dialogue box name as the section-1 for the target material and section -2 for the shot material. After that materials are assigned for the sections assignment as shown in figure 3.4
- Now the solid section has been created, it can be assigned to the geometry for this select the section assignment and assign the section-1 and section-2 as shown in the figure 3.5

3.4 ASSEMBLY

- In this we have to do the assembly of the target and shot for this first Instances must be created for target and shot. Then by using the translate instance assembly of the target and part done as shown in figure 3.6.
- After the assembly the meshing is done as shown in the figure 3.7. After that thetype of the elements must be selected.

3.5 CREATING A STEP

- The step is where the user defines the different fields like velocities, interactions and boundary conditions. In the step there are two stages initial and impact

  .First interactions are created. In the interactions the selected method is Dynamic explicit, surface-surface-contact (Explicit) and give mechanical method as penalty contact type.
- In the first step as we are going to vary the velocities select the velocities in the predefined fields as v_1=0 and v_2=35m/s as shown in the below figure3.8.
- In the impact field select the field output what we required as stress and strains etc. Then apply the boundary conditions as U1=0 and UR3=0.Applying of boundary conditions are shown in the figure 3.9

3.6 CREATING JOB

- The job must be created for the analysis as shown in the figure3.10. The name ofthe job we have given is shot then submit the job for the analysis.

3.7 RESULTS

- The results of the residual stresses are taken in the X-axis, X direction in this theshot didn't show any effect on the target material the deformable shape of the target material is as shown in the figure.
- Same procedure is adopted with different velocities like 3m/s, 35m/s, 45m/s, 55m/s.

3.8 CHANGING THE SHOT SIZE AND SHOT MATERIAL

By using the same procedure what we have explained above we most change the size of the shot as 212.5µm, 200 µm, 210 µm, 220 µm. Then the values of the residual stress are tabulated until we get the constant stress values. Then by changing the shot material as Al_2o_3 by taking 35m/s,45 m/s as velocity and 300 µm, 310 µm, 320 µm as shot size. The mechanical properties we have considered for Al_2o_3 are given in the table 3.5,3.6.

TABLES

Table 3. 1 Mechanical properties of Aluminium 6061

Property	Values	Units
Density	2700	Kg/m^3
Young's Modulus	70	GPa
Poisson's Ratio	0.33	-

Table 3. 2 Johnson-cook Parameters of Aluminium 6061

Material	A (MPa)	B (MPa)	N	m	Melting Temperature (K)	Transition Temperature (K)
Aluminium 6061	324	114	0.42	1.34	853	298

Table 3. 3 Mechanical Properties of Cast Steel

Property	Values	Units
Density	7638	Kg/m^3
Young's Modulus	200	GPa
Poisson's Ratio	0.256	-

Table 3. 4 Johnson-cook Parameters of Cast Steel

Material	A (MPa)	B (MPa)	n	m	Melting Temperature (K)	Transition Temperature (K)
Cast Steel	792	510	0.014	1.03	1793	298

Table 3. 5 Mechanical Properties of Al_2O_3

Property	Values	Units
Density	3840	Kg/m^3
Young's Modulus	300	GPa
Poisson's Ratio	0.21	-

Table 3. 6 Johnson-cook Parameters of Al_2O_3

Material	A (MPa)	B (MPa)	n	m	Melting Temperature (K)	Transition Temperature (K)
Al_2O_3	880	450	0.64	0.6	2298	298

FIGURES

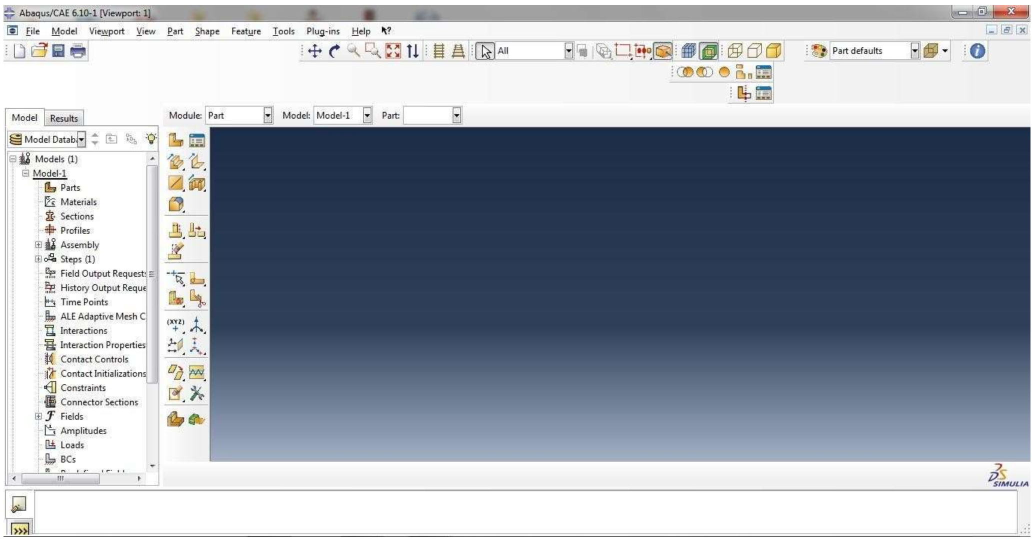

Figure 3. 1 Abaqus home screen

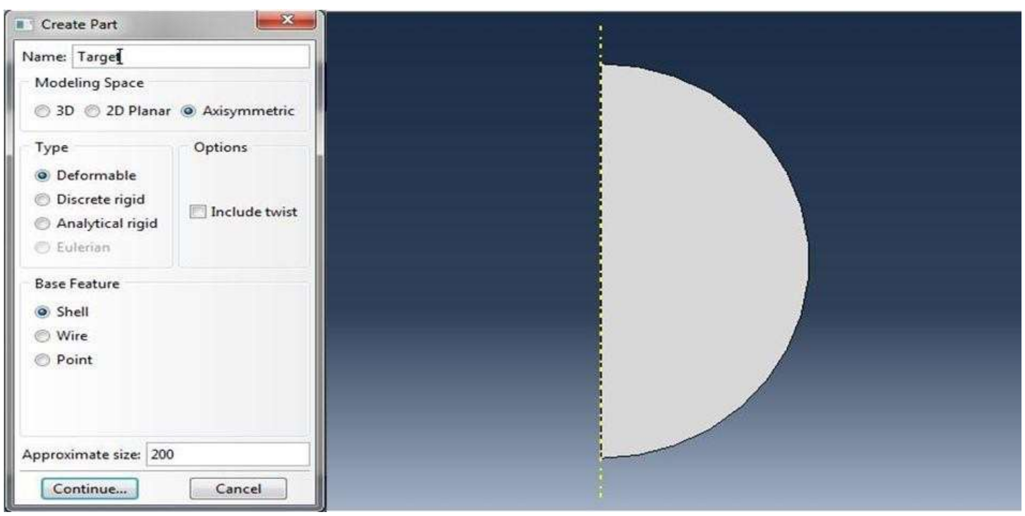

Figure 3. 2 Creating part

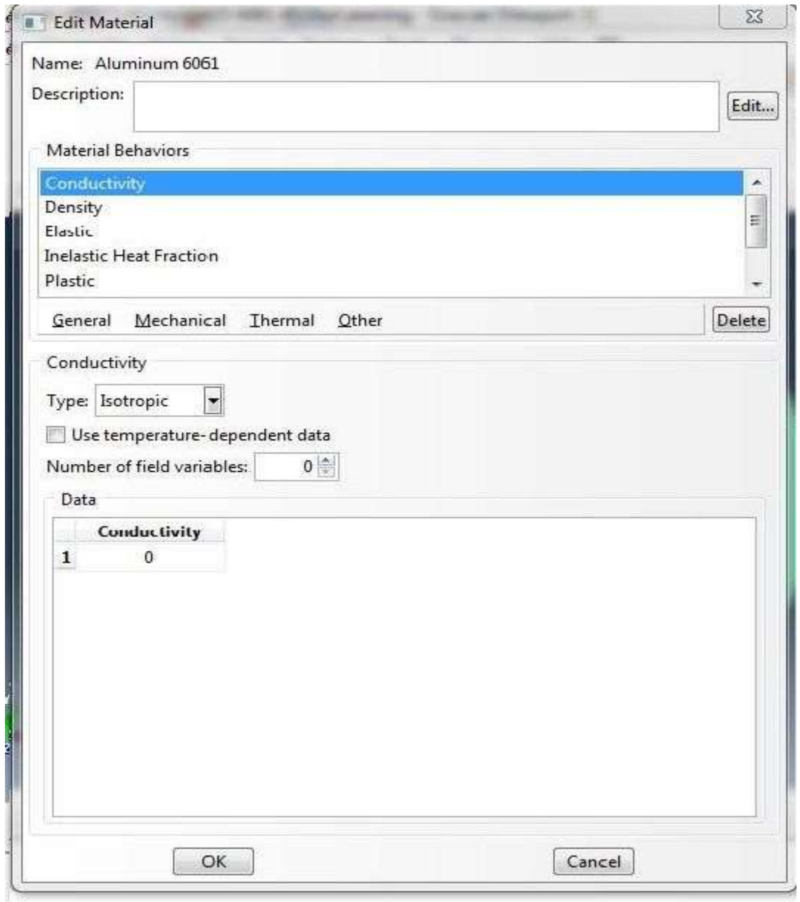

Figure 3. 3 Defining material properties

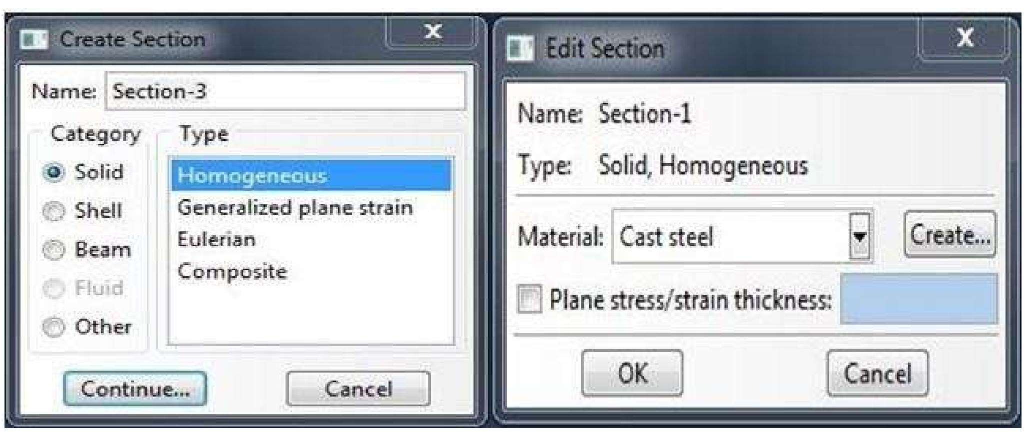

Figure 3. 4 Creating Sections

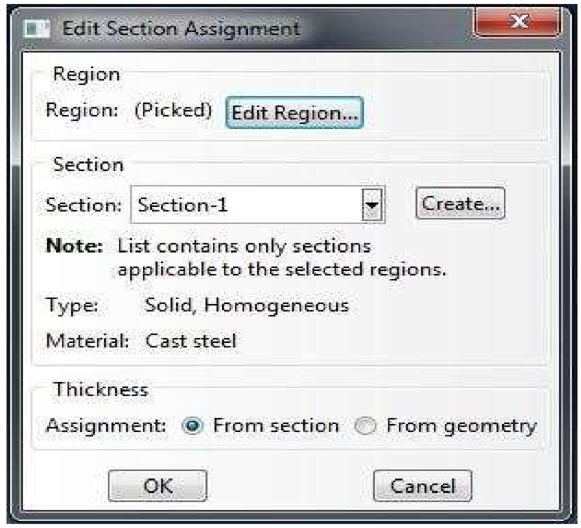

Figure 3. 5 Section assignment

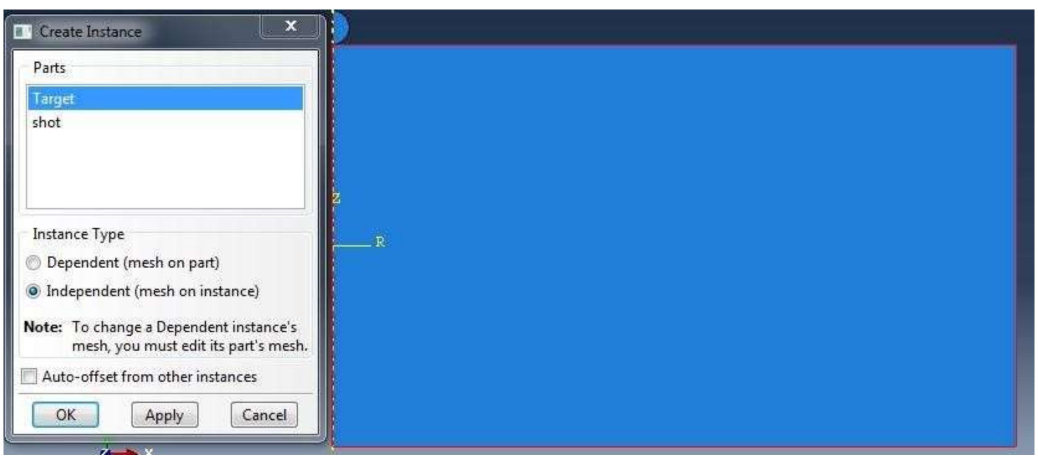

Figure 3. 6 Creating instances and assembly of shot and target

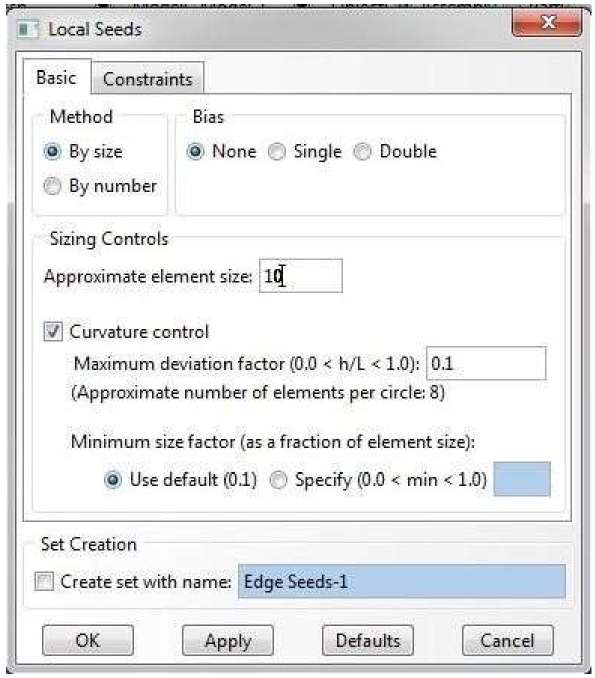

Figure 3. 7 Meshing of materials

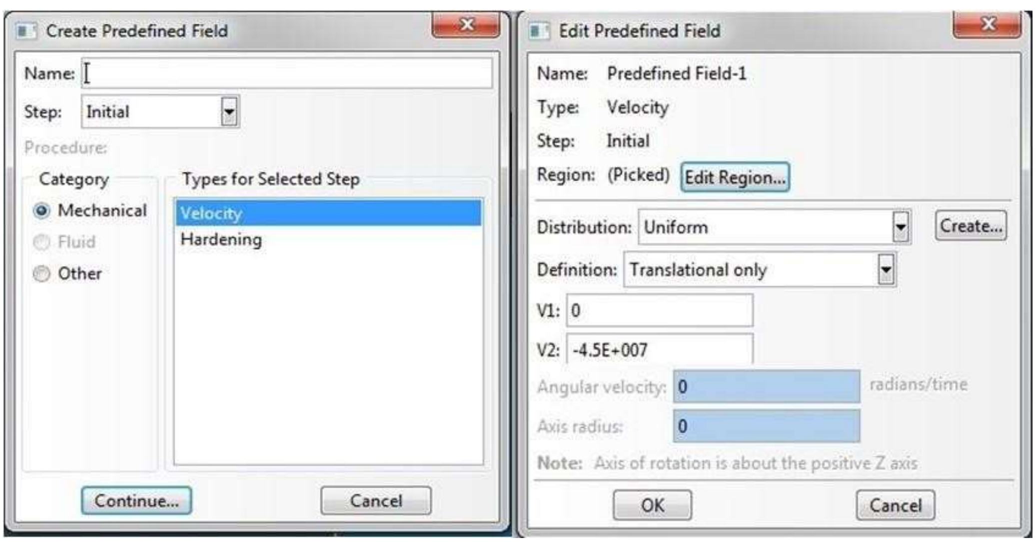

Figure 3. 8 Creating predefined field

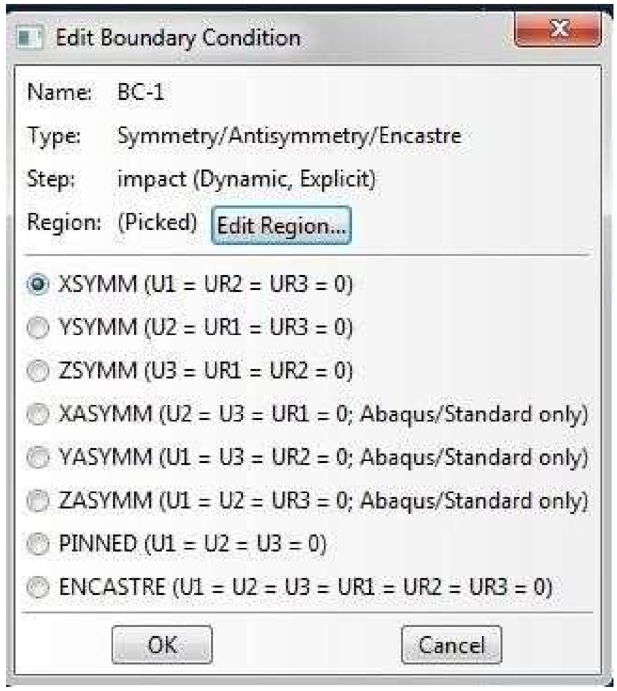

Figure 3. 9 Applying boundary conditions

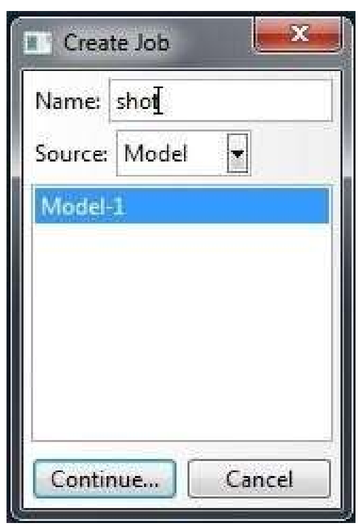

Figure 3. 10 creating job

CHAPTER 4 - RESULTS AND DISCUSSIONS

The results of the various parameters like shot size, velocity of shot and residual stress of the Aluminium6061 as target and cast steel and Al_2O_3 as shot materials are discussed below

4.1 RESULTS & DISCUSSIONS FOR ALUMINIUM6061(Cast steel as shot material)

4.1.1 EFFECT OF VELOCITY

- The velocity comparison graph for the Aluminium6061 as target material and cast steel as the shot material is shown in the below figure 4.1, 4.2, 4.3, 4.4 for varying velocities (such as 212.5 µm, 200 µm, 220 µm, 240 µm).
- Form the above graph we can conclude that as the velocity of the shot increases the depth of the maximum compressive residual stress increases, magnitude of the compressive residual stress and depth of the compressive residual stress has been increased.
- The figure 4.5 shows deformations occurred due to the change in the velocities of the shot.
- By the values of maximum magnitude of the compressive residual stress (MPa) and velocity m/s we can conclude that with the increase in the velocity the magnitude of the compressive residual stress varies polynomial.
- The depth of maximum compressive residual stress increases linearly with the increasing the velocity.

4.1.2 EFFECT OF SHOT SIZE

- In the above column we have studied the effect of velocity of the shot on the target material now we are going to study the effect of the size on the target material
- Figure 4.6 shows the deformation of target materials by varying the shot size.
- The figure 4.7 is shot size comparison graph which is drawn is for the compressive residual stress and the depth of the target from this we can conclude that the depth of compressive residual stress, depth of maximum compressive residual stress and the magnitude of the compressive residual stress has been increased.

- As the shot size has increased the maximum magnitude of the compressive residual stress has also been increased linearly.
- As the size of shot has been increased depth of the compressive residual stress also increased linearly.
- By considering the stress values of different shot size and with same velocity we can conclude that with increase in shot size the residual stress at the surface is decreasing.

4.2 RESULTS & DISCUSSIONS FOR ALUMINIUM6061(Al2O3 as shot material)

4.2.1 EFFECT OF VELOCITY

- The velocity comparison graph for the Aluminium6061 as target material and Al2O3 as the shot material is shown in the below figure 4.8, 4.9, 4.10.
- Form the above graph we can conclude that as the velocity of the shot increases the depth of the maximum compressive residual stress increases, magnitude of the compressive residual stress and depth of the compressive residual stress has been increased.
- The figure 4.11 shows deformations occurred due to the change in the velocities of the shot.

4.2.2 EFFECT OF SHOT SIZE

- Now we are going to study the effect of shot size on Aluminum6061. Figure 4.12 represents the deformation of target material by varying different shot materials.
- In case Al2O3 the shot size required is more compared to Cast Steel in order to obtain the compressive residual stress.
- The effect of different shot sizes with same velocity is shown in graph 4., by this graph we can conclude that with increase in shot size the residual stress at the surface is decreasing.
- As the shot size has increased the maximum magnitude of the compressive residual stress has also been increased linearly.
- As the size of shot has been increased depth of the compressive residual stress also increased linearly.

4.3 EFFECT OF SHOT MATERIAL

- The shot materials we used for simulation are Cast Steel and Al2O3. For getting compressive residual stresses with Al2O3 we require shot size of larger diameter as compared to the Cast Steel.

- The graphs with same velocity and different shot size of both the materials are shown below in Figure 4.10.

Tabular data of the results obtained

For Cast Steel Material

Table 4. 1 Residual stress obtained for different velocities of shot diameter 212.5 µm

Depth of the Target material (in µm)	Velocity of the shot 25m/s	Velocity of the shot 30m/s	Velocity of the shot 35m/s	Velocity of the shot 45m/s	Velocity of the shot 55m/s
10	-325.238	-309.085	-220.55	-118.731	-44.6614
20	-417.33	-403.839	-308.552	-271.894	-226.896
30	-491.212	-508.296	-403.285	-365.407	-338.342
40	-544.432	-576.919	-481.785	-465.121	-411.605
50	-551.066	-604.599	-529.519	-513.797	-468.649
60	-557.215	-591.241	-541.511	-533.536	-496.43
70	-524.113	-595.475	-540.117	-540	-502.946
80	-488.641	-564.381	-527.638	-534.22	-519.749
90	-427.504	-512.107	-520.576	-517.619	-512.533
100	-370.47	-452.158	-479.883	-513.323	-508.015
110	-312.505	-391.687	-433.137	-483.538	-490.818
120	-256.388	-327.615	-385.25	-448.091	-478.661
130	-200.569	-275.707	-334.938	-409.751	-450.649
140	-151.384	-212.242	-285.016	-369.633	-420.364
150	-100.995	-167.731	-238.724	-330.996	-392.025
160	-56.2849	-114.413	-195.645	-290.012	-351.451
170	-10.9708	-66.8894	-149.38	-246.563	-314.048
180	30.4112	-24.8961	-108.766	-205.893	-279.905
190	68.5116	16.0366	-65.3781	-167.909	-245.489
200	75.275	54.9027	-29.2227	-129.16	-211.311
210	60.1409	89.6417	7.086	-98.8183	-176.588
220	48.7307	79.4962	39.1865	-61.8876	-139.181
230	40.2165	66.0793	70.1457	-29.0515	-107.725
240	33.6905	54.6081	79.0355	-0.24875	-76.128
250	28.6113	45.9695	64.857	31.2106	-46.273
260	23.806	39.4882	54.2001	58.6386	-16.7406
270	19.9552	33.2069	46.738	82.852	11.3962
280	17.7931	28.3589	39.8958	71.0493	37.3344
290	15.5708	24.809	33.8286	61.0426	64.1451
300	12.8786	21.3028	28.9872	52.4139	80.7381

Table 4. 2 Residual stress obtained for different velocities of shot diameter 200 µm

Depth of the Target material (in µm)	Velocity of the shot 25m/s	Velocity of the shot 35m/s	Velocity of the shot 45m/s
10	-210.05	-93.8771	39.2097
20	-323.665	-267.807	-182.172
30	-459.512	-389.611	-297.96
40	-534.885	-493.562	-415.876
50	-552.063	-532.281	-426.397
60	-569.913	-545.482	-461.916
70	-544.094	-550.528	-455.08
80	-475.326	-540.246	-456.956
90	-407.511	-507.116	-461.994
100	-336.259	-451.141	-462.983
110	-271.229	-400.777	-455.433
120	-208.051	-340.808	-444.047
130	-147.344	-286.698	-401.104
140	-90.3324	-231.774	-351.991
150	-39.1371	-180.58	-300.449
160	9.06017	-133.079	-248.852
170	52.7637	-85.3805	-200.204
180	87.8437	-43.4976	-156.549
190	70.3349	-0.320477	-117.295
200	56.8157	34.6909	-77.3181
210	45.7973	71.9766	-39.814
220	37.9817	80.6141	-3.60302
230	30.8214	66.9891	29.4519
240	24.9729	55.0481	59.5823
250	20.8233	45.2747	80.5483
260	17.5548	36.9078	68.3969
270	14.6193	30.9806	55.9488
280	11.5971	25.8832	47.7568
290	9.387928	21.5265	41.1112
300	8.47954	18.0708	33.9688

Table 4. 3 Residual stress obtained for different velocities of shot diameter 220 µm

Depth of the Target material (in µm)	Velocity of the shot 25m/s	Velocity of the shot 35m/s	Velocity of the shot 45m/s
10	-373.289	-348.322	-279.87
20	-446.858	-433.701	-386.432
30	-516.1	-526.041	-495.177
40	-570.211	-587.432	-561.712
50	-585.734	-631.288	-608.295
60	-578.464	-614.03	-606.882
70	-558.909	-597.895	-609.294
80	-525.269	-581.943	-589.403
90	-464.409	-557.557	-571.037
100	-402.065	-512.865	-542.409
110	-340.242	-464	-518.66
120	-284.146	-406.063	-480.785
130	-224.51	-354.698	-442.3
140	-173.244	-306.614	-398.164
150	-121.609	-257.492	-355.821
160	-73.7745	-211.645	-311.598
170	-29.7363	-164.757	-268.874
180	13.0353	-122.592	-225.43
190	51.4854	-80.0944	-186.617
200	84.7826	-40.6388	-143.184
210	71.3258	-6.52572	-111.266
220	58.3611	27.9659	-76.9055
230	48.4951	58.7188	-43.639
240	40.3268	87.062	-9.08427
250	34.5188	74.8303	22.3627
260	28.8094	63.6015	51.6023
270	24.3072	54.1372	76.9671
280	21.4044	46.6061	84.2612
290	18.4843	40.4251	71.6415
300	15.6826	35.0169	61.3631

Table 4. 4 Residual stress obtained for different velocities of shot diameter 240 μm

Depth of the Target material (in μm)	Velocity of the shot 25m/s	Velocity of the shot 35m/s	Velocity of the shot 45m/s
10	-569.499	-485.152	-447.793
20	-588.776	-524.672	-518.546
30	-651.342	-576.237	-595.102
40	-674.852	-630.969	-650.405
50	-676.572	-648.614	-685.63
60	-645.465	-659.203	-684.468
70	-626.232	-650.087	-679.715
80	-580.79	-615.919	-659.121
90	-522.261	-589.813	-634.313
100	-461.738	-558.252	-597.383
110	-401.433	-515.138	-566.212
120	-343.59	-470.411	-533.954
130	-287.052	-418.326	-499.172
140	-232.149	-370.02	-458.41
150	-182.173	-326.56	-416.674
160	-134.028	-279.072	-375.907
170	-90.4339	-235.665	-329.828
180	-45.5277	-193.057	-286.886
190	-4.88063	-152.707	-246.449
200	34.0324	-112.438	-205.516
210	68.3996	-76.0312	-169.189
220	88.5031	-41.5011	-136.258
230	73.7861	-6.6144	-102.46
240	61.6566	23.5652	-73.7921
250	52.8138	54.3044	-41.7688
260	46.2093	81.9302	-12.44
270	40.1297	75.2192	15.9726
280	34.5201	65.4549	42.2355
290	30.0074	57.0977	67.563
300	27.0089	49.6975	89.8148

For Aluminium oxide (Al_2O_3) material

Table 4. 5 Residual stress obtained for different velocities of shot diameter 300 µm

Depth of the Target material (in µm)	Velocity of the shot 35m/s	Velocity of the shot 45m/s
10	-67.5853	-1.57369
20	-100.399	-26.2014
30	-141.84	-44.5845
40	-156.43	-84.0415
50	-215.853	-129.542
60	-251.472	-181.665
70	-292.639	-226.22
80	-314.049	-270.418
90	-308.549	-286.119
100	-287.887	-284.996
110	-254.482	-276.98
120	-218.584	-251.485
130	-179.388	-226.058
140	-140.796	-192.134
150	-104.019	-160.566
160	-63.7773	-124.538
170	-27.6254	-91.9155
180	9.63292	-55.7798
190	42.6863	-22.9163
200	67.0699	10.0824
210	53.9183	38.7087
220	43.8464	65.3391
230	35.4623	52.3445
240	28.4656	42.4243
250	23.236	34.6942
260	19.4815	28.5047
270	16.4149	23.9181
280	13.5099	20.4853
290	11.7763	15.1441
300	10.4486	12.666

Table 4. 6 Residual stress obtained for different velocities of shot diameter 310 µm

Depth of the Target material (in µm)	Velocity of the shot 35m/s	Velocity of the shot 45m/s
10	-167.151	-48.5767
20	-163.041	-90.3658
30	-199.737	-94.5239
40	-212.757	-118.826
50	-249.313	-154.069
60	-272.208	-190.134
70	-315.473	-237.222
80	-328.63	-269.783
90	-329.684	-290.689
100	-307.949	-284.705
110	-274.859	-280.056
120	-234.846	-259.051
130	-197.821	-236.503
140	-156.115	-206.555
150	-116.653	-179.075
160	-79.2386	-145.4
170	-39.989	-115.596
180	-7.24083	-83.295
190	30.8269	-53.7863
200	59.5306	-23.2517
210	63.5041	5.17128
220	50.3034	35.588
230	40.7358	60.3011
240	33.3017	53.6934
250	27.6059	43.3281
260	23.4838	35.5736
270	20.1313	29.2382
280	17.2873	25.2818
290	15.0891	21.5848
300	12.7967	18.3056

Table 4. 7 Residual stress obtained for different velocities of shot diameter 320 µm

Depth of the Target material (in µm)	Velocity of the shot 35m/s	Velocity of the shot 45m/s
10	-216.051	-119.183
20	-220.486	-148.793
30	-199.642	-127.383
40	-254.95	-176.185
50	-260.145	-170.509
60	-286.505	-225.411
70	-316.187	-265.625
80	-328.775	-298.861
90	-332.753	-319.175
100	-317.396	-314.251
110	-287.146	-301.002
120	-259.089	-282.786
130	-220.135	-255.559
140	-183.868	-229.485
150	-146.692	-195.458
160	-107.966	-164.797
170	-72.9603	-133.264
180	-38.3061	-99.131
190	-3.18943	-67.5097
200	29.782	-36.2994
210	59.6976	-3.99777
220	61.7759	23.782
230	50.0861	50.0469
240	41.1068	62.049
250	34.466	51.1596
260	29.6824	42.8047
270	24.695	35.5835
280	20.8616	30.5874
290	18.0092	26.1384
300	15.9575	22.3111

VELOCITY COMPARISON

Target material: Aluminium6061

Shot material: CAST STEEL

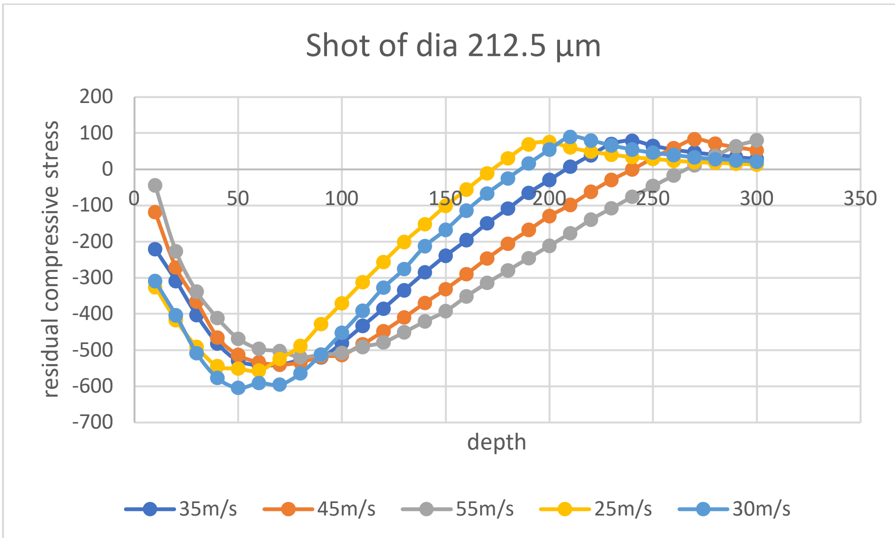

Figure 4. 1 Velocity comparison for diameter of 212.5 µm

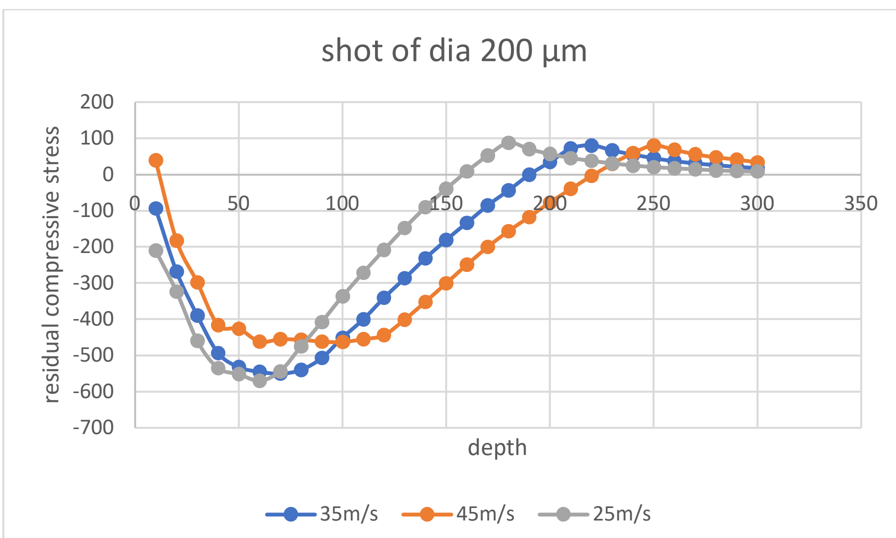

Figure 4. 2 Velocity comparison for diameter of 200 µm

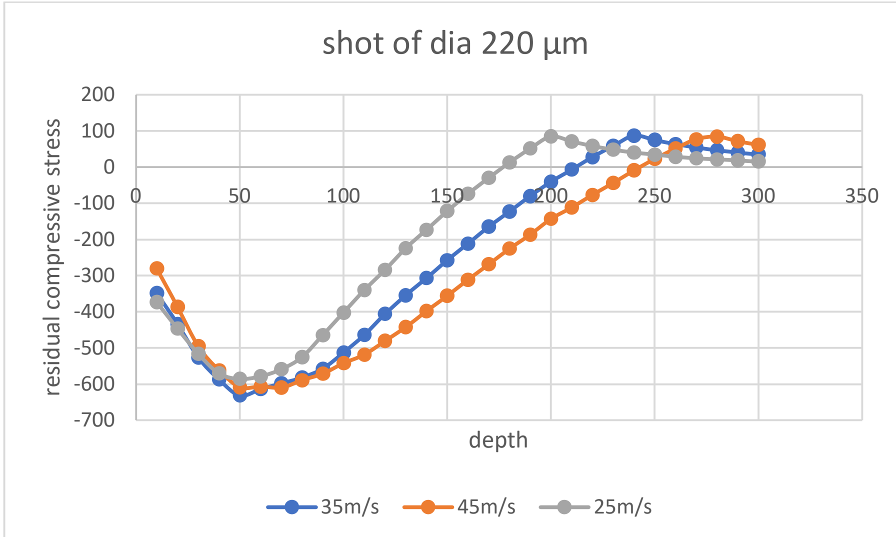

Figure 4. 3 Velocity comparison for diameter of 220 µm

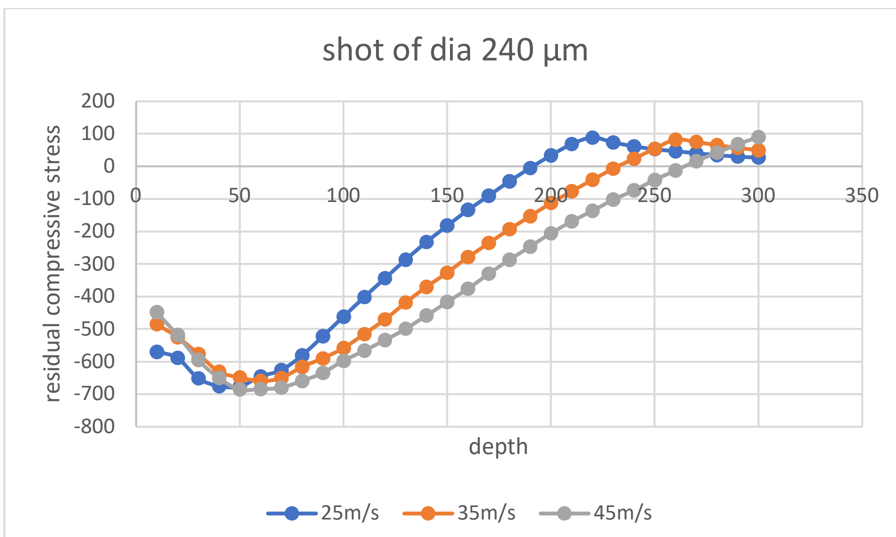

Figure 4. 4 Velocity comparison for diameter of 240 µm

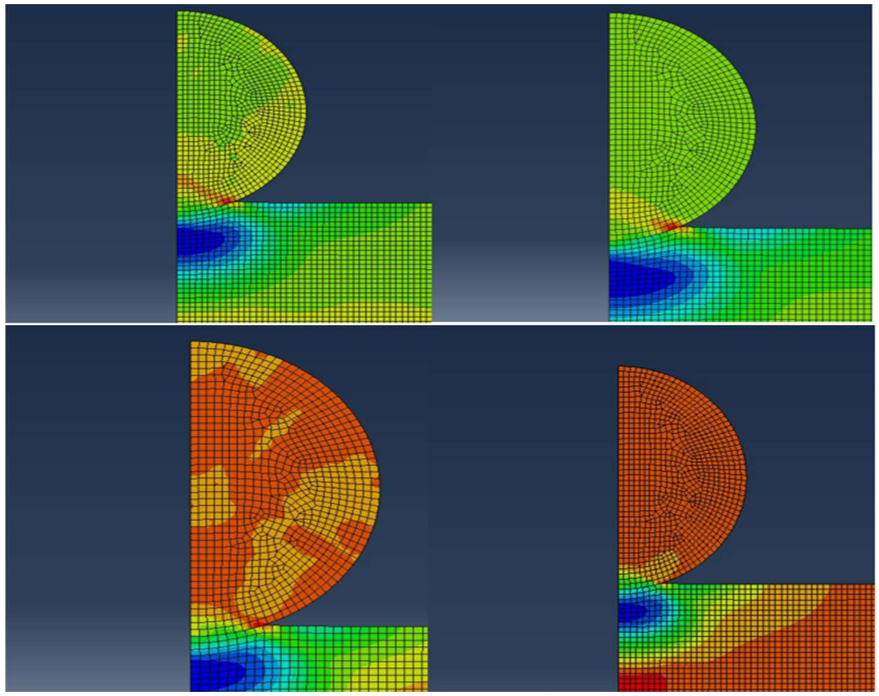

Figure 4. 5 Deformation of target materials due to different velocities of shot

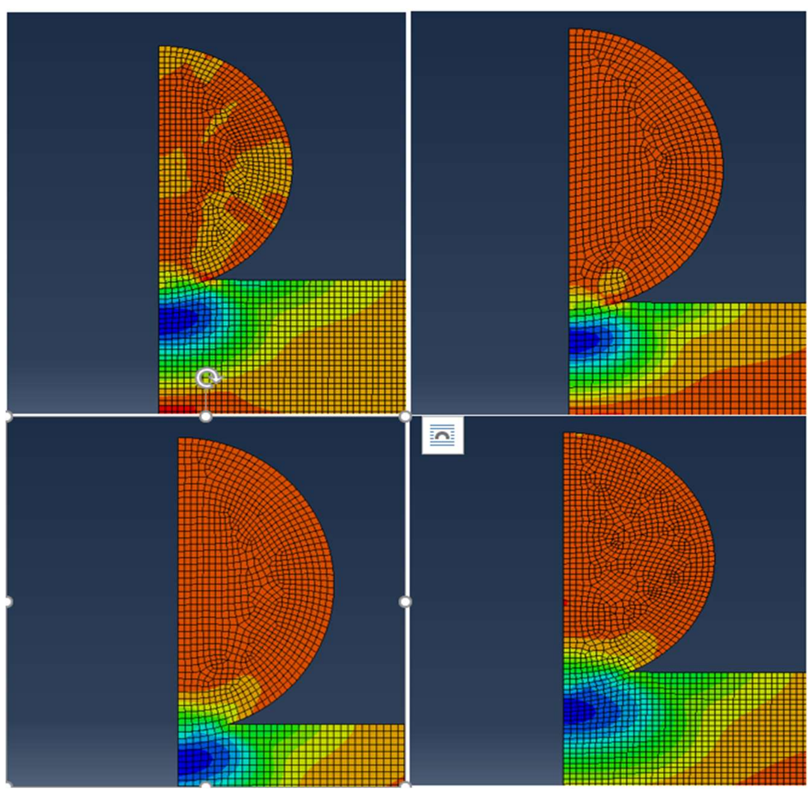

Figure 4. 6 Deformation of target materials due to different shot size

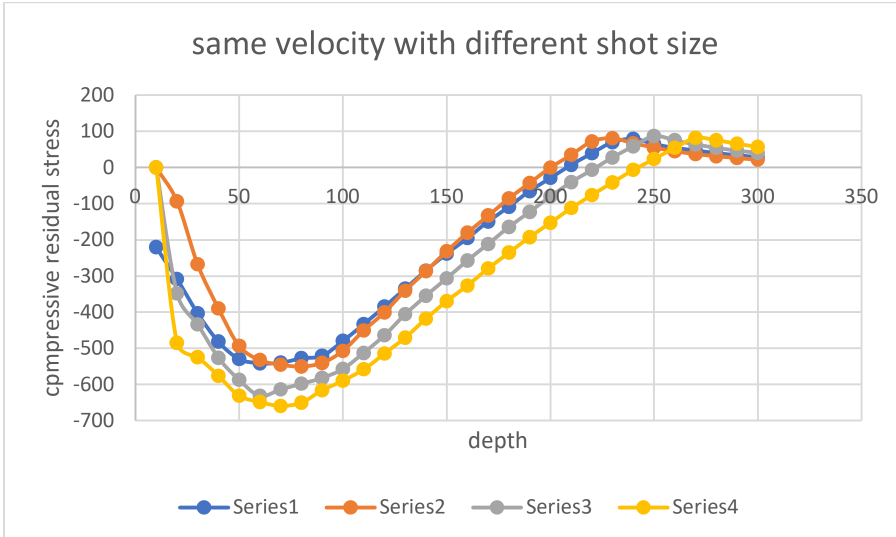

Figure 4. 7 Shot size comparison graph drawn by making velocity constant

Shot material: Al2O3

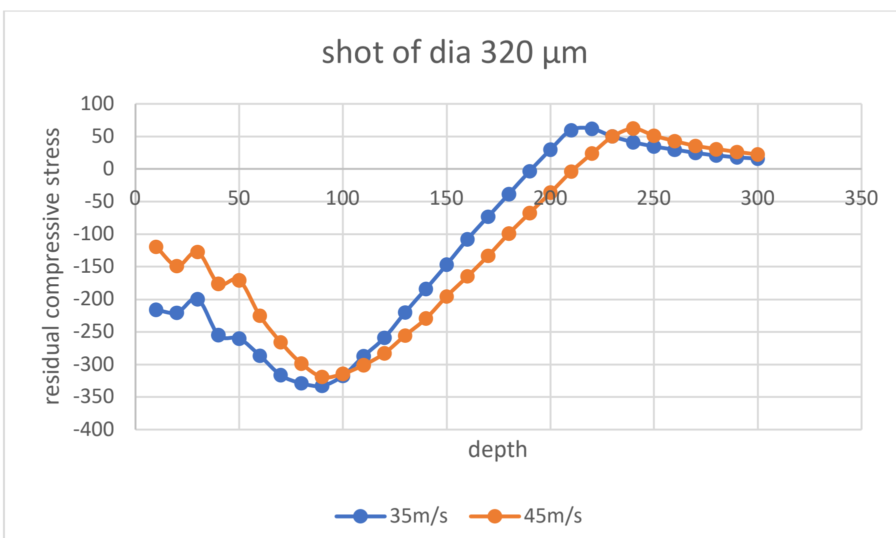

Figure 4. 8 Velocity comparison for diameter of 320 µm

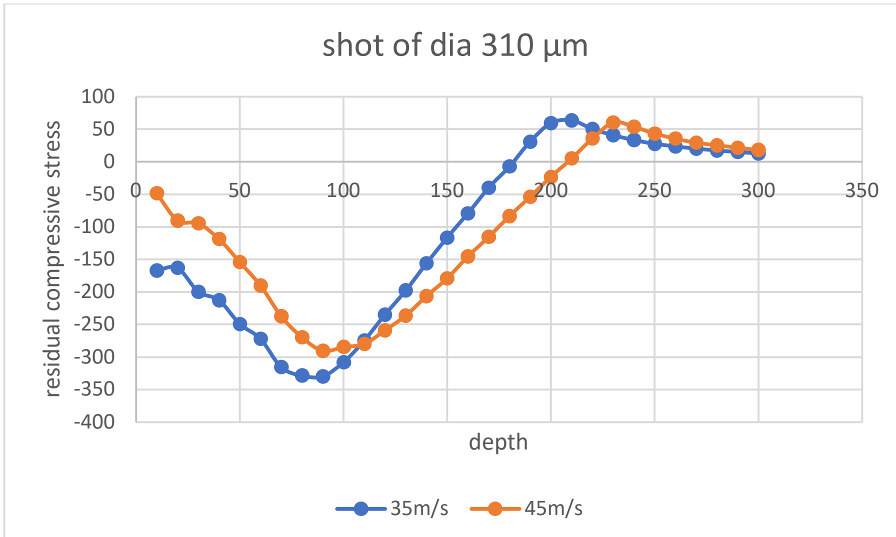

Figure 4. 9 Velocity comparison for diameter of 310 µm

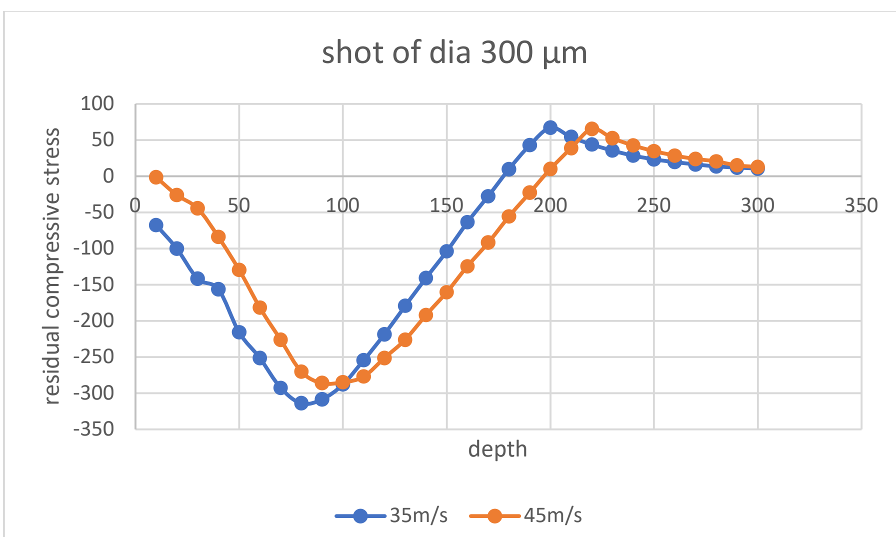

Figure 4. 10 Velocity comparison for diameter of 300 µm

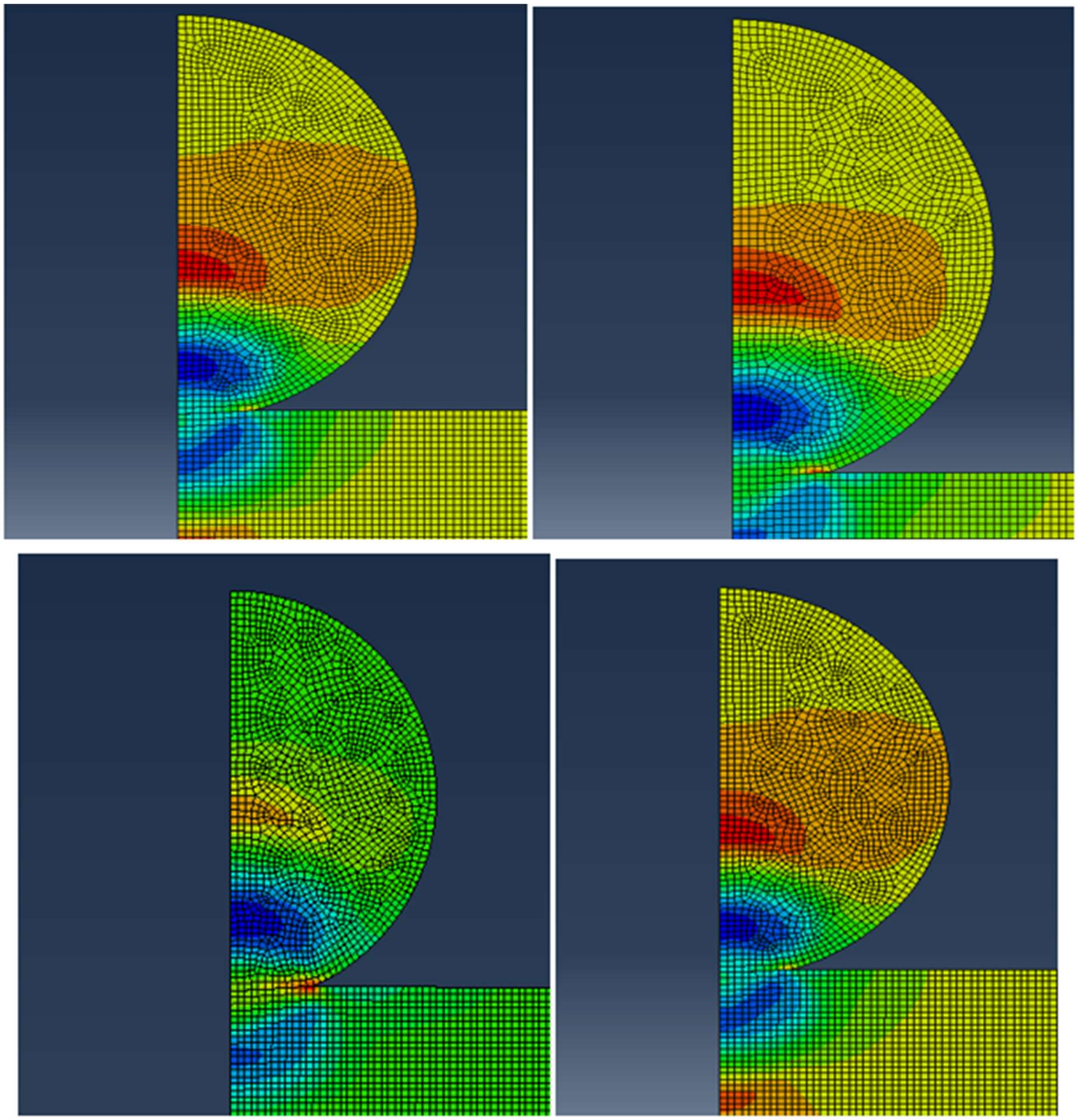

Figure 4. 11 Deformation of target material due to different velocities

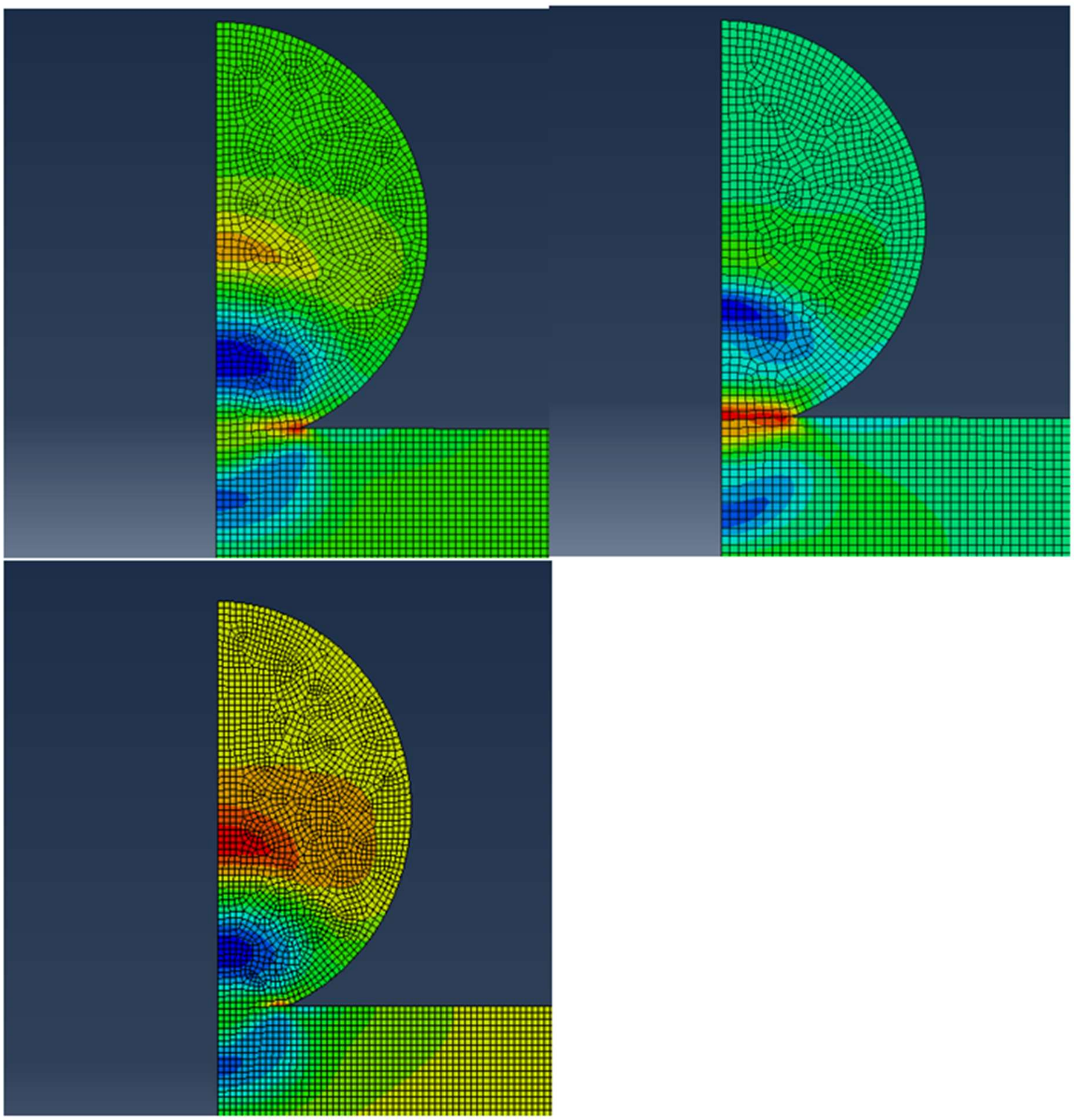

Figure 4. 12 Deformation of target material due to different shot sizes

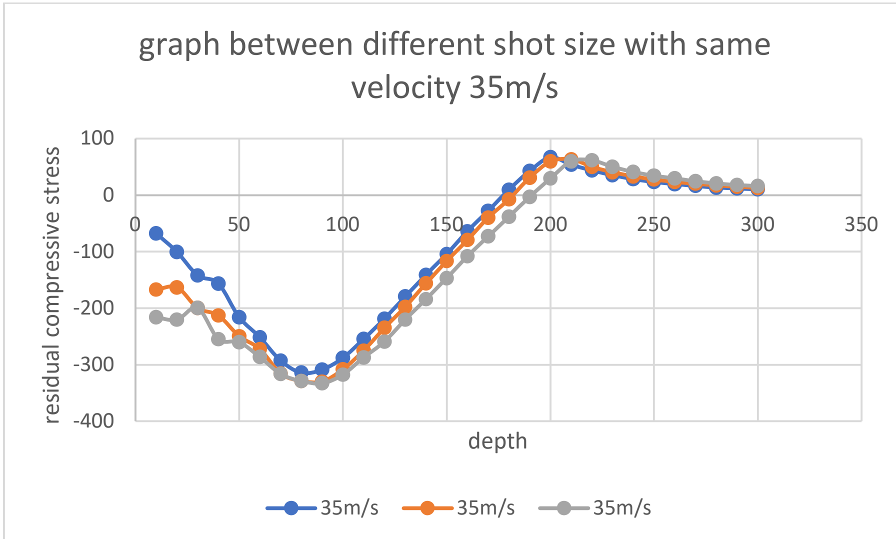

Figure 4. 13 Shot size comparison graph drawn by keeping velocity constant of 35m/s

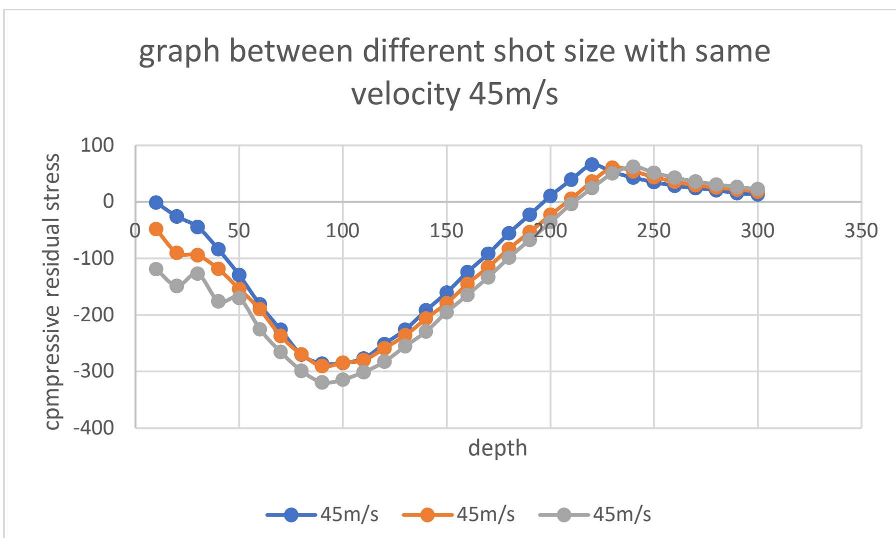

Figure 4. 14 Shot size comparison graph drawn by keeping velocity constant of 45m/s

CHAPTER 5 - CONCLUSIONS & FUTURE SCOPE

5.1 CONCLUSIONS

- The results of the simulation showed that an increase in shot velocity and shot size largely increases the magnitude and depth of the residual stress field created in the target materials.
- The penetration depth of compressive residual stress increases with an increase in shot velocity and shot size in both the target materials.
- Hardness of shot material is one of the important parameter we observed, by fixed the all parameters like target material, shot velocity & shot size, exceptthe shot material. The shot material of higher hardness given higher magnitude and depth of residual stress.
- The magnitude of surface compressive residual stress increases with an increase in shot size in both the target materials. Whereas shot velocity is not a significant parameter for surface compressive residual stress.
- Using Al_2O_3 as a shot material results in a faster rate of strain hardening of target materials when compared to steel shot. The overall depth of the compressive layer is greater when Al_2O_3 is used as a shot material comparedto steel.
- The generation maximum magnitude of compressive residual stress is a polynomial function of shot velocity. Where as it is a linear function of shot size.
- The present work also indicates that the proposed finite element analysis is useful for the investigation of the influence of various parameters on the shot peening process. This process can successfully be simulated by the finite element package ABAQUS.
- From the simulation values we can conclude that the shot material Aluminium oxide (Al_2O_3) gives the better residual compression stress value when compared to Cast Steel material.

5.2 FUTURE SCOPE

In this present work, effect of some shot peening process parameters on residual stress is inquired. The future research can try to find the effect of other shot peening process parameters like coefficient of friction between the shot and target material, attack angle, multiplicity of shot, etc.

There is no practical experiment work done in this thesis work. In the future research, several shoot peening experiments are highly required, and it is necessary to compare the simulation result with the experiment results to adjust the model setting, also adjust the coefficient of empirical equations.

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