Investigation of Structural and surface integrity requires understanding the effects of manufacturing and surface processes (e.g. machining, forming, shot peening, and laser-shock peening) on residual stress, surface roughness and cold work of the surface and subsurface layers of the processed material, including the effect of these alterations on the surface-related physical and mechanical properties. Anyone who is not closely familiar with the challenges of maintaining the safety and integrity of commercial, military, corporate and private aircrafts, may ask "What's Shot Peening?" This article is primarily targeted to delineate the role of shot-peening to induce residual stresses, which improves life of aircraft landing gear steels [1].

Shot Peening is a cold process which uses millions of tiny spheres of steel, glass or ceramic (in the order of over 0.5-1.5 mm in diameter) impacting on to the surface of metallic components. These spheres are propelled at about 50-70 m/s on to the surfaces of metal parts to permanently deform the surface, and create dimples (Fig. 1(a), and (b)). The multiple indentations subject the material subsurface and surface to plastic loading due to progressive shot effects. The outer layers are subjected to an in-plane stretch, whereas the elastic region surrounding the subsurface plastic-zone tries to retain its original shape during unloading [2]. However, continuity conditions between the elastic and the plastic zones do not allow for this to occur. Consequently, a compressive residual stress field is developed in the near-surface layer of the structural component, to maintain equilibrium in the peened component, a tensile residual stress field is developed through the depth of the component. This compressive residual stress induced by shot peening reduces the effective applied stresses of the component during application, resulting in delayed crack initiation and retarded crack propagation from the surface. Shot-peening is therefore an effective method widely used in the industry, which can considerably improve the fatigue strength and life of cyclically loaded metallic components by inducing compressive residual stress and work-hardening into the surface region [3].

There are a several parameters involved in shot peening which need to be regulated in order to tailor compressive residual stress distribution within the component. These parameters can be sorted into three groups relating to the shot, the workpiece and the process. In order to control the resulting residual stress pattern in a peened part, it would be highly desirable to determine quantitative relationships between these parameters and residual stress characteristics. The evaluations of the shot peening mechanism are largely based on experimental work that is very difficult, tedious, costly and time consuming. The availability of powerful finite element codes, such as ANSYS, LSDYNA, ABAQUS, etc. allow simulation of dynamic processes. Modelling and numerical simulations can also provide as insight into the spatial and temporal evolution of deformation and stresses during the impact of shot on the target material.

In the current article, we present how finite element analysis of ceramic shots impacting on metallic target plates can be used to understand the effect of shot velocity and shot size on the compressive residual stress. To carry out simulation of shot-peening process, explicit dynamics tools of Finite Element Package, ANSYS R19 has been used. The ANSYS explicit dynamics suite enables to capture the physics of short-duration events for products that undergo highly nonlinear, transient dynamic forces.

A 2-Dimensional (2D) axisymmetric Finite Element model with half symmetry is developed to simulate the perpendicular impact of a single elastic sphere on an elastic-plastic workpiece. The main model consists of two parts that involved a deformable 2D equivalent of a 40 mm thick and 100 mm wide plate (workpiece) made of AISI 4340 steel, and a ball made of Silicon Carbide ceramic. Figure 2 shows the 2D Finite element model that was used to simulate the single shot impact on the workpiece. The geometry of the workpiece is kept constant in all analysis. The boundary condition on the workpiece was bottom end fixed, and the far end was kept free. The contact surface of the workpiece was kept free. The meshing was done using four-node quadrilateral element. Very fine mesh size of 5 micron was used in the vicinity of contact between the ball and the workpiece to capture the nonlinear force displacement behaviour that is typical of a contact problem. The Johnson-Cook [4] material model was chosen as the constitutive model and the material model parameters of AISI 4340 steel already incorporated within ANSYS database were used to carry out the simulation.
The effects of key parameters, such as, shot velocity and shot size, on the mechanical response of the workpiece were examined. In all of these models the workpiece was assumed to be an elastic-plastic with isotropic hardening material. Unlike the experimental process, the results of the simulation are independent of distance between centre shot and workpiece surface. Therefore, this distance is assumed to be 1 mm for quick running of the model. The velocity of SiC shot is assumed to be in the vertical direction and applied to the body as an initial condition. All results were obtained from a variation of residual stress along the path that is created by selecting nodes along the central axis in target plate.

**Effect of shot velocity:** The single shot finite element analysis is performed to investigate the influence of shot velocity. Five different impact velocities were used with rigid shot with diameter \( D = 1 \) mm. Figure 3(a) shows the variation of residual stress along the depth after unloading, for the five impact speeds selected. Figure 3(a) shows that an increase in the velocity of shot results in an increase in magnitude of the maximum residual stress at lower velocities of impact, but the maximum residual stress for the three velocities 50 m/s, 60 m/s, and 70 m/s are very close to each other. However, an increase in the velocity of shot results in an increase in the depth of the compressive residual stress meaning more volume of material in the subsurface is subjected to compressive residual stress.

**Effect of shot size:** The effect of shot size (diameter of impacting sphere) on the residual stress distribution is shown in Fig. 3(b). The impact velocity of each shot media was kept constant at 50 m/s. An increase in the size of the shot media results in decrease in magnitude of the maximum compressive residual stress created in the target plate surface, and an increased depth of the compressed residual stress. Therefore, more volume of subsurface materials are subjected to compressive residual stress.

**Summary:** A 2D finite element dynamic analysis with consideration of the unloading effect was conducted to simulate the shot peening process and to predict the residual stress distribution within AISI 4340 steel. The effects of shot velocity, shot size upon the variation of residual stress after spring-back have been examined and discussed. The results reveal that increase in shot velocity largely increases the magnitude and depth of the residual stress field created in target plate. However, the increase in the shot size results in decreased magnitude of the residual stress field although the depth of maximum von Mises stress increases and the compressive stressed volume increases. 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 be simulated by finite element analysis and can be potentially adopted to design the shot-peening process parameters for achieving desired residual stress distribution within subsurface of aircraft components.

**References**


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