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Analysis of surface finish and residual stresses with shot peening on cylindrical specimens

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ABSTRACT

Machining of cylindrical metal pieces effects the surface parameters due totool and type of contact. Due to the surface contact of the tool with the work material, the surface texture may deteriorate depending on the machining parameters applied. In order obtain good surface finish, the tool and machining parameter are the major considerations. In this paper shot peening was considered to determine good surface finishing. Cylindrical rods of different materials were considered for obtaining good surface finishing using the shot peening process. The nozzle was turned to an angle of 10 degrees from the principal axis. The blast pressure was controlled to obtain required surface finish. The surface hardness obtained after shot peening was measured. The residual stresses induced from the depth of the surface are determined and compared for various peening pressures.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Materials, Processing & Characterization.

1. Introduction

The impinging of peens on the surface of work material with high pressure modifies the surface texture. In shot peening process the shots are blasted at a regulated pressure on the work material. The peens generate a micro dent on the work material. In-order to obtain a better surface finish technique the peens are continuously blasted. The peen stretches and compresses the surface layer to obtain good quality surface. Due to which residual stresses are induced on the surface of the work material. Fig. 1 shows the impact of peens which creates a dent on the surface of work materialFig. 2

The nozzle is tilted at an angle from the vertical axis to have more peen blast on the surface. During the operation, to avoid back pressure and blooming of the peens back to the nozzle, a defined distance is maintained between the nozzle and work material.

1.1. Surface roughness

For all engineering application good surface finish and grater dimensional accuracy is required. The imperfections and regularities are responsible for surface texture. The irregularities of the surface present in the form of hills and valleys with different height and spacing. Vibrations, material of the work piece, type of machining are the factors that are affecting the surface roughness. Surface texture is divided in to primary texture (roughness) and secondary texture (waviness). Fig. 3 shows the quantitative surface roughness measurement parameters.Fig. 4Fig. 5Fig. 6

Vibrations induced during machining which will affect the primary texture, deflections or deformation of work piece due to self-weight which will affect the secondary texture. For estimating surface roughness three qualitative methods are used that is peak to valley method (Rt), average roughness method (Ra), form factor method(K). Out of all three methods average roughness method (Ra) gives accurate results.

2. Literature review

To the improvement of surface finish of the machined work materials, different machining operations have been applied. The surface finish process improves the alignment in assembly of parts, temporary and permanent joints. Many researchers have worked on improving the surface roughness parameters of machined parts. They have varied the machining parameters, used different proportions of water and coolants to remove the heat from the work materials. Many of the investigations used by the researchers have been reviewed and their interpretations are discussed.

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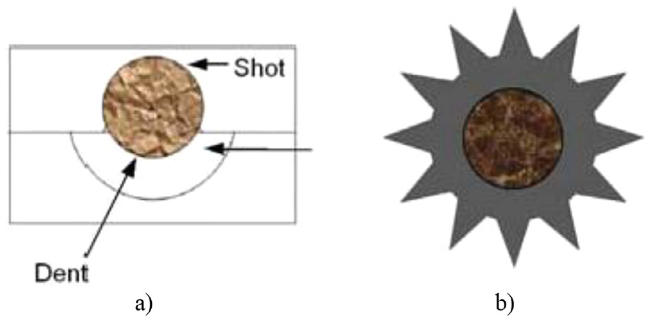

Fig. 1. a) Dent b) Impact of peens on the work material.

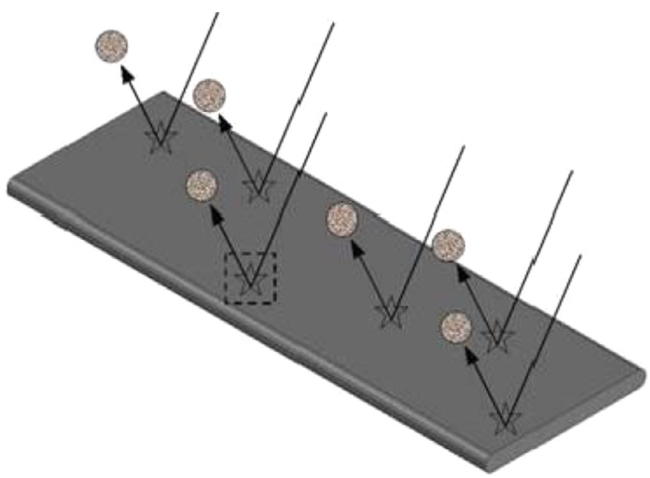

Fig. 2. Blooming of peens during shot peening process.

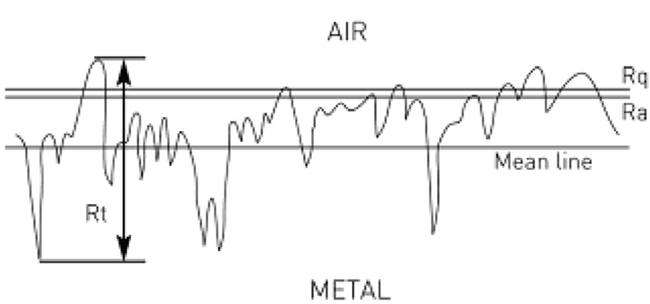

Fig. 3. Schematic diagram of surface roughness.

Initially machining and grinding process is used to reform the surface texture with good characteristics. Later abrasive particle was impinged on the surface without fluid medium, it was observed that surface texture changed due to impact of abrasives which raised the temperature of work materials. To avoid this rise in temperature, fluids were accompanied with abrasives to decrease the contact temperatures. The jet pressures of the fluids mixed with abrasives were varied to study on the surface characteristics off spring steels and titanium alloys [1].

Micro shot peening was done on metals to measure the surface texture characteristics, and effect of temperature due to the blasting of shots on to the metals like HSS and tool steels [2]. Crack growth behavior on boundary surfaces of steels was reduced due to the austenite grains [3]. Fatigue strength was improved by shot peening on spur gears with cavitations impact [4]. Due to this process the yield strength is moved to plastic state, by refining the surface finish [5]. Residual stresses were investigated during the process to enhance the fatigue life. This cavitations shot peening process induced residual stresses along the depth of the work material [6]. X-ray diffraction method was used for measuring the residual stresses induced due to cavitation peening with oil

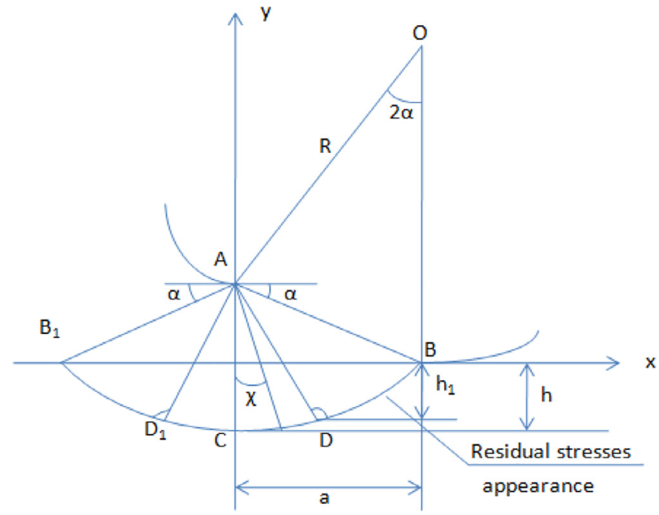

Fig. 4. Analysis of plastic zone.

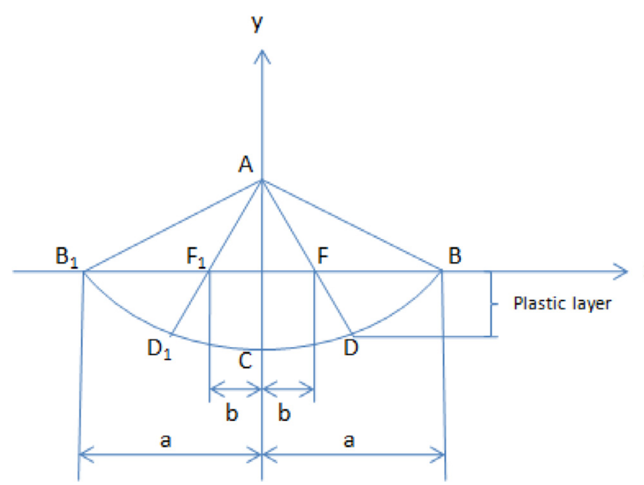

Fig. 5. Levelled plastic zone.

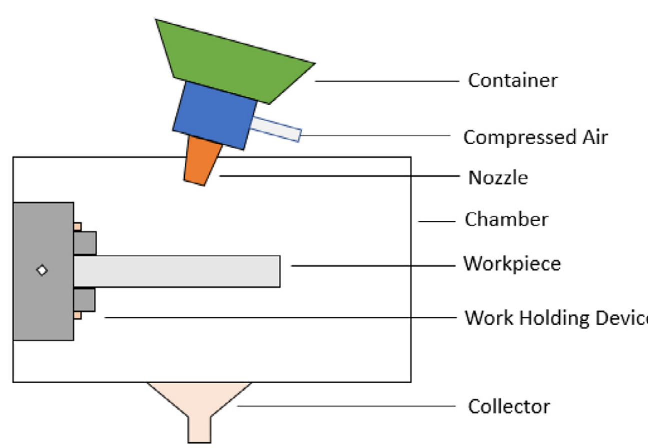

Fig. 6. Schematic illustration of Air type Shot peening experimental set up.

jet. In some researches peening nozzle velocity was varied to determine the stresses induced in the materials [7]. With the combination of ultrasonic frequency and shot peening the surface layer formation was measured and observed in microscopic level, that the peeks on the surface were reduced [8]. With this process large compressive stresses were observed in soft steel [9]. The surface hardness of the materials were measured with varying shot sizes and nozzle distances from the materials.

Some of the researchers worked on analysis of surface due to shot peening. Finite element method was use to analyze the surface characteristics after indentation [10]. It is observed that the residual stresses generated with shot peening process on the tension surface of Al 6063 work material improved the fatigue life and reduced the crack propagation [11]. To improve the fatigue life anodizing process was done on the peened materials. Due to this process the electrolyte reacted with the surface of work material leading to refinement of grain structure, chemical composition and surface characteristics [12]. Wear characteristics are investigated on carburized steel materials, by spraying molybdenum on the materials. The surface texture of these coated materials is studied using scanning electron microscopy after applying the surface finishing process. It is perceived that wear properties of these coated materials enhanced when compared to non-coated materials [13]. Optimization of the shot size has been done as it effected the residual stresses along the depth from the surface of the work materials. The shot size made a deep impact on the surface finish and residual stresses [14].

3. Methodology

In a stress system based on the loading the types of stresses are induced. In the present investigation the three dimensional stress system is considered. The resultant residual stresses are determined. The stresses along the depth of the work material from the surface are studied. Considering the impact of the dents on the work material, the blasting pressure creates a dent on the surface which induces residual stresses along the longitudinal and transverse direction. For the condition of lane strain, the shear stress corresponding to the principal axis are assumed to be zero ($\tau_{yz,}\tau_{zx} = 0$).

Rolling/sliding contacts transmit normal pressure and tangential stresses and transverse stresses. The residual stresses induced in the work material is determined from the following equations:

Dimensionless depth in longitudinal direction, $X = x/b$
b = Half Hertzian length
X' = dummy variable
Dimensionless depth in transverse direction, Y =(y/b).
y = depth in transverse direction
$\varnothing_p$ = contact pressure
F = contact force of shots
W = peen force
h = depth of dent

$$\phi_p = \frac{-b^2}{\pi}\int_{X_{\min}}^{X_{end}} P(X')(X-X')\tan^{-1}\left[\frac{X-X'}{Y}\right]dX'$$

$$\phi_p = \frac{-b^2}{\pi}Y\int_{X_{\min}}^{X_{end}} Q(X')\tan^{-1}\left[\frac{Y}{X-X'}\right]dX'$$

$$\sigma_x = \frac{1}{b^2}\frac{\partial^2\phi}{\partial^2 Y^2} = \frac{-2}{\Pi}\left\{\int_{X_{\min}}^{X_{end}}\frac{Y(X-X')^2}{\Lambda^4}P(X')dX' + \int_{X_{\min}}^{X_{end}}\frac{(X-X')^3}{\Lambda^4}Q(X')dX'\right\}$$

$$\sigma_y = \frac{1}{b^2}\frac{\partial^2\phi}{\partial X^2} = \frac{-2}{\Pi}\left\{\int_{X_{\min}}^{X_{end}}\frac{Y^3}{\Lambda^4}P(X')dX' + \int_{X_{\min}}^{X_{end}}\frac{(X-X')}{\Lambda^4}Q(X')dX'\right\}$$

$$Z = f(x,y) = a$$

$$z = \left(-2/\prod)((y^3/\Lambda^4\right)P(X') + y^2(x-x')/\Lambda^4)$$

$$\Lambda = \left[(X-X')^2 + Y^2\right]^{1/2s}$$

$$\tau_{xy}(X,0) = \frac{U}{H}\left(\frac{\Pi}{W}\right)^{3/2}\frac{\mu\bar{U}_d}{\sqrt{32}} - H\left(\frac{2W}{\Pi}\right)^{1/2}\frac{dP}{dX}$$

4. Experimental investigation

Investigations were done on different work materials, which were subjected to shot peening at a regulated blast pressures. The work materials were turned on CNC machines and the surface roughness was measured. During turning operation the machining parameters are similar for all the work materials. The shot peening process was done on machined work materials: mild steel, brass, copper and aluminium. The shot peen size used in this investigation has a diameter is 0.1 mm. Three peening pressures applied on the specimens are 0.139 MPa, 0.20684 MPa and 0.27579 MPa.

The shot peening parameters used in the experimental setup for the test specimens is shown in Table 1.

5. Results & discussion

The specimen's surface roughness was measured after CNC turning. To improve the surface finish, shot peening was performed on the specimens by different peening pressures. Later the surface finish is measured and plotted for comparison. From the plots it is observed that the surface finish improved with increase in peening pressure and after peening pressure of 0.207 Mpa, the surface finish deteriorated slowly. The peening pressure 0.0207 MPa was optimum to improve the surface finish of specimens when compared with other peening pressures. The surface finish of the specimens are shown in Fig. 7.The surface finish of aluminium specimens improved by 80.51%, copper specimens improved by 59.1%, brass specimens improved by 67.32% and mild steel specimens by 64.27%.

The residual compressive stress induced by surface finishing processes is of primary practical importance. Due to these compressive stresses, which offsets the applied tensile stresses, gives rise to improved performance in fatigue and stress corrosion situations. The variations of residual stresses for different peening pressures on the specimens have been plotted and compared. The shot peening has induced an increase in residual stress along the depth of the specimen from the surface layer to a certain depth. This variation of compressive residual stress is observed due to the reduction in relative plastic deformation from the peened surface.

Table 1
Shot peening parameters.

Details	Parameters
Shot size diameter	0.1 mm
Shot material	Cast steel MI-70H
Hardness of shot material	55HRC
Air Pressure	0.2 MPa
Standoff distance	120 mm
Shot specific gravity	7.8
Peening pressure	0.138, 0.207, 0.276 MPa

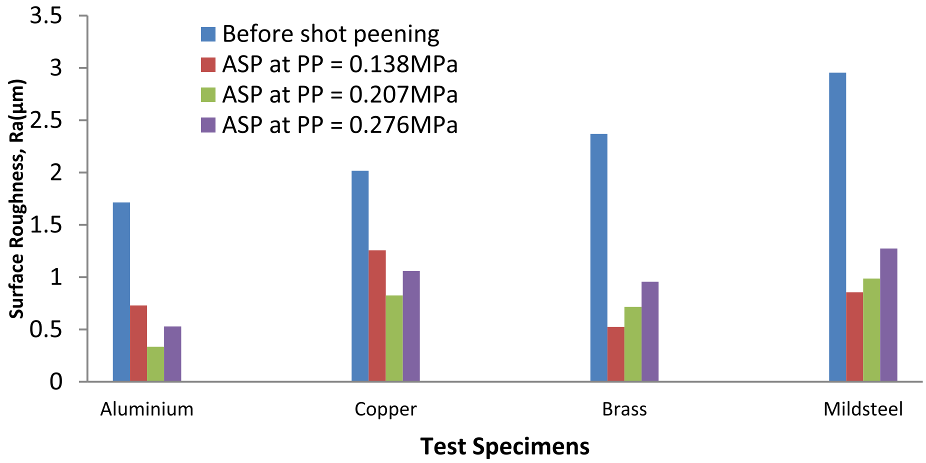

Fig. 7. Variation of surface roughness on test specimen before and after shot peening.

The nucleation takes place to support the compressive residual stresses along the depth. This compressive residual stress creates a tensile stress along the longitudinal direction, due to which the compressive stresses increased to a certain depth until the layer of tensile nature is reached. Later it was decreased and tensile stress was observed in the adjacent layers along the depth. This behavior of the peened material increases the fatigue nature of the materials.

The variations of residual stresses for aluminium specimens with different peening pressures are shown in Fig. 8. The residual compressive stresses are less on the surface for peening pressure 0.207 MPa. The stresses have increased upto a depth of 0.003 m. A maximum stress was observed at due to 0.1389 MPa. These stresses are found to decrease to a depth of 0.006 m from the peened surface.

The residual compressive stresses for copper are less on the surface for peening pressure 0.207 MPa. The stresses have increased upto a depth of 0.003 m is shown in Fig. 9. A maximum stress was observed at due to 0.1389 MPa. These stresses are found to decrease to a depth of 0.005 m from the peened surface. At the depth of 0.002 m from the surface of the specimen compressive residual stresses are of same magnitude. The trend of stresses followed same for peening pressure 0.1379 MPa and 0.20684 MPa until 0.003 m depth.Fig. 10

The residual compressive stresses for brass are less on the surface for peening pressure 0.207 MPa. The stresses have increased upto a depth of 0.003 m. A maximum stress was observed at due to 0.1389 MPa. These stresses are found to decrease to a depth of

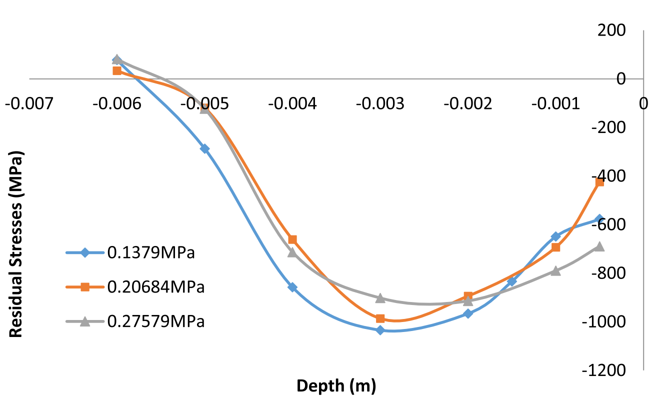

Fig. 8. Residual stress profile for aluminium specimens at different peening pressures.

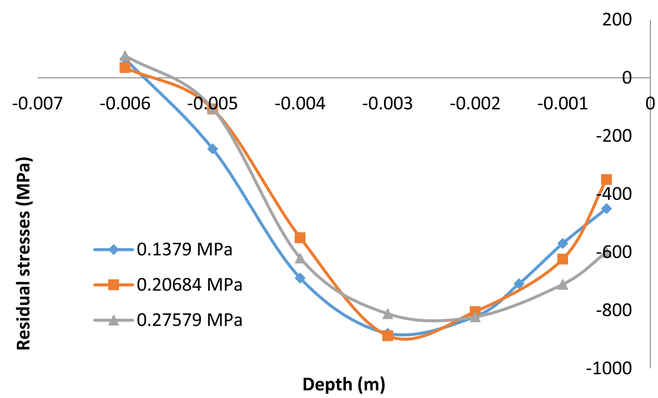

Fig. 9. Residual stress for copper specimens at different peening pressures.

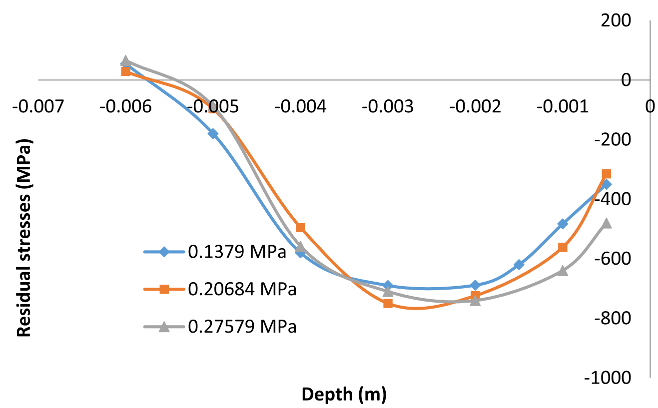

Fig. 10. Residual stress for brass specimens at different peening pressures.

0.005 m from the peened surface. At the depth of 0.003 m from the surface of the specimen compressive residual stresses are of same magnitude. The trend of stresses followed same for peening pressure 0.1379 MPa and 0.20684 MPa, 0.2768 MPa at only 0.003 m depth. The trend of stresses followed differently for other depths.

The residual compressive stresses are less on the surface for peening pressure 0.207 MPa. The stresses have increased upto a depth of 0.003 m as shown in Fig. 11. A maximum stress was observed at due to 0.1389 MPa. These stresses are found to decrease to a depth of 0.005 m from the peened surface. At a depth

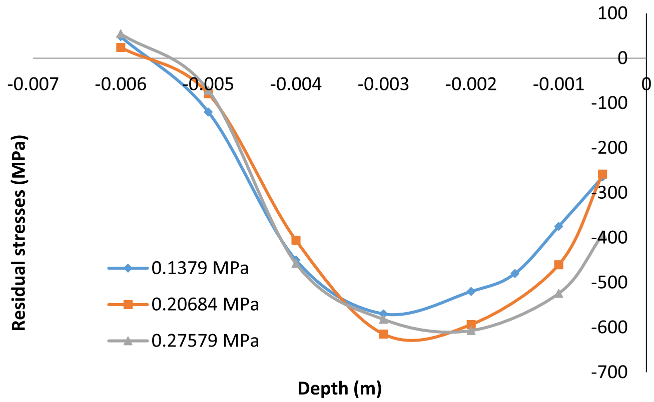

Fig.11. Residual stress for mild steel specimens at different peening pressures.

of 0.004 m from the surface of the specimen residual stresses are of same magnitude. The trend of stresses was same for only peening pressure 0.20684 MPa and 0.27579 MPa from 0.003 m to 0.006 m depth from the surface of the specimen.

Residual stresses, surface roughness and work hardening are identified as the main changes induced in the surface layer of the material due to surface finishing processes. The sub surface residual stresses distribution has been determined for the test specimens across the depth. Maximum stresses were found at contact of shot peens. It is observed that maximum stresses are induced. The residual stresses are low on the peened surface layer due to plastic deformation. The resistance of the surface layer is increased along the depth due to the compression of one layer over the other.

It is observed that maximum stresses are induced at the surface which leads to bending. The residual stresses are due to yielding. The stress profiles along the depth of the material are plotted when the materials were subjected to different peening pressures. The impact of the shots creates a temperature difference, which is later reduced due to the air.

6. Conclusions

The shot peening was done on the cylindrical specimens with different peening pressures. The surface finish obtained for peening pressure 0.207 MPa was observed to be the best parameter for surface finishing process. The micro valleys on the surface have been decreased due to the yielding. Dislocations level has been decreased for a maximum extent. Work hardening was low due to the impact of residual stresses on the surface of the specimens. The residual stresses were minimum on the surface layer in test specimens due to plastic deformation and were maximum at depth of 0.003 m from the surface of the test specimen. The residual stresses were maximum for a peening a pressure of 0.20684 MPa. The aluminium test specimens were subjected to maximum residual stresses of 1034.4954 MPa when compared with remaining material test specimens.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential completing interests:

We the authors of this paper have collaboratively worked in writing the paper. Each author has given their best to complete the paper. We would like to thank the management of Malla Reddy Engineering College (A), for providing us the resources in this work.

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