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Research Article

EVALUATION OF THE EFFECTIVENESS OF THE SHOT PEENING PROCESS FOR THIN-WALLED PARTS BASED ON THE DIAMETER OF IMPRESSIONS PRODUCED BY THE IMPACT OF SHOT MEDIA

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ABSTRACT
The paper presents the results of studies on the effectiveness of the shot peening process for thin-walled parts based on the diameter of impressions produced by the impact of shot media. It is also described the current applications of this treatment for the thin-walled parts. The authors described an innovative measuring device which was used in the research. The material used in the studies was non-alloy steel C45. The relationships between beads diameter and thickness of workpieces on diameter of impression were presented.

Keywords: shot peening, thin walled parts, metal treatment.

INTRODUCTION

Shot peening has been widely used in the engineering industry for almost one hundred years. The process has been partially normalized and is fully automated. Current research on the process involves examining the influence of various technological parameters on stress and deformation as well as surface layer properties of a workpiece. The aim of further research is to determine the relationships between conditions of the shot peening process and the material, geometry and rigidity of parts treated by shot peening [1].

The shot peening process is basically characterized by three categories of variables [2]. The first one is the intensity of treatment. This parameter determines the amount of energy of shot media (e.g. beads or pellets). The second parameter is saturation, or the increase in compressive stresses in the surface layer as a function of time of treatment. The final variable is the degree of coverage, that is, the percentage of surface which underwent the actual elastic-plastic deformation during processing [2].

An interesting group of structures are thin-walled workpieces, where the relationships between treatment-induced stresses and strains and the parameters of this treatment are non-linear. This results from lower weight of produced parts, which entails their reduced wall thickness. Although construction elements produced thereby are lighter and cheaper, their rigidity and fatigue strength are lower. This problem can be solved by the application of shot peening as finishing, which will improve some properties of the surface layer of such parts [3].

To better illustrate the problem of rigidity and strength, it is worth mentioning cases where the application of shot peening leads to a significant improvement of fatigue life of parts. A classic example is that of a low-pressure steam turbine rotor (Fig. 1a). The rotor is rotating with a velocity of about 3000 rev/min, the paddle extends due to the action of the centrifugal force and high temperature. This leads to the occurrence of tensile stresses and vibrations in the region of blade-rotor connection as well as hydrogen embrittlement on the face of the blade. A negative consequence of this are frequent and very costly breakdowns of steam turbines in thermal power plants. By treating the blades and rotor disc surfaces with shot peening, stream turbine failures can be eliminated [4].

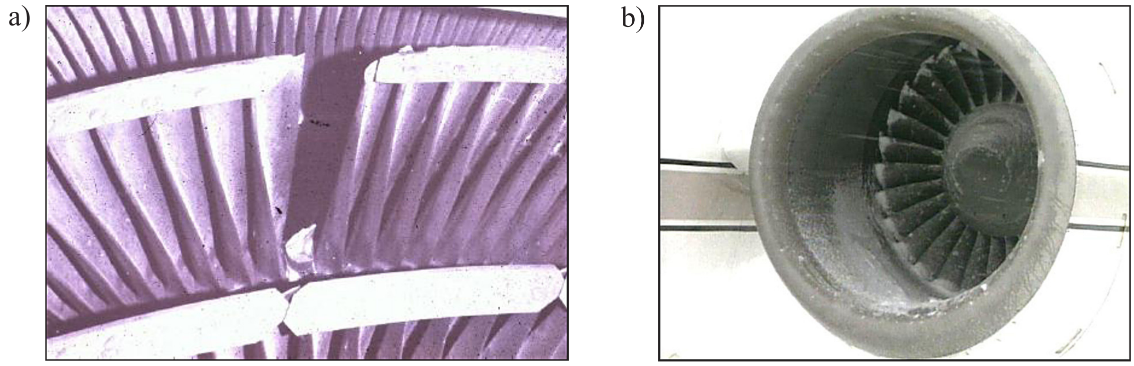


Fig. 1. Blade failure in: a) stream turbine in a steam power plant [4], b) axial compressor of an aircraft jet engine [5]

Compressor rotors in aircraft jet engines are critical for both engine efficiency and flight safety. Many tragic accidents in aviation history resulted from the damage of a single blade of the axial compressor rotor. Given that, the rotational speed of the compressor reaches up to 20 thousand rev/min, even the slightest rotor dynamics imbalance leads to higher vibrations and rapid damage of the jet engine. The blades can be damaged due to their additional extension and friction against the housing or due to the impact of a foreign body, e.g. chunks of ice from the wing. The shot peening technique is widely used to improve tensile strength and flexural strength of rotating components of an axial compressor, which, in turn, improves the fatigue life of blades and their resistance to catastrophic damage [6].

Over the past two decades the German company KSA GmbH developed and implemented a large-scale automated shot peening technology at the Airbus factory. The method describes upon a phenomenon of controlled plastic deformation of material due to a concentrated impact of a steel bead shot. Low intensity treatment leads to production of convex surfaces, while high-intensity shot peening produces concave surfaces (Fig. 2a) [7]. The process can also be run on both sides simultaneously to produce cylindrical cones from a metal plate disc. This is done by the application of 6 mm diameter beads to treat the inner surface of the work piece, 4mm diameter beads to its outer surface, and a lower intensity shot flow. The above forming method can be used to produce properly corrugated plating for aircraft and space shuttles, which previously required manual adjustment [7].

In the pneumatic conveying of polymer pellets in the chemical industry, pipe conveyors would often fail, as their temperature is greatly increased due to prolonged friction of the medium being conveyed against smooth walls of the pipeline. The increase in the pipe wall temperature caused local plasticization of the pellets, which, in turn, led to conveyor congestion and halt of the conveying process. The application of intensive shot peening to the internal surfaces of pipes caused their roughness and surface layer hardness to increase significantly. The increase in their surface roughness led to a decrease in the temperature of the pipeline walls, while the significant increase in hardness contributed to reduced consumption of the conveyor surface [9].

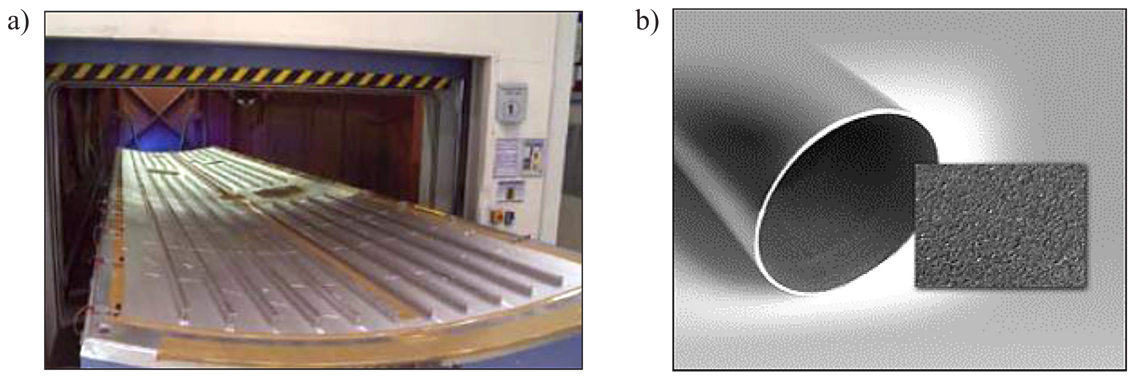


Fig. 2. Shot peening of thin metal sheets: a) aircraft plating [8], b) cylindrical inner surface of a pipeline / transporter [9]

An analysis of the literature reveals that shot peening has a variety of applications in many sectors of industry. An important issue regarding the selection of machining parameters is the assessment of shot peening effectiveness.

Previous studies on shot peening effectiveness did not take into account the fact that thin-walled materials undergo elastic deformation due to the impact of shot media. This phenomenon has a significant influence on effectiveness of the shot peening technique and should, therefore, be taken into consideration at the stage of selecting machining parameters.

The purpose of this study was to determine the effect of workpiece thickness on the diameter of an impression formed by the shot media. The observed variation in the diameter impression is regarded as a measure of shot peening effectiveness.

RESEARCH METHODOLOGY

The aim of the study involved determining the effect of workpiece thickness, shot media diameter and the distance from the point of workpiece fixing on the effectiveness of the shot peening process, reflected in the diameter of the impression formed on the workpiece surface due to the impact of shot media (Fig. 3). The preliminary examination involved determination of a range of the tested parameters, i.a. three diameters D of the bearing beads applied, five thicknesses g of the test samples with the dimensions of 90 mm × 15 mm × *g*, and five distances *L* from the point of workpiece fixing.

The fixed parameters of the experiment included the type of workpiece material (C45 non-alloy steel), surface roughness (after grinding and manual lapping) in the range of Ra = 0.32÷0.63 μm, shot working pressure of 0.3 MPa and bead impact path set to 260 mm. At constant pressure, the shot medium velocity varied from about 4 m/s for 4.00 mm diameter beads to about 6 m/s for 5.50 mm diameter beads. For the beads with a diameter of 4.00 mm, a loss of compressed air occurred at the walls of the measuring tunnel due to a relatively considerable difference between the cross-sectional areas of the beads and the channel. For beads with a diameter of 5.50 mm, this difference was substantially lower. Hence, the velocity of the shot medium increased with an increase in its diameter.

The experiment was planned using a monoselective test method to investigate the influence of kinetic energy of beads with a diameter *D* (4.00 mm, 5.00 mm and 5.50 mm, respectively), for samples with a thickness *g* (0.50 mm, 1.00 mm, 1.50 mm, 2.00 mm, 3.00 mm) and a distance *L* from the point of workpiece fixing (10 mm, 20 mm, 30 mm, 40 mm, 50 mm) on the diameter of produced impressions. Using the combination D×*g*×*L*, we obtained 75 measuring points. The measurements were repeated five times at each point. Mean values and standard deviations were calculated. The results were put to statistical and multivariate linear regression analysis. The validation test demonstrated that the test stand had appropriate measurement accuracy.

The measurements were performed on the test stand for making impressions (Fig. 4). It consisted of a measuring system (2), a compressor (1) and an electronic control system (5). The components were fixed to the base (2) of the stand. Inside the rack (14) there was a square section hollow tunnel and a decompression slot. The upper part of the rack was provided with two sensors (13) for measuring the time of bead travel between the sensors. The upper part of the test stand comprised a stage (12) with a special clamp (10). The clamp made the workpiece (11) rigidly secured, so as to allow the beads to impact the workpiece surface at varying distances from the point of its fixing. Between the workpiece and the stage there was a small air space which enabled free deflection of the workpiece due to the shot medium impact.

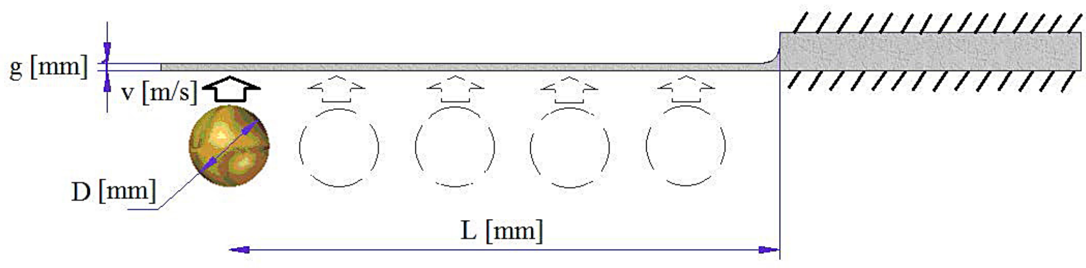


Fig. 3. Test parameters for a workpiece with thickness *g*

A ball bearing bead (4), also called shot medium, gains a set airspeed in the wind tunnel of the rack (14) by a dose of compressed air. Compressed air with a pressure of 0.3 MPa is located in the cylinder (3). The compressed air is produced by a compressor (1) equipped with an indicator gauge (15). When pressed, the trigger (8) opens the solenoid valve (9) which conveys a dose of compressed air from the cylinder (3) into the wind tunnel of the rack (14), setting the bead (4) to the initial velocity *v*. The digital signal from the sensors (13) is transmitted over the wires (7) directly to the electronic control system (5) where two travel times of the shot medium (4) are conditioned and then displayed on the display (6). The design of the experimental test stand is claimed in patent application no. P.408630, which relates to assessing efficiency of the shot peening process for thin-walled parts based on the diameter of the produced impressions.

The diameters of the impressions on the workpiece surface were measured using a toolroom microscope. Figure 5 shows the relationship between impression diameter and workpiece thickness, with the shot medium diameter and distance from the point of fixing maintained constant. The image is magnified ten times.

RESULTS AND ANALYSIS

It has been found that there is a strong correlation between the thickness *g* of the workpiece and the diameter *d* of the impression produced by the shot medium with the known diameter *D* and the velocity *v* (Fig. 5). The shot peening efficiency increases with an increase in the transverse dimension of the workpiece; for thicker samples, however, the relationship $d = f(g)$ is less evident (Fig. 6). This can result from insufficient rigidity

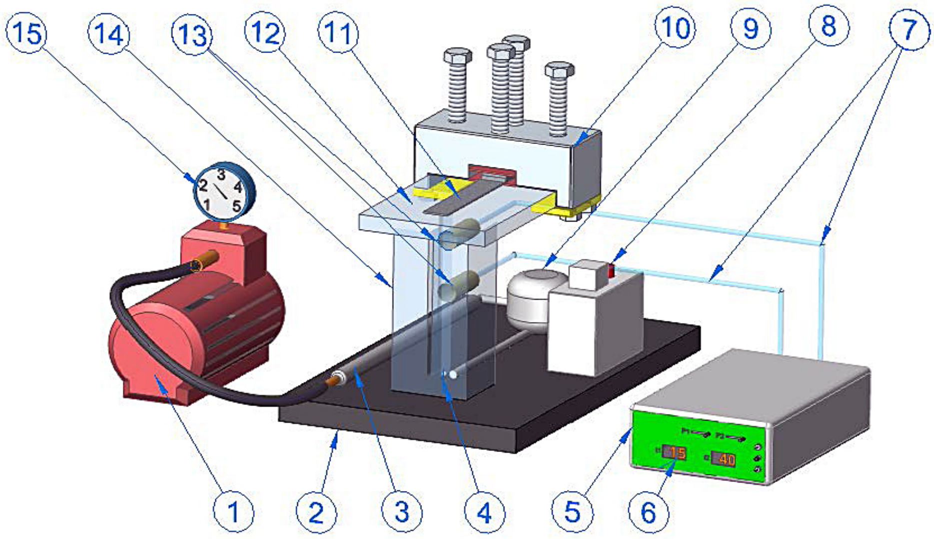
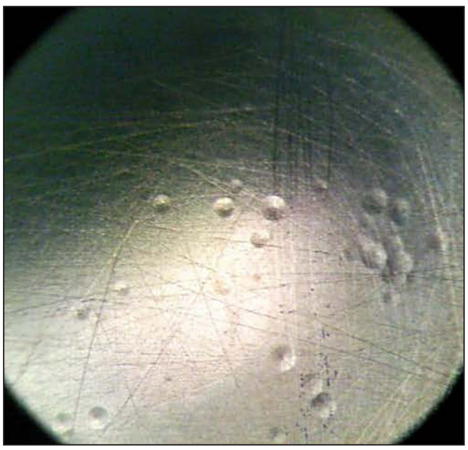


Fig. 4. Test stand for assessing effectiveness of the shot peening process (described in the text)

a)



b)

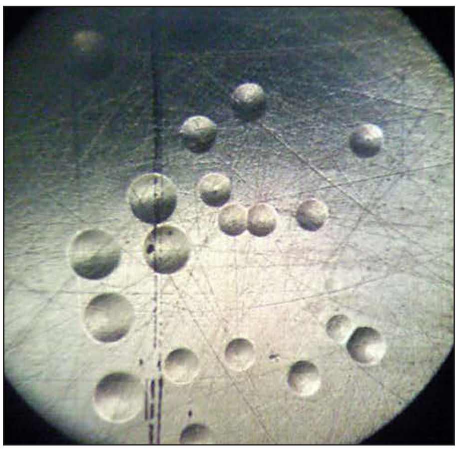


Fig. 5. Impressions on the workpiece surface: a) workpiece thickness $g = 0.50$ mm, b) workpiece thickness $g = 3.00$ mm, magn. 10×

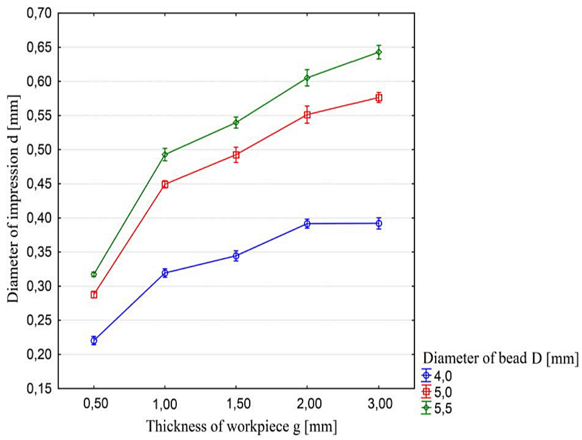


Fig. 6. Diameter of the resulting impression as a function of workpiece thickness for different bead diameters

of thin samples. Probably, due to the impact of the shot medium, a thin-walled sample (e.g. with a thickness g = 0.50 mm) undergoes a temporary deflection in the bead-workpiece contact area, which results in dispersion of the impact kinetic energy of the elastic deformation work. Consequently, the shot peening efficiency for thin samples can be more than half lower than for thicker samples. To produce strain on the surface of a thin-walled workpiece that is comparable to that of thicker samples, shot peening velocity must be significantly increased.

The results do not reveal the effect of the distance L from the point of workpiece fixing on the diameter d of the workpiece impression (Fig. 7). The higher the distance between the point of fixing and the impact point is (Fig. 3), there is no observable reduction in the diameter of the impression which would indicate a decrease in the efficiency of the shot peening process. What can be observed, however, are small deviations from the mean diameter of the impressions at the distance L = 30 mm from the point of workpiece fixing; these deviations can be observed for different bead diameters. This can be attributed to the occurrence of mechanical vibrations which differ from those in other regions of the workpiece. It is recommended that additional tests be conducted to investigate this region.

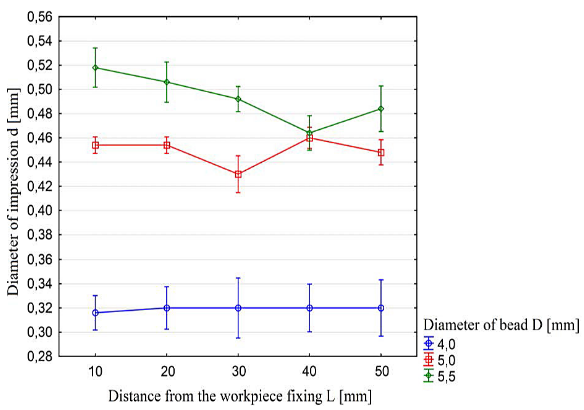


Fig. 7. Diameter of the resulting impression as a function of distance from the workpiece fixing for different bead diameters

As expected, there is a relationship between the diameter D of the shot medium (ball bearing beads) and the diameter d of the produced impression (Fig. 8). An increase in the diameter of the beads leads to an increase in the diameter of the impression. One can also observe that the relationship $d = f(D)$ no longer holds when higher diameter beads are used, despite the described increase in velocity. It can be claimed that with the increase in the bead diameter, the contact surface at the point of impact increases, but the impact depth decreases.

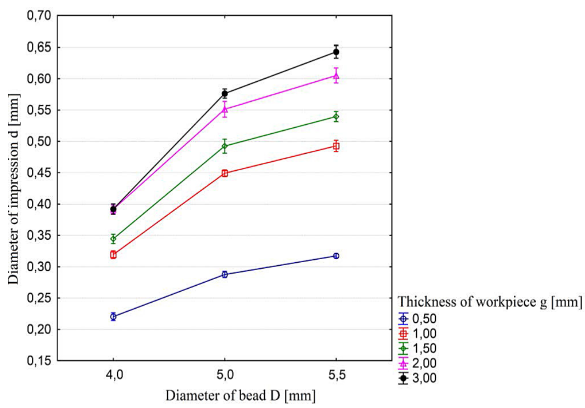


Fig. 8. Diameter of the resulting impression as a function of bead diameter for different workpiece thicknesses

Figure 9 illustrates the influence of individual parameters on the efficiency of processing variables. The chart shows the interaction between the parameters used in the experiment and their varying effects on the diameter of produced impressions. The input parameters can be set in such a manner to produce the smallest (approx. 0.20 mm) diameter impression (e.g. when D = 4.00 mm, g = 0.50 mm, L = 30 mm). It is also possible to determine the local extreme of the maximum impression diameter, e.g. when D = 5.50 mm, g = 3.00 mm and L = 30 mm. When the parameters are set in this way, the impression diameter is about 0.63 mm, so it is three times higher than the one in the previously discussed case.

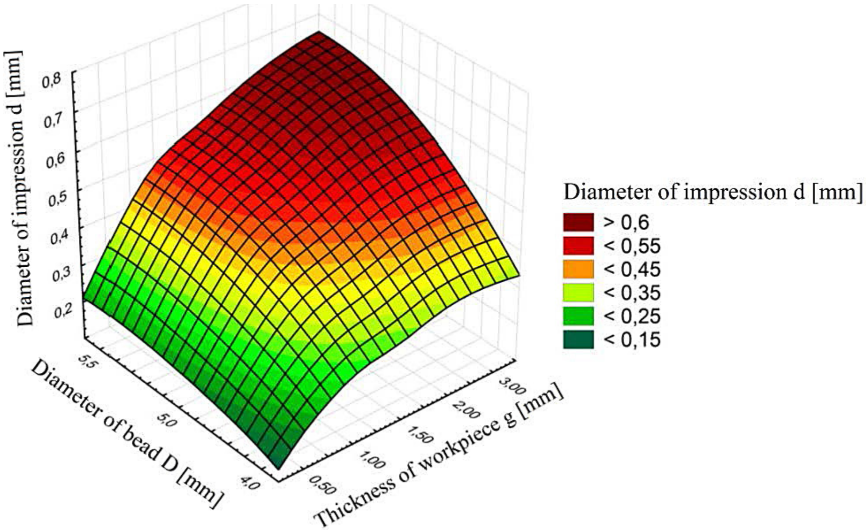


Fig. 9. Diameter of the resulting impression as a function of workpiece thickness and bead diameter

CONCLUSION

The experiment allowed us to determine the effect of selected geometric parameters on the effectiveness of the shot peening process for thin-walled parts. The process effectiveness was determined based on the diameter of produced impressions. As a result, the following conclusions have been drawn:

1. Workpiece thickness has the greatest effect on shot peening effectiveness. The smallest impressions were observed for the lowest thickness workpiece (g = 0.50 mm). It can be assumed that such parts should be subjected to more intense treatment to produce the effect obtained for thicker samples.
2. The distance from the point of workpiece fixing does not affect the effectiveness of the shot peening process as measured by the diameter of impressions produced by the shot medium.
3. The diameter of the shot medium affects the size of the resulting impression. The higher the diameter of the shot medium (beads) is, the higher is the diameter of produced impressions, and thus the higher is the effectiveness of the shot peening process.
4. Further studies should focus on identifying the form of workpiece mechanical vibrations induced by the shot medium. The use of a time-lapse camera in the impact area should provide interesting results in this regard.
5. The range of shot medium diameters applied in investigations should be higher: the diameters should be smaller than 4.5 mm and greater than 5.50 mm.

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