MODIFIED SHOT PEENING PROCESSES – A REVIEW

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ABSTRACT

Shot peening is widely used surface modification process to improve the surface characteristics such as hardness, fatigue strength etc. of metal components. But the basic shot peening process cannot be efficiently used for all the materials used for industrial applications. So, modifications in shot peening process are also going on, which can be applied for different material surfaces to improve the surface characteristics. Modified shot peening processes such as microshot peening, water jet peening, oil jet peening, cavitation shotless peening and ultrasonic peening have been successfully used for surface modifications. This paper elaborates the use of these different modified shot peening processes and demonstrates the results obtained by different research scholars on different materials.

KEYWORDS: *Surface modification, Cavitation shotless peening, Ultrasonic peening, Compressive residual stresses, shot media.*

I. INTRODUCTION

Shot peening is a cold working process used to produce a compressive residual stress layer and modify mechanical properties of metals. It entails impacting a surface with shot (round metallic, glass or ceramic particles) with force sufficient to create plastic deformation. It is similar to sandblasting, except that it operates by the mechanism of plasticity rather than abrasion: each particle functions as a ball-peen hammer. In practice, this means that less material is removed by the process, and less dust created. Peening a surface spreads it plastically, causing changes in the mechanical properties of the surface. Shot peening is often called for in aircraft repairs to relieve tensile stresses built up in the grinding process and replace them with beneficial compressive stresses. Depending on the part geometry, part material, shot material, shot quality, shot intensity, shot coverage, shot peening can increase fatigue life from 0–1000%. Plastic deformation induces a residual compressive stress in a peened surface, along with tensile stress in the interior. The tensile stresses deep in the part are not as problematic as tensile stresses on the surface because cracks are less likely to start in the interior.

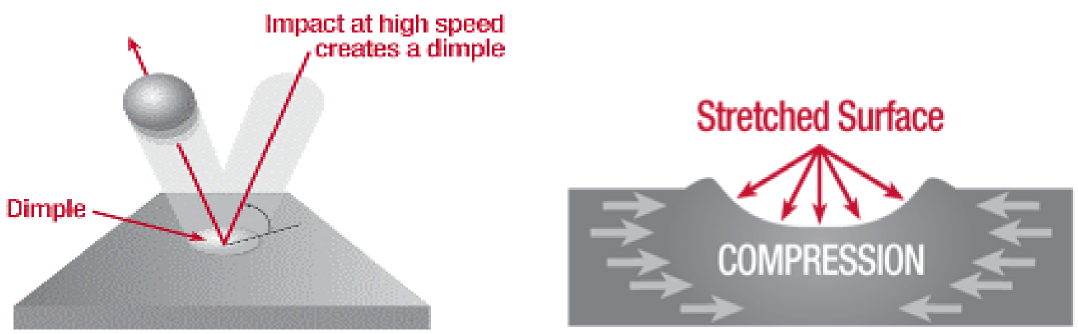

Figure 1. Mechanism of Shot Peening

In shot peening, small spherical media called shot bombard the surface of a part. During shot peening process, each piece of shot that strikes the material acts as a tiny peening hammer, imparting to the surface a small indentation or dimple. To create the dimple, the surface of the material must yield in tension. Below the surface, the material tries to restore its original shape, thereby producing below the dimple, a hemisphere of cold-worked material highly stressed in compression. Nearly all fatigue and stress corrosion failures originate at the surface of a part, but cracks will not initiate or propagate in a compressively stressed zone. Because the overlapping dimples from shot peening create a uniform layer of compressive stress at metal surfaces, shot peening provides considerable increases in part life.
The basic shot peening process principle is used by many research scholars to improve the surface characteristics. They have modified the process to enhance its capability to be used for different material surfaces.

II. CLASSIFICATION OF MODIFIED SHOT PEENING PROCESSES

A. Micro shot peening
B. Water jet peening
C. Oil jet peening
D. Cavitation shotless peening
E. Ultrasonic Peening

A. Micro shot peening

Micro shot peening is carried out using minimal spherical particle called fine-particle or micro shot. The sizes range from 0.03 to 0.5mm in diameter. Generally, the micro shots are made of high speed tool steel, cemented carbide, glassy alloy and ceramic, having high hardness. Gao Y. et al. [3] investigated Compressive Residual Stress Field (CRSF) introduced by shot peening in 40Cr steel. Shot peening was carried out on an air-blast machine with the cast steel shot with hardness of 50 to 60 HRC. Altogether, about 60 kinds of heat-treating and shot-peening conditions were included. The experimental results show that the maximum of compressive residual stress field for a given material is almost the same even under different shot peening techniques and the surface residual stress values are dependent on both the mechanical properties of target materials and peening parameters. Harada Y. et al. [8] investigated the influence of microshot peening on the surface layer characteristics of the structural steel. Fine-particles or microshots, which are smaller and harder than the conventional peening media, are used. They are made of cemented carbide or amorphous alloy having diameters in the range from 0.03 to 0.15 mm. Surface roughness, compressive residual stresses, hardness and wear resistance in the peened work pieces were measured. The effect of processing temperature on the surface layer characteristics was also examined. The use of hard microshot such as cemented carbide and amorphous alloy was found to cause a significantly enhanced peening effect for the structural steel. It was also found that the surface of the work piece peened by microshot was sufficient for wear resistance. Warm shot peening using microshots was also carried out to examine the influence of the processing temperature on the surface layer characteristics at different working temperatures. The optimum working temperature in the peened work piece of the spring steel was around 300 ◦C.

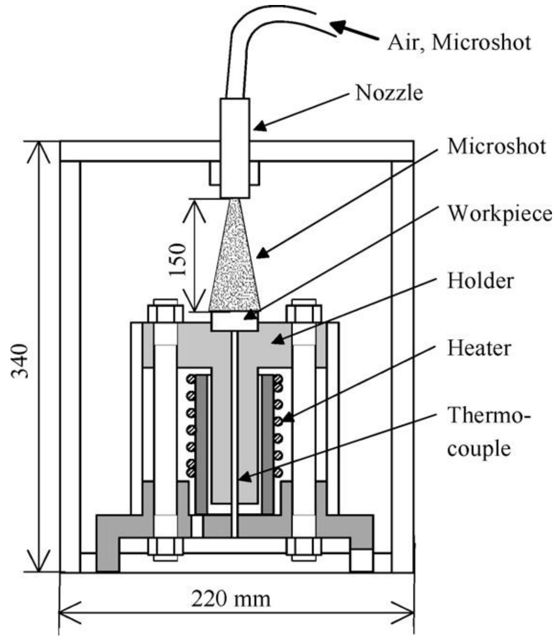

Figure 2. Schematic illustration of the air type shot peening.

Harada Y. et al. [13] investigated the effects of microshot peening on the surface characteristics of high-speed tool steel. New shot media made of cemented carbide have been developed to enhance the peening effect. New media is smaller and harder than the conventional one. A compressed air-type microshot peening apparatus with a heating furnace was produced experimentally. Surface roughness, compressive residual stress, and hardness of the peened work pieces were measured. X-ray diffraction method was used to obtain the distribution of compressive residual stresses. The effects of processing temperature on the surface characteristics and the effect of microshot peening on fatigue characteristic were also examined. The use of microshots in warm peening was found to cause a significantly enhanced peening effect for the high-speed tool steel.
Mahagaonkar S. B. et al. [15] used full factorial design of experiment (DOE) technique and an air blast type of shot peening machine to design the experiments. Effects of process parameters such as pressure, shot size, stand-off distance, and exposure time on surface micro hardness for AISI 1045 and 316L materials were investigated. An ANOVA was carried out to identify the significant peening parameters. In the case of 316L material, the maximum surface hardness was found to be in the range of 450–824 Hv, whereas it was found to be in the range of 314–360 Hv for AISI 1045. A critical assessment was made so as to understand the variation of micro hardness in the direction of peening. It was found that the process parameters that have influence on surface hardness of AISI 1045 in decreasing order of significance are: exposure time, nozzle distance, shot size, and pressure. For 316L material, the order of significance is: nozzle distance, shot size, exposure time, and pressure. Empirical equations between the peening parameters and the surface micro hardness for both materials were developed, which are useful in predicting the surface micro hardness.

B. Water jet peening

In water jet peening, high velocity water droplets continuously impinge over the surface. These droplets produce high peak loads that can cause localized plastic deformation of material and stretching of the layers of the surface. Upon unloading, the elastically stressed sub surface layers tend to recover to original state, but the continuity of material in both elastic and plastic zones does not permit this to happen. Water jet peening results in the formation of compressive residual stress on the surface layers without modifying the surface topography. Rajesh N. et al. [4] proposed a novel approach for predicting residual stresses induced on materials treated with high pressure water jets, i.e. water jet peening. It makes use of Reichardt's theory for predicting the velocity distribution of droplets and liquid impact theory for predicting the impact pressure and duration of impact of high velocity droplets. For predicting residual stresses, transient dynamic finite element analysis is considered for the material treated with high velocity water droplets. Impact nature of droplets was simulated by applying impact pressures over a very short duration, estimated using Reichardt's theory and liquid impact theory.

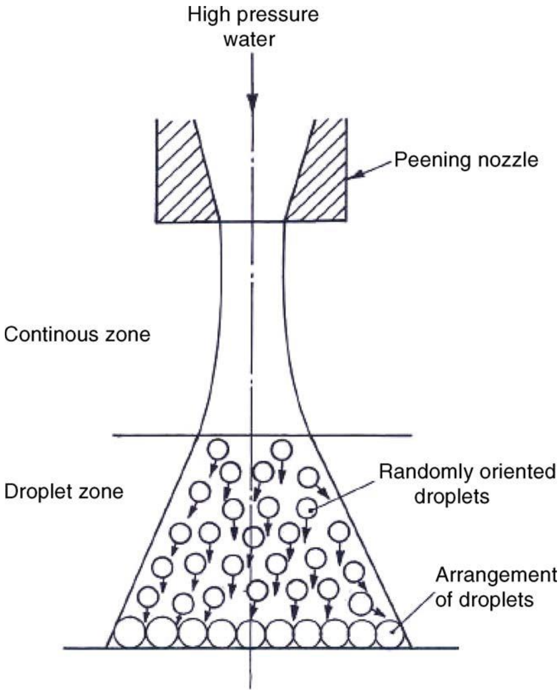

Figure 3. A schematic diagram showing an impact of single set of droplets on the material surface.

The proposed model is found to predict the surface stresses to an accuracy of 10%. The magnitude of compressive stresses induced with stationary pressure is slightly higher than that induced with impact pressure. But, the extent over which the compressive stresses are induced with stationary pressure is less. In contrast to this, the application of impact pressures due to droplets induced compressive stresses over a larger region thus indicating the suitability of proposed approach for accurate prediction of the region of coverage and the magnitude of residual stresses on water peened surface. Finally, the practical relevance of the proposed approach was shown by comparing the predicted results with the experimental results obtained by water peening of 6063-T6 aluminium alloy.

Sadasivama B. et al. [16] studied the influence of Abrasive water jet peening (AWJP) with elastic prestress on the surface and subsurface residual stress distributions and surface texture of spring steel(ASTM228) as well as titanium(Ti6Al4V) and nickel (inconel 718) . A design of experiments (DOE) and an analysis of variance (ANOVA) were used to identify the parameters with primary contributions to the dependent variables. . The results obtained from this study showed the following: (1) The average surface roughness (Ra) resulting from AWJP ranged from approximately 2.5 mm to nearly 15mm. The Ra increased with increasing jet pressure and abrasive particle size. There was no influence of prestress on the surface texture. (2) Compressive residual stresses resulted from all AWJP conditions was approximately 500 MPa. The magnitude of surface residual stress increased with an increase in abrasive particle size and elastic prestress. (3) The depth of compressive residual stress ranged from 80 to nearly 600 mm. The depth of compressive residual stress increased with an increase in abrasive particle size and jet pressure, but was not influenced significantly by the applied prestress. According to the results of this study, AWJP with elastic prestress can serve as a viable method of surface treatment in situations that require an increase in surface roughness and a compressive residual stress.

C. Oil jet peening

Oil jet peening is recently developed peening process to introduce compressive residual stresses without much change in the surface topography. Oil jet peening is similar with water jet peening but only difference is oil jet is used instead of water jet to improve the surface characteristics. Oil jet peening is carried out using hydraulic oil. At every oil drop of impingement, the pressure builds up within a few milliseconds and causes local plastic deformation at the impact spot. Grinspan A.S. and Gnanamoorthy R. [9] suggested a new surface modification process to introduce compressive residual stresses at the surface of components. In this process, instead of oil droplets a high velocity cavitation jet (cloud of oil bubbles) impinges on the surface of the component to be peened. The impact pressure generated during implosion of cavitation bubbles causes severe plastic deformation at the surface. Implosion of bubbles causes indentations on the surface. Consequently, beneficial compressive stresses are developed at the surface. Aluminium alloy AA6063-T6 specimens were peened at a constant cavitation number with various nozzle travelling velocities. Residual stress induced by oil jet cavitation peening was measured using X-ray diffraction. Oil cavitation jet peening results in a smooth and hard surface. The developed compressive residual stresses at the peened surface are about 52%, 42%, and 35% of yield strength in samples for peened at nozzle travelling velocities of 0.05 mm/ s, 0.10 mm/ s, and 0.15 mm/ s, respectively. Grinspan A.S. and Gnanamoorthy R. [10] used a high-pressure oil jet to impinge on the surface to be peened. Preliminary studies were carried out on the medium carbon steel at the oil pressure of 50 MPa. The compressive residual stress induced on the surface of unpeened and oil jet-peened AISI 1040 steel was 21 MPa and 200 MPa, respectively without changing the surface topography. The magnitude of compressive residual stresses induced depends on stand-off distance. The surface hardness was increased 10% compared to unpeened specimens. The surface roughness is not much affected by the peening process. Oil jet-peened specimens exhibited superior fatigue performance compared to the unpeened specimens. The improvement in the fatigue strength was 17%. The cracks mostly initiate at the surface of both unpeened and peened specimens. Oil jet peening delays crack initiation at all stress levels.

D. Cavitation shotless peening

In Cavitation peening, numerous impacts are induced on the surface by the cavitation of bubble collapse which produce compressive residual stress on the material surface in the same way as in shot peening. Peening by means of cavitation impact can peen the surface without the use of shot. Soyama H. et al. [1] studied the use of a cavitating jet to produce compressive residual stresses on stainless steel (JIS SUS304 and SUS316) and copper (JIS C1100). They concluded that it is necessary to measure the principal stress for the evaluation of the formation of compressive residual stress by using a cavitating jet. X-Ray diffraction method is used to measure the compressive residual stresses. Principal stresses become compressive stresses without any damage after short exposure time (10s) to the cavitating jet. An optimum time for the formation of compressive residual stress without damage has been revealed. The optimum processing time is about 1/25 to 1/5 of the incubation period for both stainless steel and copper. Considering the optimum cavitation number, a cavitating jet with a relatively low pressure such as 20 MPa can produce compressive residual stress on the surface even with stainless steel. The cavitation intensity of the cavitating jet does not matter for the value of the virgin residual stress on the material surface.

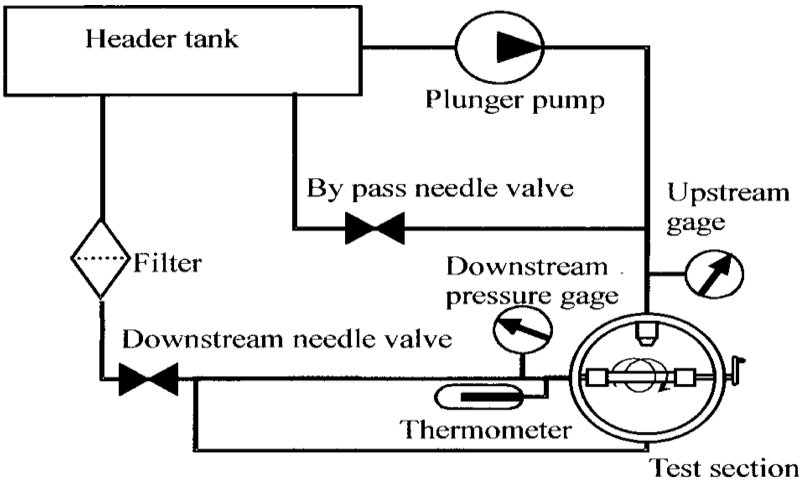

Figure 4. Cavitating jet apparatus for cavitation shotless peening

Soyama H. et al. [2] used Cavitation Shotless Peening to improve the fatigue strength of Aluminium Alloy (JIS AC4CH). Cavitation impact enables the surface of a material to be peened without the use of shot. . Cavitation impacts were produced and controlled by using a submerged high speed water jet with a cavitating jet. A rotating bending fatigue test was carried out using both non-peened and cavitation shotless peened specimens. It was concluded that the fatigue strength of aluminium alloy JIS AC4CH is 50% stronger than that of non peened specimen by using the cavitation shotless peening with a relatively low pressure such as that produced by a 30 MPa plunger pump. Cavitation shotless peening introduces compressive residual stress into the surface of aluminium alloy. Cavitation shotless peening produces various intensities of impact and pits of various sizes due to plastic deformation. It can be used as a peening method instead of single or multiple stage shot peening.

Soyama H. et al. [5] investigated Cavitation shotless peening (CSP) method to introduce compressive residual stress in titanium alloy, Ti–6Al–4V for the purpose of enhancing the conventional fatigue and fretting fatigue life and strength. In Cavitation shotless peening (CSP) impacts are generated by a submerged cavitating jet (without shots). This method provided higher compressive stress at surface as well as up to a depth of 40 μm from the surface than that with the shot peening method. Further, the surface treated by CSP was considerably less rough compared to that by the shot peening method, which is a highly desirable feature to improve the fretting fatigue performance. The magnitude and depth from the surface of the residual compressive residual stress, developed by CSP method, depends upon the processing time per unit length.

Soyama H. and Macodiyo D.O. [7] investigated the use of cavitation shotless peening(CSP) to improve the fatigue strength of a spur gear. In cavitation shotless peening (CSP), cavitation impacts induced by bubble collapse are used to peen the surface. In order to evaluate the improvement of the fatigue strength of a spur gear after CSP, rotating bending fatigue test of round bar was carried out on carburized chrome–molybdenum alloy steel (JIS SCM420), which is a representative material for gears. The bending fatigue testing of gear teeth was investigated. It was observed that fatigue strength of gear specimen treated by CSP improved by about 60% relative to that of non peened gear.

E. Ultrasonic shot peening

Ultrasonic shot peening (USP) is based on the vibration of spherical shot using high power ultrasound. Because of the high frequency of the system, the surface of the specimen to be treated is peened with a very high number of impacts over a short period of time. USP process can cause a compressive residual stress field on the surface of the ductile material. Such residual stress has significant influence on the mechanical behaviour of the material.

Xing Y.M. and Lub J. [6] studied Ultrasonic shot peening on soft steel to induce residual stresses. Here, Moiré interferometry, a high-resolution optical technique, is used to measure the residual stress. It proves to be relatively accurate technique for the measurement of the residual stress distribution. The experimental results show that ultrasonic shot peening can cause a large compressive residual stress of up to 309MPa on the material surface in soft steel. It can help to protect the cracks from initiating and propagation on the material surface so as to promote its mechanical properties.

Toh C.K. [11] investigated the possibility of inducing compressive residual stresses on machined surfaces by the use of ultrasonic cavitation, with the aim of reducing or eliminating burr formation. Experimental results are presented on the performance of ultrasonic cavitation peening on the residual stress in Stavax stainless steels and on micro-burr formation. Using ultrasonic cavitation peening, compressive residual stress regime was induced on the work piece subsurface, with the maximum magnitude being on the work piece surface. The immersion time has a greater effect on minimizing burr height formation at lower work piece hardness. At higher work piece hardness, a longer immersion time resulted in a lower micro-burr height formation. The use of a lower ultrasonic frequency has a greater effect on minimizing burr-height formation, regardless of work piece hardness and immersion time. The ultrasonic frequency of 40 kHz has the most significant effect in minimizing burr height formation. Mordyuk B.N. and Prokopenko G.I. [12] used the ultrasonic impact peening (UIP) technique to improve fatigue durability of metallic materials due to the surface nanocrystallization and hardening process. Plastic deformation of surface via multiple impacts of high velocity impact pins may produce a number of beneficial properties of surface layers in different metallic materials. They are the following: (i) nanocrystalline structure (in a layer at least of about 10 µm thick); (ii) surface compressive residual stresses (down to -700 and -1000MPa for AISI 321 stainless steel and a-titanium, respectively); (iii) work hardening of the surface layer (Hv up to 4.4 GPa and 691MPa for AISI 321 stainless steel and a-titanium, respectively). The two dimensional finite element model is used to simulate the indent formation process during single impaction. The solid steel pin and the Al alloy plate are modelled as a rigid material and an elasto-plastic material, respectively. The FE modelling based on the indentation of a rigid high-velocity pin impacting an elasto-plastic surface also shows that the thickness of the deformed layer depends on the pin lateral velocity. Thus, the FE modelling in the conjunction with the micro structural analysis results shows that the optimal pin lateral velocity can be chosen considering two competitive factors, namely the decreasing of the surface roughness and diminution of thickness of the nanocrystalline surface layer. At the same time, the higher the ‘‘sliding’’ velocity of pin the lower the indent depth and the thinner the hardened nanocrystalline surface layer. Moreover, the refinement of the surface structure down to nano-scale range may not be induced at all if the impacted energy of pins is not large enough due to excessively high lateral velocity.

Shiou F.J. and Ciou H.S. [14] proposed a vibration-assisted spherical polishing system driven by a piezoelectric actuator developed on a machining center to improve the burnished surface roughness of hardened STAVAX plastic mold stainless steel and to reduce the volumetric wear of the polishing ball. The optimal plane surface ball burnishing and vibration-assisted spherical polishing parameters of the specimens have been determined after conducting the Taguchi’s L9 and L18 matrix experiments, respectively. The surface roughness Ra = 0.10 µm, on average, of the burnished specimens can be improved to Ra = 0.036 µm (Rmax = 0.380 µm) using the optimal plane surface vibration assisted spherical polishing process. The improvement of volumetric wear of the polishing ball was about 72% using the vibration assisted polishing process compared with the non-vibrated polishing process. Applying the optimal plane surface ball burnishing and vibrated spherical polishing parameters sequentially to a fine-milled freeform surface carrier of an F-theta scan lens, the surface roughness of Ra = 0.045 µm on average, within the measuring range of 149 µm x 112 µm on the freeform surface, was obtainable.

III. CONCLUSION

1. Micro shot peening can be efficiently used for different types of steels such as structure steel, high speed tool steel etc. Considerable improvement in surface hardness, fatigue strength can be achieved by the processes. The effect and range of processing temperature can also be predicted.
2. Water jet peening can also be viable method to improve residual stresses on hard surfaces such as spring steel, titanium.
3. Oil jet peening does not improve the surface as finish to a much extent but can improve the compressive residual stresses in materials like medium carbon steel and aluminium alloy.

4. Cavitation peening is used successfully on hard materials like titanium alloy and chrome–molybdenum alloy steel. With cavitation impact, there is considerable improvement in residual stresses and fatigue strength of material surfaces.
5. Ultra sonic shot peening gives good results on soft materials. It reduces the probability of crack initiation and propagation on the material surface so as to promote its mechanical properties.

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