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Role of Process Parameters in Synthesis of Automated Shot Peening Mechanism

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Abstract

Shot peening is one of the applications of shot blasting for increasing the fatigue life of various components subject to fatigue stress. It is a cold working process used to produce a compressive residual stress layer in the work-partCritical process parameters should be taken into account for designing an automated mechanism for shot peening process Ranges of these critical parameters should be determined to design the mechanism. Critical parameters that can be used in synthesis of automated shot peening mechanism are highlighted in this paper. Degrees of freedom (DOF) requirements for the mechanism always depends on control of number of critical parameters during the process.

Keywords: *Shot peening parameters, fatigue life, shot peening intensity, automated mechanism.*

1. Introduction

Shot peening is one of the applications of shot blasting for increasing the fatigue life of various components subject to fatigue stress. It is a cold working process used to produce a compressive residual stress layer in the work-part. It also modifies mechanical properties of metals. 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 modern usage peening is applied by throwing tiny cast steel balls or "shot" at high velocity hence the term "shot peening". [1]

Actually the effect of peening was discovered centuries ago by sword smiths and black smiths who found the peening the surface of a sword or wagon spring would greatly increase its resistance to breaking when bent or loaded repeatedly. The reasons for this improvement were not then understood. The round knob of the "ball peen" hammer was the smith's tool for applying this process to cold (not hot) parts.

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 up to 1000%. Shot Peening allows metal parts to accept higher loads or to endure a longer fatigue life in service without failure. In usual applications shot peening can be done without changing the part design or its material.

T. Hong et al. [2] represents a computational modelling of the shot peening process, in which the finite element method was employed to study the elastic–plastic dynamic process of shots impacting on a metallic target and discrete element method was used to study multiple particles dynamics.

The depth of compressive residual stress zone increased linearly with the shot diameter increasing and the magnitude of surface residual stress remained almost constant with varying shot diameter. With increasing shot impact velocity, the maximum sub-surface residual stress and the depth of compressive residual stress zone increased significantly. Variation of surface residual stress, maximum sub-surface residual stress and depth of compressive residual stress zone with incident angle (alpha) is presented as shown in fig. 1.

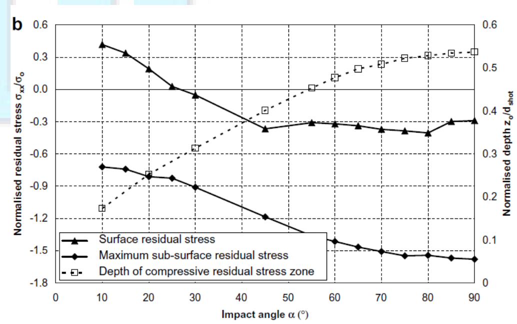

Fig. 1 Influence of incident angle (ν = 75m/s) [2]

Normal or close to normal impact with $\alpha \rightarrow 90°$ produced the most beneficial compressive residual stress within the target. It is referenced from experimental data that for θ = 35^{o} case, a very high percentage (about 68%) of shots had normal impact velocity ν =43.5 m/s, however this value was much smaller than the initial velocity ν = 75 m/s because of the low angle of attack. When θ = 90°, less than 20% of shots retained their initial velocity on impact, but these shots naturally impacted with a much higher normal velocity (ν = 75 m/s) than that of the θ = 35° case.

It will be useful to effective quality control, by identifying the most significant parameters which affect the residual stress profile and must be carefully controlled during shot peening.

Dr. David Kirk [3] has analysed the effect of shot impact angle on the peening intensity. This paper reveals relation of varying shot impact angle to other shot peening parameters. The paper examines the validity of two closely-related topics almen saturation intensity and depth of the indents being produced with shot impact angle. It is shown that both depth and intensity vary as $\sin\theta^{1.5}$ - rather than as simply $\sin\theta^{1.0}$, where θ is shot impact angle. The experiment was done by dropping ball bearings from known heights onto inclined flat specimens to get indent shape and depth. Experiment was done for both, perpendicular impact angle and oblique impact angle.

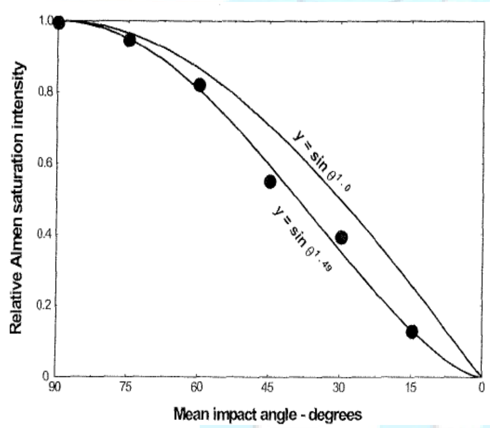

Fig. 2 Effect of mean impact angle on almen saturation intensity N strips, S110 shot [3]

Fig. 2 illustrates the several differences between predictions based on a $\sin\theta^{1.0}$ function as compared with a $\sin\theta^{1.5}$ function. At high impact angles the two functions have very similar values. Differences increase with decrease in impact angle. When θ = 30° then $\sin\theta^{1.0}$ has a value of 0.5 - implying that we can achieve 50% of the saturation intensity that one can achieve with perpendicular impacting. The observed similarity of indent depth and Almen saturation intensity function confirms that they are directly connected. The shape and size indentations will, of course, change during practical peening as indentations overlap one another and work-hardening occurs.

P.M. George et al. [4] has done optimization of critical parameters with the use of Taguchi method. The experimental results obtained confirm the adequacy and effectiveness of this approach. The Taguchi method is used to formulate the experimental layout, to establish the order of predominance among the identified critical parameters and predict the optimal setting for each of the process parameters. The critical process parameters that have been taken for study are: (a) work height (distance of the component from the blade edge); (b) shot flow rate; (c) exposure time; (d) shot size.

The optimum peening intensity is obtained by setting work height at 1016 mm, shot flow rate at 95 kg/min, exposure time at 6 min and shot size at S230. The peening intensity is found to increase by 32.45% at this optimum level. Based on these results, it can be inferred that for optimum intensity, the amount of shot required is comparatively less.

Franck Petit-Renaud [6] worked on shot peening machine. In aerospace and automotive industries have for years considered shot peening as a state-of-the-art process for the surface improvement, forming and life improvement of many parts. The work described in this paper is a study of the effect of a range of process parameters on the residual stress profiles produced by shot peening coupons of case carburized 17CrNiMo6 steel. It was found that the most significant parameters were air pressure, the mass flow, the impact angle and the exposure time. Further important and significant interactions were also detected between exposure time and air pressure; nozzle size and mass flow; air pressure and impact angle; nozzle size and air pressure.

The immediate effect of bombarding high velocity shots onto a metallic target is the creation of a thin layer of high magnitude compressive residual stress at or near the metal surface, which is balanced by a small tensile stress in the deeper core. As it is well known, most fatigue failures and stress corrosion failures normally start at or near the surface stressed in tension. Therefore, by reducing the net tensile stresses at and near the surface of the component, fatigue crack initiation and stress corrosion can be delayed, improving the fatigue life of the component treated.

Statistical analysis led to several models corresponding to the five types of results felt to be most important in terms of the final material condition RSM (A high compressive residual stress), DRSM (The greatest value for the depth of the maximum compressive residual), SPOL (The deepest shot peened outer layer), RSSf (A high compressive residual stress at the surface after peening) and [RSSf-RSSi]. The difference [RSSf-RSSi] was not considered so important (RSSf was more important than the level of change), although it was a good indication of the effect of the process on a component.

2. Almen strip testing

Shot peening process can be measured by an almen strip testing. An almen strip is a thin strip of SAE 1070 steel used to quantify the intensity of a shot peening process. Developed and patented by John O. Almen, the strip was originally supported by 2 knife edges; later improvements see it being supported on 4 small balls. The strip is placed in the chamber in place of the item to be shot peened, usually near to an area of the item where the result is deemed critical, sometimes located by a special fixture. Compressive stress introduced by the peening operation causes the strip to deform into an arc, which is measured using a gauge.

3. Synthesis of automated shot peening mechanism

The mechanism is to be designed for bevel gears. In bevel gear, maximum tensile stress will be generated at root surface of the tooth under loading condition. The gear and the pinion always have different face angle. Therefore, there should be a revolute joint which can be used to align nozzle perpendicular to the root face. The gear and the pinion will always have different dimensions which are peened in one setup. Hence, mechanism should have more two linear degree of freedom for standoff distance and another can be used to cover full face of the root.

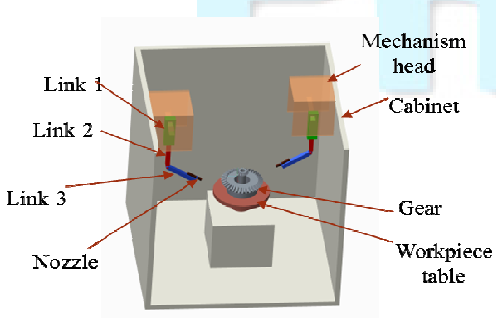

Fig. 3 Initially designed mechanism that can be used for automatic shot peening process

Two prismatic joints can be used to control these parameters during processing. In short, the selection of mechanism must have three degrees of freedom (3-DOF) to achieve objective of shot peening. There can be three different possible configurations for mechanism with two prismatic and one revolute joints:

- PPR
- PRP
- RPP

Figure 3 shows initially designed PPR mechanism which can be used to do automatic shot peening process for gears. Critical parameters which are reviewed from above literatures, are to be controlled during the process.

4. Summary

Design of automated mechanism for shot peening process depends on critical process parameters to be controlled to a specific level of accuracy. Critical parameters should be controlled during the process. It is found from the literature that angle of attack, distance between nozzle and target surface and peening time are crucial before design considerations of the mechanism. These parameters should be critically reviewed for components to be peened and fixture as well as shot peing mechanism design should be followed subsequently.

Stand-off distance between nozzle and target surface should be between 100 to 150 mm, according to peening intensity required. Shot impact angle should be perpendicular to the surface. By controlling these two parameters nozzle can be aligned and positioned to get required peening intensity.

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