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MODELING OF FATIGUE LIFE BY SHOT PEENING

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ABSTRACT

Shot peening is widely used to improve the fatigue properties of components and structures. Residual stresses, surface roughness, and work hardening are the main beneficial effects induced in the surface layer from shot peening, which depend on the correct choice of the peening parameters. The purpose of this work is to develop fatigue life that related to stainless steel 316 L with thickness of (2) mm by using shot peening process. Our modeling to improve fatigue life by shot peening process independent on velocity of shot at height of (0.75m) at angle nozzle of (90˚) at time shot(45s) with variable velocity(v) . The best value of (v) that we found are (12.8m/s) it's improving fatigue life to stainless steel 316 L about (200%) from its initial state.

KEYWORDS: Shot Peening, Fatigue, Modeling, Stainless Steel

INTRODUCTION

Shot peening is a cold working process in which small spherical parts called shots are blasted on a surface of a metal work-piece with velocities up to 100 m/s. This treatment leads to an improvement of fatigue behavior due to the developed compressive residual stresses and also to an increase of the surface hardness due to the cold working effect of shot peening. [1]

Shot peening, which is a surface enhancement technique, has widespread applications in automobile, aircraft, and marine industries. It is a cold-working process that hardens the surface of a metallic component by bombarding it with a stream of small particles called shots. The process induces a state of compressive residual stress at the material surface and the cold working. Benefits from shot peening can be attributed to the compressive stresses and the cold working induced in the surface. Compressive stresses are beneficial in increasing resistance to fatigue failure, corrosion fatigue, stress corrosion cracking, hydrogen assisted cracking, fretting, galling, and erosion caused by cavitations. Benefits obtained due to cold working include work hardening, corrosion resistance, closing of porosity, and testing the bond of coatings. [2]

Shot peening is a fairly recent renovation of a very ancient art and in order to have a clear conception of what occurs in the peening process, it might be well to go back in history and consider some of the early aspects of cold working or, as it would have been referred to in olden days, hammer hardening. In the Iliad, the Greek chronicler, Homer, refers to copper breast plates and spear heads and very poetically describes how some spear points penetrated the breast plates with ease while others merely bent on striking and fell to the ground without more than denting the armor of the wearer. The connotation of his writing is that some mystic force had permitted the spear of one warrior to penetrate the breast plate of his enemy while, in the other case, the armor of one would bend and turn aside the spear of his enemy. It wasn't the power of positive thinking that drove the spear head into the armor in one case and caused the armor to bend the spear head in another. It was the plain old fact that the reliable armorer knew from practical tests that cold hammered weapons and breast plates were harder and stronger than those which had been placed in a fire. The intuitive mystic, on the other hand, was so enthralled by the supposed merits of fire that his last operation was to heat the metal and thus anneal or soften it. Also, the unreliable armorer may have been smart but lazy. He observed that the longer he hammered the copper, the harder it became to form it to the desired shape and he knew that by heating it, he could restore the softness and ductility and thus make his job easier. By annealing just previous to the final light taps of the hammer, he left the armor or spear head soft and probably cost the life of his customer. Another historical use of cold working which is more directly analogous to modern shot peening was the old time blacksmith's art of hammer peening the tension side of carriage springs. He found out that if he bent the flat carriage spring in the same manner that it would be bent as part of a loaded carriage and then ball peened the convex (tension) side while bent, he could improve the life of the springs even for greater loads or when smaller springs were used. Today, we call this "strain peening" and some of the increases in service life of parts so treated are phenomenal. The old time blacksmith merely knew from past experience that it worked so he went ahead and did it. His shot was as big as the ball on the ball peen hammer he used. The striking intensity depended on the mass of the hammer and the strength of his muscles, modified of course, by whatever good judgment he had managed to accumulate from past experience. His peening rate was one indention at a time so one would suspect that a large ball was used to cover as much area as possible per blow and thus save some time. Any craftsman who was proud of his work would add the peening operation; however, he could hardly afford to use all of his day just to improve a few springs [3]. Shot peening was independently invented in Germany and the United States in the late 1920s and early 1930s. The first commercial implementation was done in the United States on automotive valve springs [4].

Shot peening is a cold working process in which the surface of a part is bombarded with small spherical media called shot. Each piece of shot striking the Metal acts as a tiny peening hammer imparting a small indentation or dimple on the surface. In order for the dimple to be created, the surface layer of the metal must yield in tension Figure 1. Below the surface, the compressed grains try to restore the surface to its original shape producing a hemisphere of cold-worked metal highly stressed in compression Figure 2. Overlapping dimples develop a uniform layer of residual compressive stress.

It is well known that cracks will not initiate nor propagate in a compressively stressed zone.

Because nearly all fatigue and stress corrosion failures originate at or near the surface of a part, Compressive stresses induced by shot peening provide significant increases in part life. The magnitude of residual compressive stress produced by shot peening is at least as great as half the tensile strength of the material being peened.

In most modes of long term failure the common denominator is tensile stress. These stresses can result from externally applied loads or be residual stresses from manufacturing processes such as welding, grinding or machining. Tensile stresses attempt to stretch or pull the surface apart and may eventually lead to crack initiation Figure 3.

Compressive stress squeezes the surface grain boundaries together and will significantly delay the initiation of fatigue cracking. Because crack growth is slowed significantly in a compressive layer, increasing the depth of this layer increases crack resistance. Shot peening is the most economical and practical method of ensuring surface residual compressive stresses. [5]

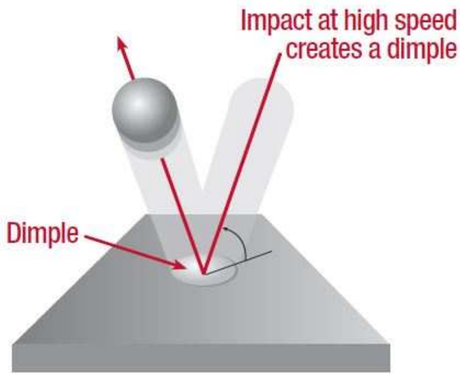

Figure 1: Mechanical Yielding at Point of Impact

Figure 2: Compression Resists Fatigue Cracking

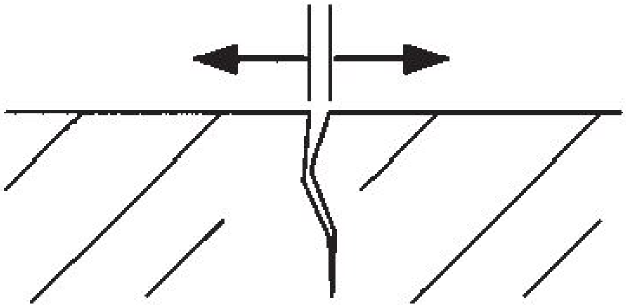

Figure 3: Crack Initiation and Growth through Tensile Stress

A strong understanding of shot peening is necessary because of its remarkable ability to increase fatigue resistance, extend fatigue life [5], increase corrosion resistance [6], lubrication and tribological applications [7], and surface nano crystallization [8] to name only a few. Shot Peening is an important design process in the automotive, aerospace, nuclear, medical, pressure vessel, and petroleum industries. It is primarily used to prevent fatigue induced failures via two mechanisms: 1.) a compressive residual stress that prevents crack growth and 2.) an increase in material hardness that prevents crack initiation. A compressive residual stress is a stress that remains in a material, at equilibrium, after all external loads have been removed. This compressive stress prevents a crack from growing by negating the tensile loading from the cyclic stress amplitude of fatigue. Shot peening induces a compressive stress near 60% of the materials [5]. A crack cannot grow through the compressive stress field hence the fatigue life increases. The fatigue benefits have been well documented. For example, shot peening has been shown to improve the fatigue strength of high strength aluminum alloys by as much as 25-35%. With shot peening's important purpose and extensive use, a strong the oretical understanding is necessary so that design engineers have reliable models to help approximate the benefits. Because of all these applications shot peening is a valuable surface treatment process for many different industries.

Properties of materials:

Table 1: Composition for Stainless Steel (316 L)

C	Cr	Ni	Nb	V	Mn	Mo	Cu	Ti	Fe
0.21	16.9	10.5	0.017	0.038	0.97	1.76	0.19	0.38	69.2

Table 2: Physical Property of 316L

Density	Elastic Modulus	Mean Co-Eff of Thermal Expansion (µm/M/°C)			Thermal Conductivity		Specific Heat 0-100°C	Elec Resistivit y
(kg/M3)	(GPa)				(W/m.K)		(J/kg.K)	(nΩ. M)
8000	**193**	**0-100°C**	**0-315°C**	**0-538°C**	**At 100°C**	**At 500°C**	**500**	**740**
		15.9	**16.2**	**17.5**	**16.3**	**21.5**		

Table 3: Mechanical Property of 316L

Tensile Stress (MPa)	Yield Stress (MPa)	Elongation (.005mm) Min	Hardness	
485	**170**	**40**	**Rockwell B (HR B) max**	**Brinell (HB) max**
			95	**217**

Table 4: Composition of Steel Shots Ws330

Element Composition	%
Carbone	**0.85 —1.10 %**
Manganese	**0.60 — 0.80 %**
Silicon	**0.60 — 0.80 %**
Sulphur	**0.04 %**
Phosphorous	**0.04 %**

Verification of the Model

In a first step the model will be compared with some analytical and experimental solutions available for the Elastic and the elastic-plastic impact of a sphere. In the model here we take constant distance (0.75m) from nozzle at angle of 90º and shot type (ws330) the variable in this model is shot velocity.

Elastic Solution

Due to Al-Hassani [9] there is an analytical solution for the contact time and the average contact pressure of a single perpendicular impact of an elastic sphere (radius r). This solution is based on Hertzian theory of contact.

Average contact pressure:

$$\overline{P} = \frac{2}{3\pi} * (2.5\pi * \rho)^{\frac{1}{5}} * \left[\frac{E}{1-\mu}\right]^{4/5} V^{2/5}$$

Where ρ=density of sphere and solid, E=Young's modulus, µ=Poisson's ratio, v=initial velocity of sphere.

Fatigue Life (NF; [cycles]) is defined as the number of stress cycles or strain reversals that a material experiences prior to fracture, to calculate the cycles that related to fatigue limit in material we use the equation below (NF) number of cycles:[10]

$$NF = \left[\frac{\sigma}{193}\right]^{\frac{1}{0.08}}$$

It is worth noting that the average contact pressure does not depend on the radius of the sphere. The FE Calculations are performed for steel. The average contact pressure in the case of the finite element solution can be calculated by two different ways. First, the distribution of the contact pressure can be interpolated with a polynomial fitting and the resulting equation can be integrated with respect to the contact radius. This procedure is quite sensitive to the contact radius which is difficult to obtain with sufficient accuracy. The second way refers to the solution of Hertz, where the average pressure p equals to the Maximum pressure p occurring at the center of the contact area.

The agreement between the analytical and numerical solution for the time of contact as well as for the average pressure is very good. The trends for the variation of the radius and velocity of the sphere are also reproduced very well. The difference between the analytical results and the FE approach are traced back to the fact that energy losses are encountered due to stress waves, which are enclosed in the finite element solution. The velocity of the sphere after the impact is less than its initial velocity. In addition the analytical solution does not consider the indentation of the work-piece by the sphere.

In order to obtain a better approach to the Hertzian solution, these calculations are repeated for a sphere which is much hard than the target. The normalized stresses, as given in for the FE solution, agree very well with the solution obtained by Hertz the stresses along the axis of rotation, which the plastic deformation will first occur at this point below the surface and when the sphere enters the target further, the plastic flow zone will grow and extend to the surface.[11]

Calculations

Here the equations we will need is the average presser (p) and (NF)

$$\overline{P} = \frac{2}{3\pi} * (2.5\pi * \rho)^{\frac{1}{5}} * \left[\frac{E}{1-\mu}\right]^{4/5} V^{2/5}$$

$$NF = \left[\frac{\sigma}{193}\right]^{\frac{1}{0.08}}$$

Table 5

V(M\S)	E	μ	$\rho(\frac{g}{cm^2})$	$\overline{P}$(Psi)	Σ(Mpa)	Nf
4	$200 * 10^9$	0.3	0.135	405.3137496	253.3210935	29951981.76
5	$200 * 10^9$	0.3	0.135	443.1546818	276.9716761	91406194.34
6	$200 * 10^9$	0.3	0.135	476.6809984	297.925624	227447861.5
7	$200 * 10^9$	0.3	0.135	506.9983619	316.8739762	491604450.7
8	$200 * 10^9$	0.3	0.135	534.8146989	334.2591868	958463416.4
9	$200 * 10^9$	0.3	0.135	560.6145227	350.3840767	1727182198
10	$200 * 10^9$	0.3	0.135	584.7461084	365.4663177	2924998219
11	$200 * 10^9$	0.3	0.135	607.4694113	379.668382	4710738882
12	$200 * 10^9$	0.3	0.135	628.9843483	393.1152177	7278331568
13	$200 * 10^9$	0.3	0.135	649.4484447	405.9052779	10860313637
14	$200 * 10^9$	0.3	0.135	668.9883493	418.1177183	63.56736591

RESULTS OF DATA

The modeling starts from initial velocity of (4) m/s because the velocities from (0-3) m/s does not change in fatigue life in metal we note that the fatigue life increases with velocity increase the maximum number of cycles is ($10.05 * 10^9$ [cycles]) at velocity of (12.8) m/s after that if the velocity increased the metal will go to fracture point .

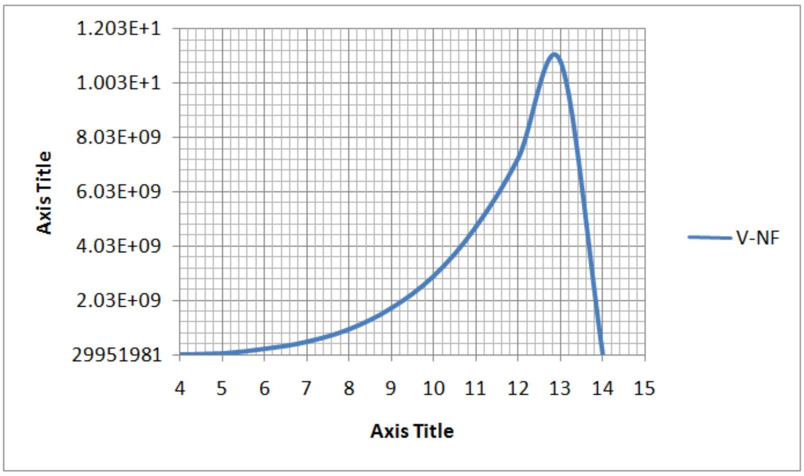

Figure 4

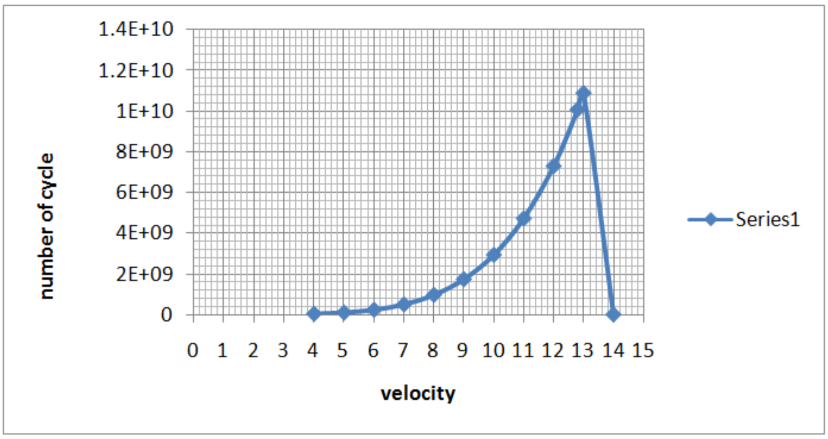

Figure 5

CONCLUSIONS

Shot peening is an important treatment of technical parts with continually growing areas of application. To increase fatigue life, corrosion resistance etc., compressive subsurface residual stresses are possessed near the surface of the work-piece. In order to obtain optimal results the process has to be controlled properly. Nowadays the adjustment of the shot peening parameters is based on modeling. Adjustments once found are controlled with the help of the controversial stainless steel 316L plate.

There is a huge demand for prediction of the value and distributions of the subsurface stresses in dependence of the parameters of the process. In addition, the insight and knowledge of the process can be improved by simulating the proceedings during the impact and the development of the residual stresses. The first results obtained from the introduced model are very encouraging, but there is still a huge lack of recording of all phenomena involved in the process.

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