96037

Simulation of Residual Stress Distribution on Shot Peening

Yoshihiro WATANABE* and Norihiko HASEGAWA**
* JAPAN, TOYO SEIKO Co.,Ltd, ** Faculty of Engineering, Gifu University

ABSTRACT

The present research aims at obtaining a theoretical solution on basis of actual measurements of residual stress by shot peening. Firstly, it was conducted that residual stress on two different strength of plate specimens have been shot peened are measured by X-ray difractometer and the effect of a few type of shot peening conditions on profiles are confirmed. The equation to simulate profiles was obtained by the superposition method of simple three stress, based on the equation that Y.F.Al-Obaid suggested. It was confirmed that the predicted stress profile shows good correspondence with experimental value in case of every shot peening conditions in this study.

KEYWORDS

Residual stress, Shot Peening, Simulation

INTRODUCTION

In recent years, automotive structural parts have become compact in accordance with strong demands for light weight. In order to enhance the performance of machines, steel components have been shot peened(1). It is generally recognized that one of the reason for improvement on fatigue durability by shot peening is surface compressive residual stress(2). And a shot peening condition decides a residual stress profile on surface layer. However, now most popularity method to confirm that profiles is only measurement by X-ray difractometer.

In this study, a simulation technique was applied to predict the residual stress distribution by shot peening. Firstly, it was conducted that residual stress on two different strength of plate specimens have been shot peened are measured by X-ray difractometer and the effect of a few type of shot peening conditions on profiles, shot diameter and shot velocity and peening time, are confirmed. The equation to simulate profiles was obtained by the superposition method of simple three stress, based on the equation that Y.F.Al-Obaid suggested(3). It was confirmed that the predicted stress profile shows good correspondence with experimental value in case of every shot peening conditions at this study.

EXPERIMENTAL PROCEDURE

The tested plate specimens(50 mm width 50 mm length and 10 mm thickness) were made of S50C carbon steel. Two kinds of specimens were prepared to clarify the different of the maximum compressive residual stress on material strength. Firstly, after machine finishing, the specimen was annealed by holding 720 ℃ for 1h followed by gradually cooling at vacuum furnace. Secondly, specimens were austenitized at 870 ℃ for 1h and oil quenched. Tempering treatment were performed at 320 ℃ for 1h. Consequently, the hardness of annealed specimens was HV220 and quenched and tempered specimens was HV550. Shot peening was conducted by means of the centrifugal type machine with shot velocity of 40 m/s and 80 m/s. Shot peening media were rounded cut wire with a diameter of 0.3 mm and 0.9 mm at the hardness of HV 700. And peening time was decided to obtain the same coverage 100% . In case of using 0.3 mm dia, peening time were 60 s and 120 s for 0.9 mm dia.
The surface residual stress of specimens after shot peening was measured by X-ray diffractmeter with 2θ - $\sin^2\Psi$ method. Stress distribution was obtained by repeating the X-ray measurement and electrochemical polishing successively.

EXPERIMENTAL RESULTS

Fig.1 shows residual stress distribution of both strength specimens after shot peening. Maximum residual stress value slightly increase with increasing diameter of shot media. And the effective layer by shot peening also increase. On the other hand, maximum residual value of quenched specimens are twice that of annealed specimens. This results showed approximately similar to those of other studies(4) which concluded that maximum compressive stress value depend on the yield strength of material. The effect of shot velocity on residual stress distribution contributes to effective layer, however, not to maximum value.
The effect of peening time, which is equivalent to coverage, on distribution shows Fig.2. As the same of above results about shot velocity, maximum value is almost same in case of different coverage. And effective layer increase with increasing coverage.

METHOD OF THEORETICAL SIMULATION

The depth of effective layer

On the basis of the Hertzian model of normal impact of a spherical hard particle on a flat surface, the relation between depth of plastic zone (h_p) and radius of particle (R) and depth of dent (Z) was defined by Y.F.Al-Obaid(3) as follows :

$$\frac{h_p}{R} = k\sqrt{\frac{Z}{R}} \qquad k : \text{const.} \tag{1}$$

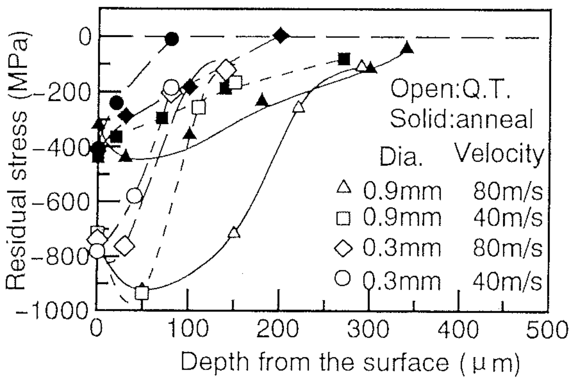

Fig.1 Residual stress distribution

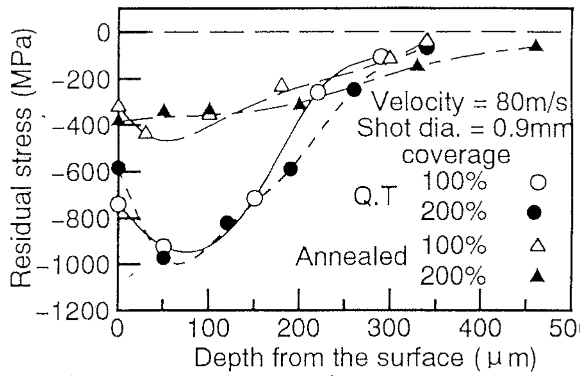

Fig.2 Residual stress distribution at two different coverage

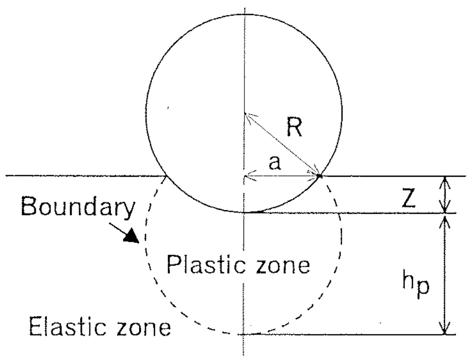

Fig.3 Scheme. of plastic - elastic boundary below the contact zone

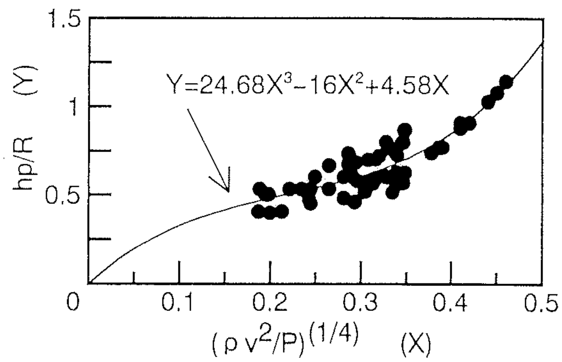

Fig.4 Relation between (hp/R) and $(\rho v^2/P)^{1/4}$

On the other hand, we assume that when a spherical projectile indents a medium exhibiting a rapid plastic behavior, the resistance to its motion may be represented by an average pressure ($\bar{p} = 3Y$) at contact zone, thus the equation of motion of the projectile is

$$M\frac{dV}{dt} = -\pi a^2 \bar{p} \tag{2}$$

where M is mass of particle, ρ is density, a is radius of contact zone and Y is a yield strength of material. By means of neglecting friction inertia of the moving metal ahead and strain hardening, eq.(2) may be integrated in term of the penetration to give

$$\frac{\bar{z}}{R} = \sqrt{\frac{\rho v^2}{3\bar{p}}} \tag{3}$$

where $\bar{z}$ is the final indentation and v is the initial impact velocity. Here, we assume that static conditions still hold in the range of impact velocities and dynamic indentations which have the same value as those obtained from static tests produce similar plastic zone. The following equation is rearranged by substituting eq.(3) into eq.(1).

$$\frac{h_p}{R} = k_1 \left(\frac{\rho v^2}{\bar{p}} \right)^{\frac{1}{4}} \qquad k_1 : \text{const} \tag{4}$$

Fig.4 shows the relation between left and right hand term of eq.(4), obtained from the rearrangement of our experimental data in past. Consequently, by means of solution of minimum square method about above data, we get the depth of the plastic zone as

$$\frac{h_p}{R} = 24.68 \left(\frac{\rho v^2}{\bar{p}} \right)^{\frac{3}{4}} - 16.0 \left(\frac{\rho v^2}{\bar{p}} \right)^{\frac{2}{4}} + 4.58 \left(\frac{\rho v^2}{\bar{p}} \right)^{\frac{1}{4}} \tag{5}$$

which is some empirical equation obtained by dimensional analysis of various experimental results.

Residual stress distribution by shot peening

It is generally recognized that there will be a plastic zone constrained by an elastic field under impact spot. After rebound of each shot the plastic zone interacts with the elastic field resulting in a residual stress. The following assumptions have been made in working out the theory of simulation of residual stress distribution. Fig.5 shows schematic illustration of three simple stress for our assumptions. In case of thick plate, we can see that stretching of the peened surface causes the sheet to develop a spherical curvature, convex on the peened side. However, there occurred the axial strain ϵ_{ax} in peened plate. In the next place, the bending stress as showed figure have been needed to return to original plate. So, the residual stress distribution, in a thin plate, may now be considered to be the results of further addition of the bending σ_B, axial σ_{ax} and source stress σ_s which will react to two other stresses.

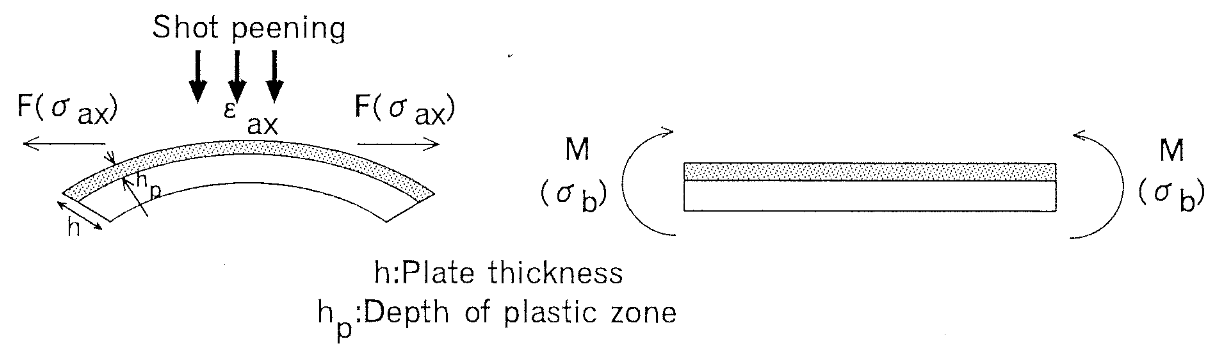

Fig.5 Schematic illustration of simple stress for assumption

$$\sigma_R(Z) = -\sigma_B(Z) + \sigma_{ax}(Z) - \sigma_s(Z) \quad (6)$$

where Z is depth from the surface. From the experimental evidence, the shape of residual stress distribution in thick target can be represented by the first half of cosine function. The strain produced by the source stress, which is acting in a plane parallel to the surface of target, may be given by :

$$\sigma(Z) = \frac{E}{1-\nu}\epsilon(Z) \quad (7)$$

where ν is the Poission's ratio, E the Young's modulus.

The assumed cosine function has a peak at a depth αh_p below the surface and may be described as follows :

$$\epsilon(Z) = \frac{\epsilon_m}{2}\left\{\cos\pi\frac{z-\alpha h_p}{(1-\alpha)h_p} + 1\right\} \quad (0 \leqq z \leqq h_p) \quad (8)$$

where ϵ_m is the maximum strain and for $z > h_p$, the function does not have a value.

The bending stress σ_B at depth z in a beam of width b and thickness h subjected to a bending moment M is given by :

$$\sigma_B(Z) = \frac{12M}{bh^3}\left\{\frac{h}{2} - z\right\} \qquad \text{where} \qquad M = \int_0^{hp} \sigma(z)\left\{\frac{h}{2} - z\right\} bdz \quad (9)$$

Similarly, the axial stress σ_{ax} is given by :

$$\sigma_{ax} = \frac{F}{bh} \qquad \text{where} \qquad F = \int_0^{hp} \sigma_s(z) bdz \quad (10)$$

Substituting these in eq.(6), we obtain the residual stress distribution as :

$$\sigma_R(z) = \frac{E\epsilon_m}{1-\nu^2}\left[-\frac{6\lambda}{h}(\frac{h}{2} - z)c_1 + \frac{1}{2}c_2 - \frac{1}{2}\left\{\cos\frac{z-\alpha h_p}{(1-\alpha)h}\pi + 1\right\}\right] \quad (11)$$

Finally, maximum strain, ϵ_m in eq.(11) is assumed by using the deflection δ at thin plate target as following equation :

$$\delta = \int_0^{\frac{L}{2}} \int \frac{M}{IE} dxdx \quad = \quad \frac{3}{2}\frac{L^2 M}{Ebh_1^3} \quad (12)$$

where b is the width, h_1 is the thickness, L is the length of plate target.

RESULTS (COMPARISON OF EXPERIMENTAL RESULTS WITH CALCULATED VALUES)

Fig.6 shows the comparison between calculated and experimental residual stress of quenched and tempered specimens. Further, the results for two different coverage are shown in Fig.7. Here, the data for the calculations are : E=200GPa, shot density $\rho = 7740 kg/m^3$, Poission's ratio $\nu = 0.3$ and $\alpha = 0.2$.

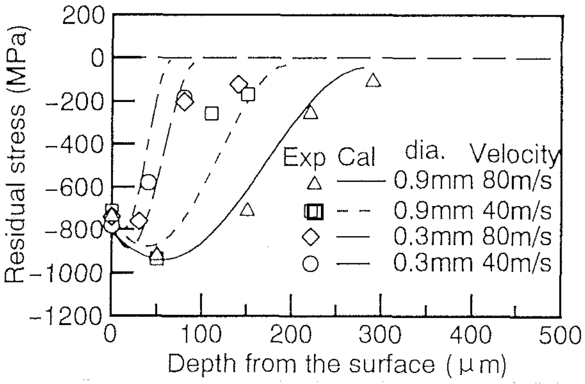

Fig.6 Residual stress distribution

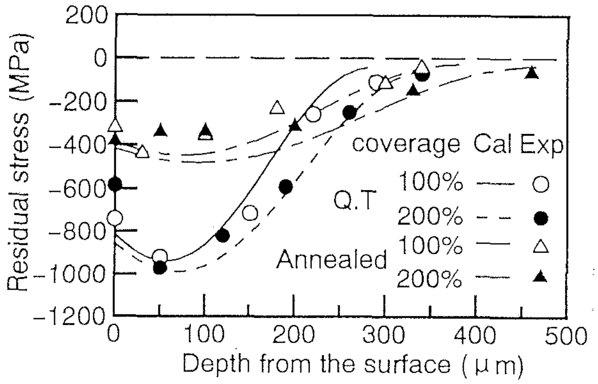

Fig.7 Residual stress distribution at two different coverage

It is seen that the predicted proflies approximately agree with the common tendency found in measured residual stress distribution at both figure.

CONCLUSION

The residual stress distribution about two types of strength for S50C carbon steel, which peened at each conditions, were measured in order to confirm the effect of shot peening conditions on stress distribution. Further, the predicted equation to simulate the residual stress profiles was obtained by the superposition method of simple three stress, based on the equation that Y.F.Al-Obaid suggested, concerning on the basis of experimental results. The summary is as follows:

Useful expressions are derived for residual stress distribution and the predictions are founded to be in reasonable agreement with experimental results. The effect of shot peening condition on stress profile, which obtained by the results of calculated and experimental value, shows approximately similar to those of other studies.

REFERENCES

1. K.Ogawa, H.Yamada, K.Saruki, M.Yokoi, M.Inuzuka, *Proc. of 4th International Conference of Shot Peening*, 445-454, 1990
2. A.Tange, *Proc. of 4th International Conference of Shot Peening*, 243-233, 1990
3. Y.F.Al-Obaid, *Journal of Applied Mechanics*, 57, 307-312, 1990
4. H.Wohfart, *Residual Stress relax*, 71-92, 1982