# FINITE ELEMENT ANALYSIS OF SHOT PEENING -ON THE FORM OF A SINGLE DENT-

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Nobuyuki Hirai*, Katsuji Tosha*, Emmanuelle Rouhaud **

* Meiji University, 1-1-1 Higashimita, Tama-ku, Kawasaki 214-8571, Japan
** University of Technology of Troyes, 12, rue Marie Curie, BP 2060, 10010 Troyes, France

## ABSTRACT

This paper presents several analyses on a dent form produced by a single shot using finite-elements. A finite element model is discussed in order to clarify the influences of peening conditions and characteristics of material on the surface aspect, which is closely related to several shot-peening consequences on the mechanical part. An axi-symmetric, two-dimensional model has been used in this research. The analysis was carried out with a constitutive law for the material with a bilinear isotropic hardening.

Shot peening was performed on a part constituted of a medium carbon steel by means of a centrifugal type machine; four shot velocities and four shot diameters were used.

The following points are presented; (1) Finite element analysis method (FEM) is able to represent almost exactly dent forms, this FEM is thus suitable to study the characteristics of peened surfaces. (2) Dent size is influenced significantly by velocity, diameter and density of shot. (3) Dent form is influenced significantly by the yield stress of the shot, the yield stress and hardening slope of the material. (4) The value of the diameter ratio (diameter of pilled-up area /diameter of dent) reaches the saturated value of 2.5, and the value of depth ratio (pilled-up height/depth of dent) reaches 0.2.

## SUBJECT INDEX

FEM, dent size, dent form, diameter ratio, depth ratio

## INTRODUCTION

Shot peening is widely used in the space and automobile industry to improve the reliability of the structures. Following the increase of the number of shot peening applications, many researchers work on this process. In recent years, finite element methods have been applied to shot peening taking advantage of computing advances. While many researches work on residual stresses, researches on the dent form are very scarce. The profile of the dent is one of the basic factors influencing surface texture which includes surface roughness and surface characteristics. Surface roughness is also an important basic factor improving heat releasing characteristics and reducing flow resistance. (Okoshi, 1954), (Iida, 1973), (Iida, 1984), (Kyriacou, 1996), (Zeng, 2002), (Rouhaud, 2002)

In order to clarify the influences of peening conditions on the material itself and on the peened surface, the profiles of the dents produced by a single shot has been analyzed using FEM analysis. In addition, shot peening was performed on a medium carbon steel, and then the FEM results were compared with the experimental results when possible. Diameter ratio and depth ratio were also investigated.

## METHOD OF RESEARCH

### Analysis

Many problems have been numerically solved using the finite element package ANSYS/LS-DYNA which uses an explicit nonlinear structural integration scheme and is well suited to analyze impact problems and contact phenomena. In order to analyze the influence of material characteristics, the shots were assumed to be rigid. To analyze the dent forms, the shot were assumed to have an elasto-plastic behavior with a bilinear isotropic hardening model.

The geometrical model is axi-symmetric and two-dimensional as shown in Figure 1; analysis conditions are presented in Table 1. The influence of velocity and shot diameter on the dent form is discussed. The influence of parameters such as density, Young's modulus, Poisson's ratio, yield stress and tangent modulus are also investigated.

### Experimental procedures

Several experiments were performed by means of a centrifugal type machine with shot velocities varying from 20m/s to 50m/s and shot diameters varying from 0.8 mm to 3.0 mm. Experimental conditions are presented in Table 2. Shot velocities were calculated using the peripheral velocity of the wheel of the shot peening machine. Shot peening was performed on a medium carbon steel (C:0.45% 180HV). The profiles of the dent were measured by a surface roughness tester. The numerical results were compared with experimental results.

In this paper, the dimensions of the dents were measured as shown in Figure 2. In addition the diameter ratio (diameter of pilled-up area /diameter of dent) and the depth ratio (pilled-up height/depth of dent) were also investigated.

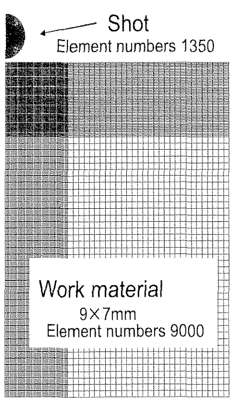


Fig.1 Analysis model

Table 1 . Conditions for analysis

| | | |
|---|---|---|
| Modeling | Axi-symmetric (two dimensional) | |
| Shot velocity V m/s | 60 | |
| Shot diameter D mm | 1.2 | |
| | Shot | Work material |
| Material model | Bilinear isotropic hardening model | Bilinear isotropic hardening model |
| Density g/cm$^3$ | 7.8 | 7.8 |
| Young's modulus GPa | 210 | 210 |
| Poisson's ratio | 0.28 | 0.28 |
| Yield stress MPa | 500 | 300 |
| Tangent modulus MPa | 2000 | 1200 |

Table2 . Conditions for experiment

| | | | | | |
|---|---|---|---|---|---|
| Shot | Diameter D mm | 0.8 | 1.2 | 2.3 | 3.0 |
| | Hardness HV | 793 | 790 | 850 | 810 |
| Specimen | Material | Medium carbon steel (S45C) | | | |
| | Annealing | 800℃×2h | | | |
| | Dimension mm | 25×25×10 | | | |
| Shot velocity V m/s | | 20,30,40,50 | | | |

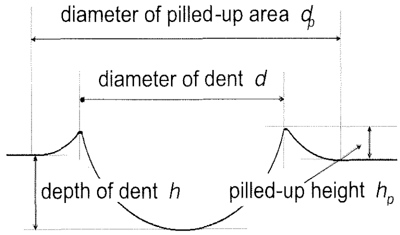


Fig.2 Definition of measured dimensions

## RESULT

### Dent form

The influence of the shot velocity on the dent form is shown in Figure 3. The dent size increases with the increase of the shot velocity.

The influence of the shot diameter on the dent form is shown in Figure 4. The dent size increases with the increase of the shot diameter but its general shape stays constant. The numerical results agree well with the experimental results as shown in Figures 3 and 4.

The influence of the shot yield stress on the dent form is shown in Figure 5. The dent form is influenced significantly by the yield stress of the shot in different ways depending on the velocity and the shot diameter.

The influence of the shot material on the dent form is shown in Figure 6 with a comparison between an elasto-plastic and a rigid shot. The energy in the shot during the impact increases with the shot velocity. The higher the energy of the impact, the more the shot is deformed. The increase in shot velocity makes, therefore, these differences even larger.

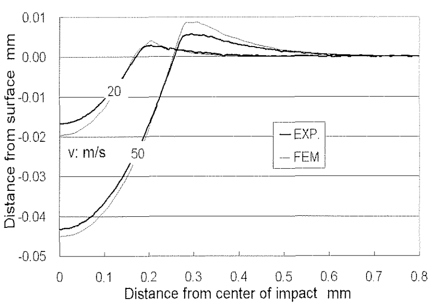


Fig.3 Influence of shot velocity on dent form

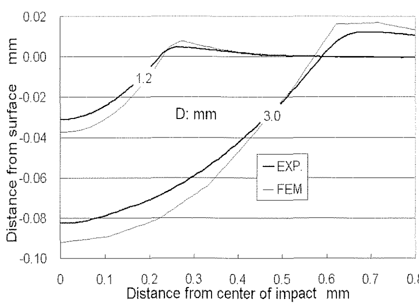


Fig.4 Influence of shot diameter on dent form

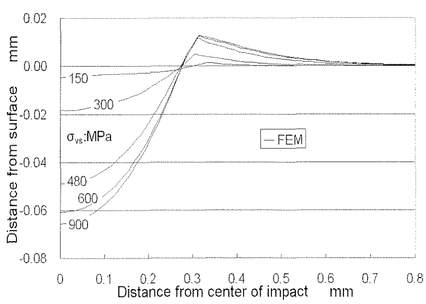


Fig.5 Influence of shot yield stress on dent form

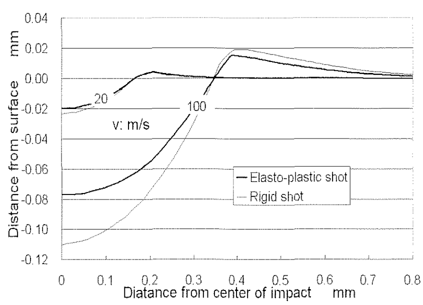


Fig.6 Influence of shot's material on dent form

**Dent size**

As shown in Figure 3, the dent size increases with the increase of the shot velocity. The relations between the shot velocity, the diameter of dent and the diameter of pilled-up area is shown in Figure 7. The relations between the shot velocity, the depth of the dent and pilled-up height is shown in Figure 8. The diameter of the dent is proportional to the shot velocity to the power of four-ninth; the diameter of the pilled-up area is proportional to the shot velocity to the power of one-half as shown Figure 7. The depth of the dent is proportional to shot velocity to the power of nine-tenth; the pilled-up height is proportional to the shot velocity to the power of five-sixth as shown Figure 8.

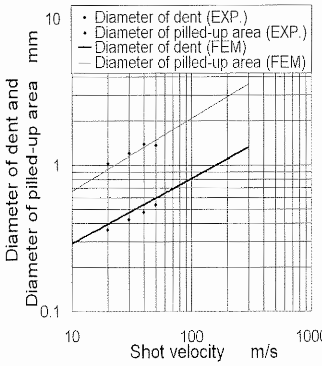


Fig.7 Relations between shot velocity and diameter of dent, and diameter of pilled-up area

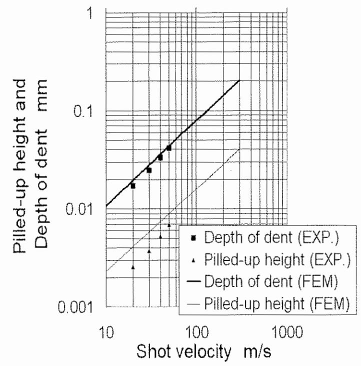


Fig.8 Relations between shot velocity and depth of dent, and pilled-up height

Concerning the influence of the shot diameter and the shot density on the dent size, the following relations are obtained for the dent dimensions.

Diameter of dent $h = k_2 D v^{9/10}$ (2)

Depth of dent $d_p = k_3 \rho_s^{1/3} D v^{1/2}$ (3)

Diameter of pilled-up area

Pilled-up height $h_p = k_4 D v^{5/6}$ (4)

$d = k_1 \rho_s^{1/5} D v^{4/9}$ (1)

where v is shot velocity, D is shot diameter, $\rho_s$ is shot density and $k_1 \sim k_4$ is constant.

The influence of the model of the shot (elasto-plastic shot or rigid shot) on the dent dimensions (diameter and depth) is shown in Figure 9 and Figure 10 respectively. While the difference on dent's diameter is not significant, the depth of the dents increases significantly with the increase of the shot velocity. The shot deformation increases with the increase of the shot velocity in the case of an elasto-plastic shot. The dent depth is, therefore, influenced significantly by the characteristics of the material of the shot.

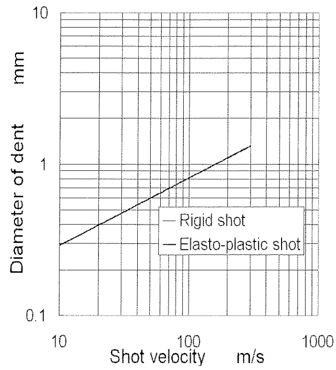


Fig.9 Influences of an elasto-plastic shot and of a rigid shot on diameter of dent

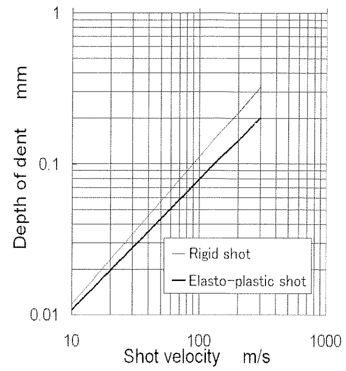


Fig.10 Influences of an elasto-plastic shot and of a rigid shot on depth of dent

The influence of the ratio of the shot's yield stress to the peened material yield stress on the diameter of the dent is shown in Figure 11. The Abscissa axis is the yield stresses ratio and the ordinate axis is ratio of the diameter of dent. In a similar way, Figure 12 focuses attention on the depth of the dent. When the shot yield stress is more than about twice the work material, the dent dimensions reach a saturated value. Similar dents are, therefore, formed when the shot yield stress is higher than about twice that of work material. When the yield stress ratio is equal to one, as the ratio of the diameter of the dent changes drastically within this range (form 0.5 to 2), other analysis of shot peening is necessary to obtain more detailed information.

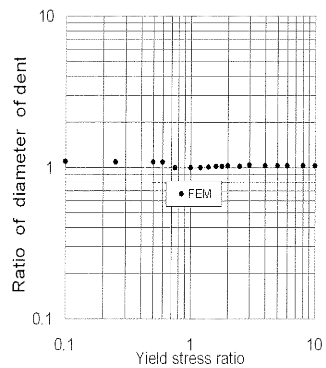


Fig.11 Influences of yield stress ratio on diameter of dent

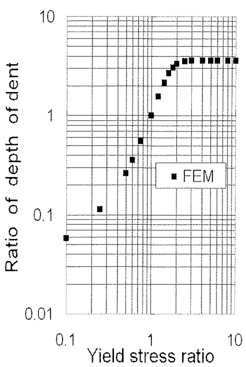


Fig.12 Influences of yield stress ratio on depth of dent

## Dent ratio

The shot velocity does not influence the diameter ratio and the depth ratio significantly as shown in Figure 13. Furthermore, the influences of the yield stress ratio on the diameter ratio and on depth ratio are shown in Figure 14. As mentioned above, constant dent form is produced whenever the yield stress ratio is beyond 2. The value of the diameter ratio reaches the saturated value of 2.5, and the value of the depth ratio reaches 0.2, when the value of the shot yield stress is twice as large as the specimen's. We can, therefore, estimate the dent profile produced by a single shot knowing the dent diameter and depth.

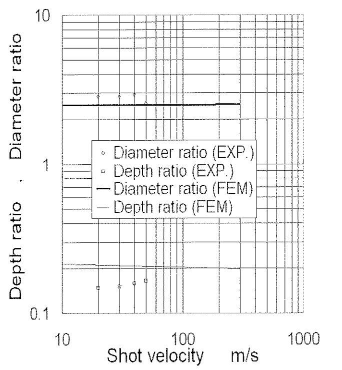


Fig.13 Influences of shot velocity on diameter ratio and on depth ratio

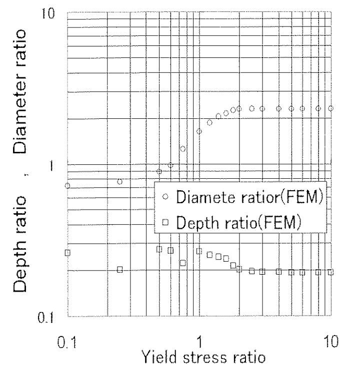


Fig.14 Influences of yield stress ratio on diameter ratio and on depth ratio

## CONCLUSION

In this paper, analyses were carried on a dent form produced by a single shot using the finite element package. In the result, following matters were presented.

(1) Finite element analysis method is able to represent almost exactly dent forms, this FEM is thus available to research the characteristics of peened surfaces.

(2) Dent size is influenced significantly by velocity, diameter and density of the shot.

(3) Dent form is influenced significantly by yield stress of shot, yield stress and tangent modulus of work material.

(4) The value of the diameter ratio reaches the saturated value of 2.5, and the value of the depth ratio reaches 0.2.

(5)The following relations are obtained on dent dimensions from analyses.

$$d = k_1 f_s^{1/5} Dv^{4/9} \qquad h = k_2 Dv^{9/10} \qquad d_p = k_3 \rho_s^{1/3} Dv^{1/2} \qquad h_p = k_4 Dv^{5/6}$$

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