Finite Element Analysis of Shot Peening
-On the profile of a single dent-

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ABSTRACT

This paper presents several analyses on a dent profile produced by a single shot using a finite-elements package. A finite element model is discussed in order to clarify the influences of peening conditions and characteristics of shot and work materials on the surface aspect, which is closely related to several peening effects. An axi-symmetric, two-dimensional model has been used in this research. The analysis was carried out for the material with a constitutive law and bilinear isotropic hardening. In order to ascertain analytic results, shot peening was performed for a medium carbon steel by means of a centrifugal type machine with four shot velocities and four shot diameters.

The following results are found in this study; (1) The smallest size of work model is 3 times the shot diameter for the dent profile to be correctly expressible. (2) Finite element analysis (FEM) is able to represent almost exactly the dent profile, so FEM is a good tool for studying the characteristics of peened surfaces. (3) Dent size is influenced significantly by velocity and diameter. (4) The following relations are obtained for dent dimensions.

Analysis result : $d = k_3 v^{4/9}$, $h = k_4 v^{8/9}$

Experimental result : $d = l_4 D v^{1/2}$, $h = l_5 D v$

where D is shot diameter, v is shot velocity, and k_3, k_4, l_4, l_5 are constants.

SUBJECT INDEX

FEM, dent size, dent form, diameter of dent, depth of dent, medium carbon steel, shot peening

INTRODUCTION

Shot peening is widely used in the space and automobile industry to improve the reliability of the structures. Because of the increasing of the number of shot peening applications, many researchers study this process. In recent years, finite element methods have been applied to shot peening through the development of computing technology. While many researches work on residual stresses, there is little research on the dent form. The profile of the dent is one of the basic factors influencing surface texture which includes surface roughness and surface characteristics. Surface roughness is an important basic factor for 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 profile of the dent, the dents produced by a single shot have been analyzed using FEM analysis. In addition, shot peening was performed on a medium carbon steel, and then the experimental results were compared with the FEM results when possible.

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. To analyze dent forms, the shot was assumed to have an elasto-plastic behavior with a bilinear isotropic hardening model. In addition, the influence of the size of work material on dent form was also investigated. The geometrical model is axi-symmetric and two-dimensional as shown in Figure 1 and analysis conditions are presented in Table 1 and Table 2. The influence of work material size and shot velocity on the dent profile is discussed. Distance ratio, Depth ratio and Diameter ratio which are important in this analysis are defined as follows.

Distance ratio = Distance from surface or center of impact (mm) / Radius of shot (mm)
Depth ratio = Depth of dent (mm) / Radius of shot (mm)
Diameter ratio = Diameter of dent (mm) / Radius of shot (mm)

Experimental procedures

Several experiments were performed using 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 3. 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 experimental results were compared with numerical ones. In this paper, the dimensions on a dent were defined as shown in Figure 2.

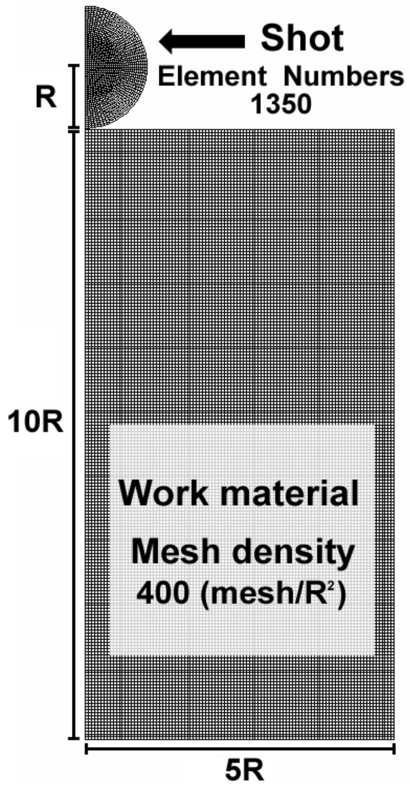

Fig.1 Analysis model (10R×10R)

Table 1. Conditions for analysis

Modeling	Axi-symmetric(two dimensional)	
Shot velocity V m/s	20,30,40,50,100	
	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

Table 2. Work material size (2R = Shot diameter)

Model	Model size	Element numbers
A	10R×10R	20000
B	8R×8R	12800
C	6R×6R	7200
D	4R×4R	3200
E	2R×2R	800

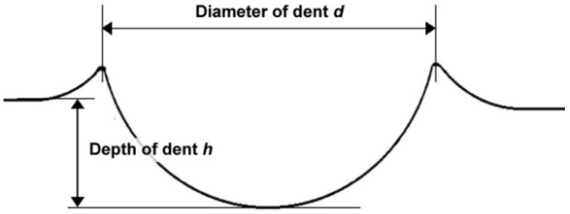

Fig.2 Definition of measured dimensions

Table3. Condition for experiment

Shot	Diameter D mm	0.8, 1.2, 2.0, 3.0
Specimen	Material	Medium carbon steel (S45C)
	Annealing	800℃×2h
	Dimension	25×25×10 mm
Shot velocity V m/s		20, 30, 40, 50

RESULT

The influence of work size

The Influence of work size on dent profile is shown in Figure 3 and Figure 4. In the case of Fig.3 at 20 m/s the dent forms for all five part thickness models are almost the same except E. In the case of Fig.4 at 100 m/s the small size model was different significantly from other models. Clearly model C provides consistent results for all velocities with the fewest elements and thus is the most efficient.

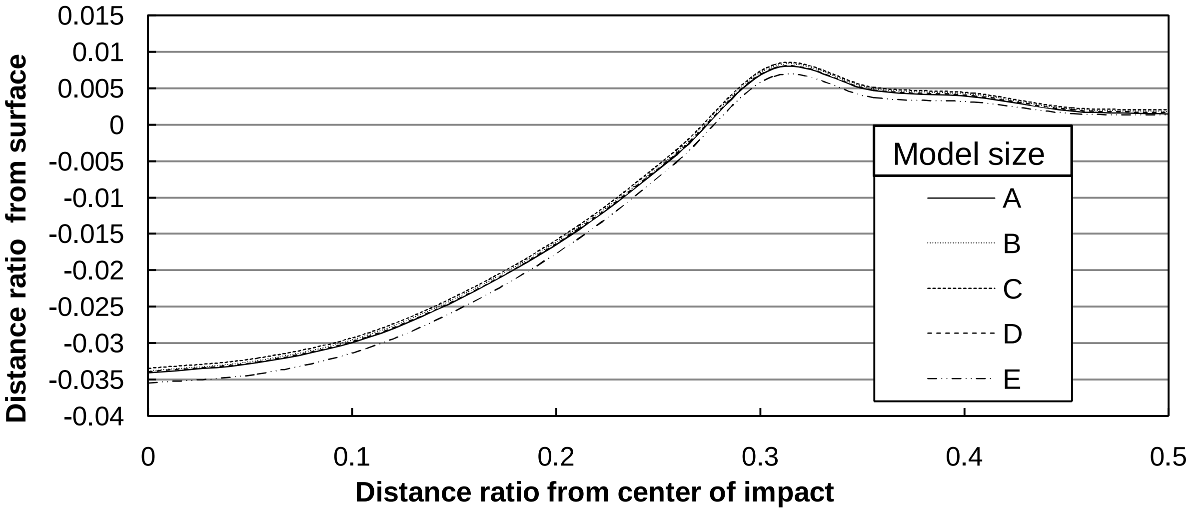

Fig.3 Influence of work size on dent form (Shot velocity: 20 m/s)

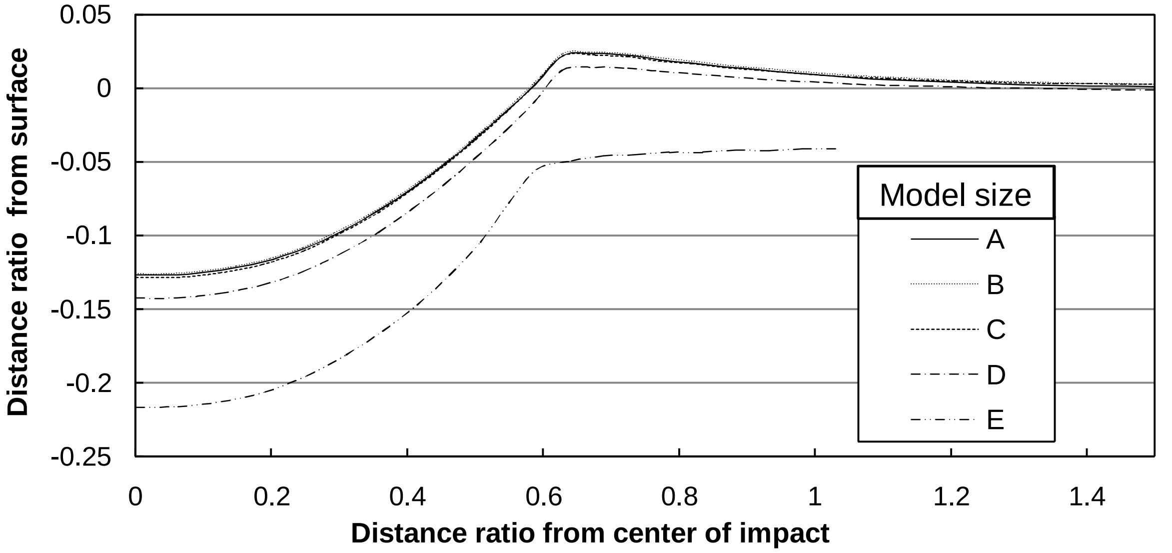

Fig.4 Influence of work size on dent form (Shot velocity: 100 m/s)

Dent profile（FEM）

The influence of the shot velocity on the dent profile is shown in Figure 5. The dent size increases with increasing shot velocity, but its general shape stays constant. The relation between the shot velocity and the diameter of dent is shown in Figure 6. The diameter of the dent is proportional to the power of four-ninths of the shot velocity. The relation between the shot velocity and the depth of the dent is shown in Figure 7. The depth of the dent is proportional to the power of eight-ninths of the shot velocity. The relations are expressed by $d = k_3 v^{4/9}$ and $h = k_4 v^{8/9}$. The relationship $h = k_4 v^{8/9}$ is slightly different from a past result of $h = kv^{9/10}$ (Hirai, 2005). It seems that the reason for the difference is that the composition of the mesh division is different from the past analysis method.

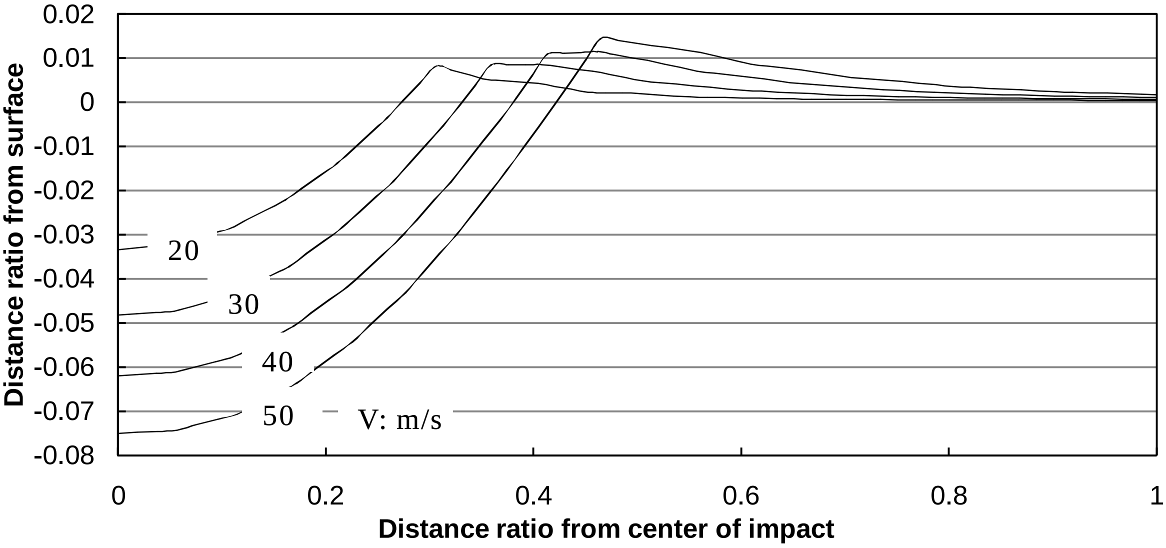

Fig.5 Influence of shot velocity on dent form

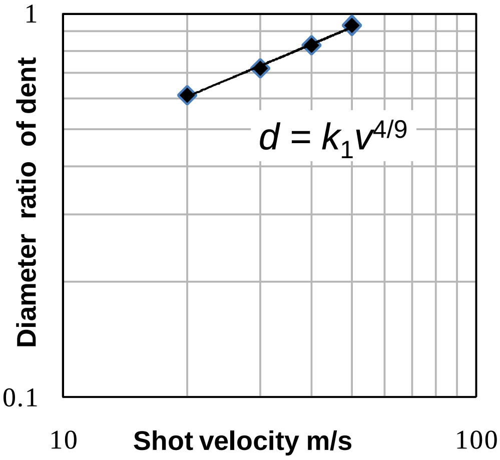

Fig.6 Relation between shot velocity and diameter of dent

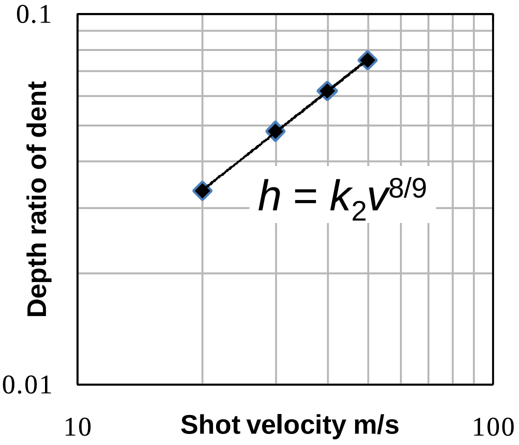

Fig.7 Relation between shot velocity and depth of dent

Dent form（Experiment）

The experimental influence of shot velocity on dent form is shown in Figure 8. The dent size increases with increasing shot velocity in the same manner as the result of the FEM analysis. The numerical results agree well with the experimental results as shown in Figure 9.

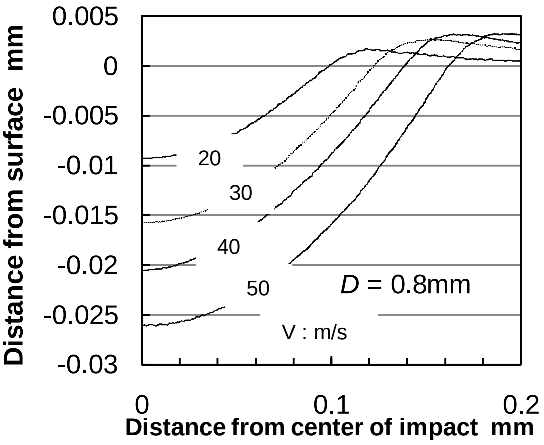

Fig.8 Influence of shot velocity on dent form

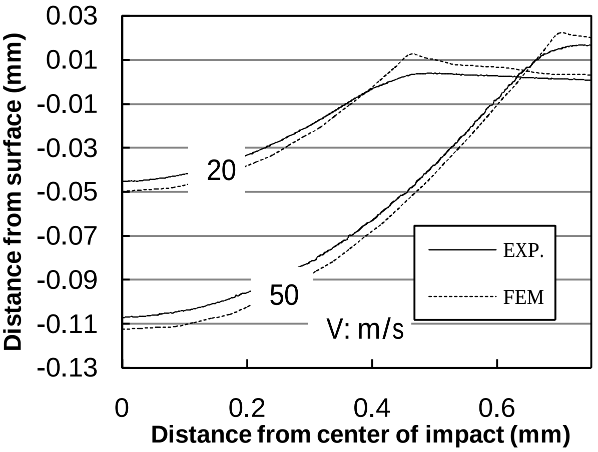

Fig.9 Comparison between experiment and FEM

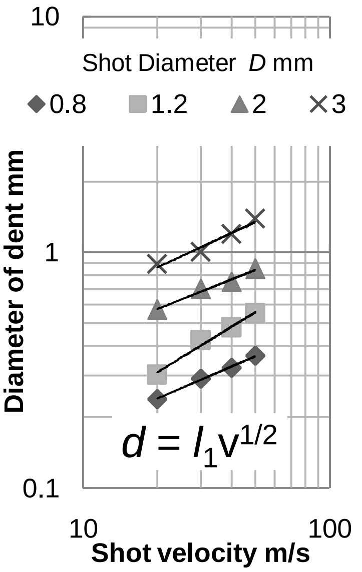

Fig.10 Relation between shot velocity and diameter of dent

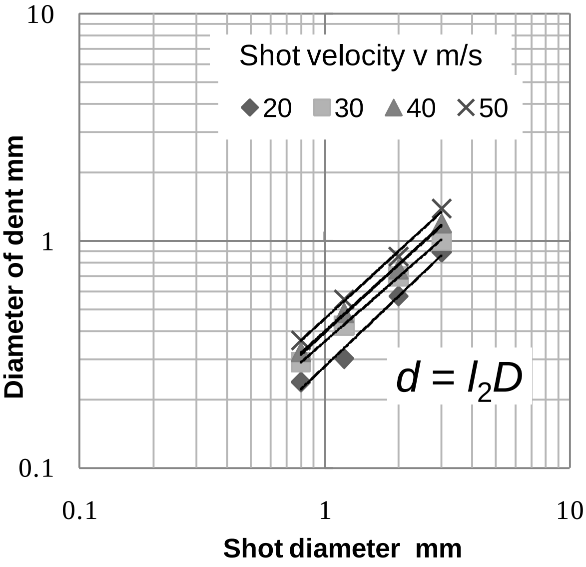

Fig.11 Relation between shot diameter and diameter of dent

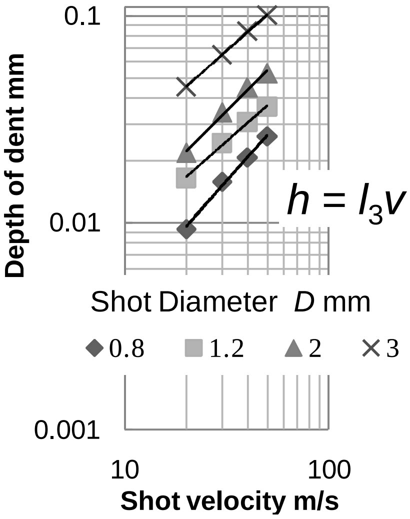

Fig.12 Relation between shot velocity and depth of dent

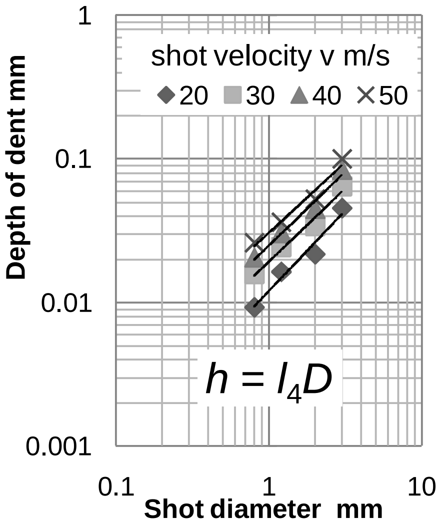

Fig.13 Relation shot diameter and depth of dent

As shown in Figure 10, the diameter of dent is proportional to the shot velocity to the power of one-half. The relation between shot diameter and diameter of dent is shown in Figure 11. The diameter of dent is proportional to the shot diameter. The relation between shot velocity and depth of dent is shown in Figure 12. The depth of the dent is proportional to the shot velocity. The relation between shot diameter and depth of dent is shown in Figure 13. The depth of the dent is proportional to the shot diameter. Finally, the relations can be expressed by $d = l_4 D v^{1/2}$, and $h = l_5 D v$.

CONCLUSION

In this paper, analyses were conducted on a dent form produced by a single shot using a finite element package. The following results were obtained:

(1) The smallest size of work model where dent profiles are accurately expressed is 3 times the shot diameter.
(2) Finite element analysis (FEM) is able to represent almost exactly the dent profile. Thus FEM is available to study the characteristics of peened surface.
(3) Dent size is influenced significantly by velocity and shot diameter.
(4) The following relations are obtained for dent dimensions.

Analysis result : $d = k_3 v^{4/9}$, $h = k_4 v^{8/9}$
Experimental result : $d = l_4 D v^{1/2}$, $h = l_5 D v$

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