Effect of Shot Peening on Surface Texture and Surface Integrity

K. Tosha

Faculty of Mechanical Engineering, School of Science and Technology,
Meiji University, Japan

Abstract
This paper describes the influence of the shot size, the shot velocity and the workpiece hardness on the characteristics of peened surfaces and surface layers. In order to clarify the clear influences of those factors, medium carbon steel（S45C）was peened by a centrifugal type peening machine using 4 different cast steel shots. Following results are obtained;（1）The diameter of dent is in proportion to the shot size and the square root of the shot velocity, and in inverse proportion to the fourth root of the workpiece's hardness.（2）The contact angle of dent is in proportion to 2/3 power of the shot velocity, and the values were varied from 11 to 18°.（3）The surface roughness is in proportion to the shot size and the shot velocity, and in inverse proportion to the square root of the workpiece's hardness.（4）The depth of work hardened layer increases proportionally to the fourth root of the kinetic energy of a shot.（5）Residual stresses in the surface layer induced by shot peening are compressive, and the maximum value in this experiment was about -390 MPa.

Keywords Surface texture, surface integrity, roughness, hardness, residual stress, critical thickness, strain induced transformation.

Introduction

Shot peening is a cold working process improving the mechanical properties such as fatigue [1], stress corrosion cracking [2] and so on [3]. Shot peening is, therefore, widely used in many industries such as aircraft, automobile, machine parts and chemical plants.

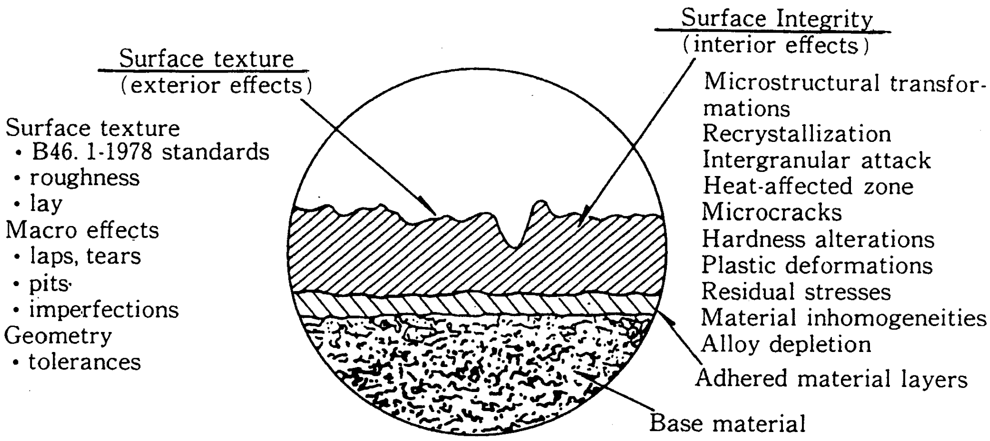
Surface texture and surface integrity, which M. Field and J. Karles first brought forward in 1964, are the description and control of the many possible alternatives produced in a surface and surface layer during manufacturing including their effects on the material performance of the surface in service [4]. As shown in Fig.1 the former concept includes surface roughness and it's layer, and the latter includes hardness alternatives, residual stresses, plastic deformations, heat-affected zone, recrystallization and so on. They influence the strength of workpiece's materials for fatigue, stress corrosion cracking, wear and so on [5].

As mentioned above, shot peening including shot blasting techniques are widely used in many industries, but few systematic studies on surface integrity exist.

In this paper, the influences of those factors - hardness, thickness and crystal phase of workpiece material on surface texture and surface integrity are shown.

Surface Texture and Surface Integrity

As illustrated in Fig. 1, this concept includes hardness alternatives, residual stresses, plastic deformations, heat-affected zone, recrystallization and so on. They are closely related to the strength of workpiece materials for fatigue, stress corrosion cracking, wear and so on.



(Machining Data Handbook)

Fig.1 Surface texture and Surface integrity

Experimental Methods

Experimental conditions on shot peening (SP) treated in this paper are shown in Table1. Hardness was measured on the perpendicular section using Micro Vickers Hardness Testing Machine. Hardness distributions were obtained from averaging data measured on the three positions in the same depth from the peened surface.

Table 1 Experimental conditions

Equipment	Centrifugal type: 15 - 35 [m/s]
Shot : Material, size	Steel : 0.55, 0.92, 1.1, 1.6, 2.2 [mm] Hardness: 650 - 800 [HV]
Peening time	1 [s] -Tf, Tf: Full coverage time
Peening angle	0, 30, 45, 60, 90 [deg] *) *)90[deg]: Normal to the peening surface
Work: Material	Medium carbon steel (0.45%C) Hardness: 180 [HV] Size: 25,25,t, t: 1 - 11.5 [mm]
X-Ray diffraction	Cr-kα, (2 1 1) plane
Residual stress measurement	FWHM middle point method

Experimental Results

1. Surface texture

1.1 Diameter of dent (*d*)

The surface texture is influenced basically by the shape of single dent.

Fig. 2 shows the influences of shot size (*D*), shot velocity (*V*) and work hardness (*H*) on the diameter of dent (*d*), and the following formula is obtained.

$$d = k_d \cdot D \cdot V^{1/2} \cdot H^{-1/4} \qquad (1)$$

where k_d is the coefficient of the formula.

The maximum influence factor in these three ones is, therefore, shot size.

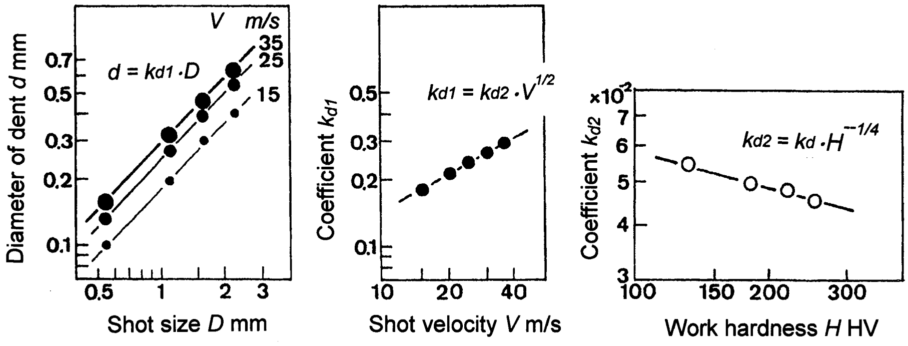


Fig. 2 Influence of shot size (*D*), shot velocity (V) and workpiece hardness (*H*) on diameter of dent (*d*)

1.2 Depth of dent (*h*)

The depth of dent is closely related to the surface roughness and the above mentioned characteristics, and they were calculated assuming the shape of dent is spherical. As shown in Fig. 3, the values were varied from 5 to 50 μm, which ranged from 1/100 to 3/100 times as large as shot size.

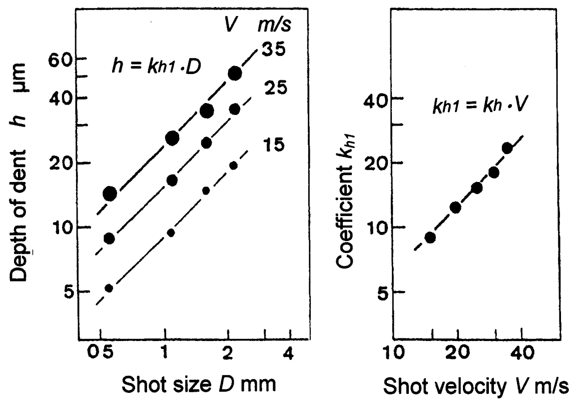


Fig. 3 Influences of size and velocity of shot on the depth of dent

1.3 Contact angle of dent (ψ)

The tribological properties of the peened surface are influenced by the affected layer and the contact angle of dent. Fig. 4 shows the influences of size and velocity of shot on the contact angle of dent. The contact angle is in proportion to 2/3 power of shot velocity and is independent of shot size.

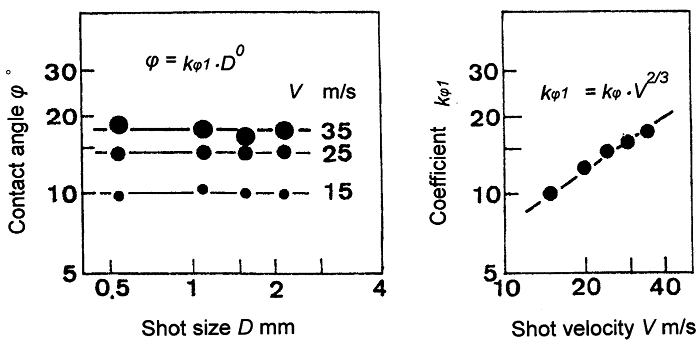


Fig. 4 Influence of shot size and velocity on contact angle of dent

1.4 Surface roughness

The surface roughness is a very important factor relating to fatigue strength, abrasiveness and heat transfer characteristics.

Fig. 5 shows the influences of shot size (D), shot velocity (V) and the work hardness (H) on the surface roughness (R_Z), and the following formula is obtained.

$$R_Z = k_R \cdot D \cdot V \cdot H^{-1/2} \qquad (2)$$

where k_R is the coefficient of the formula.

The maximum influencing factors are, therefore, shot size and shot velocity.

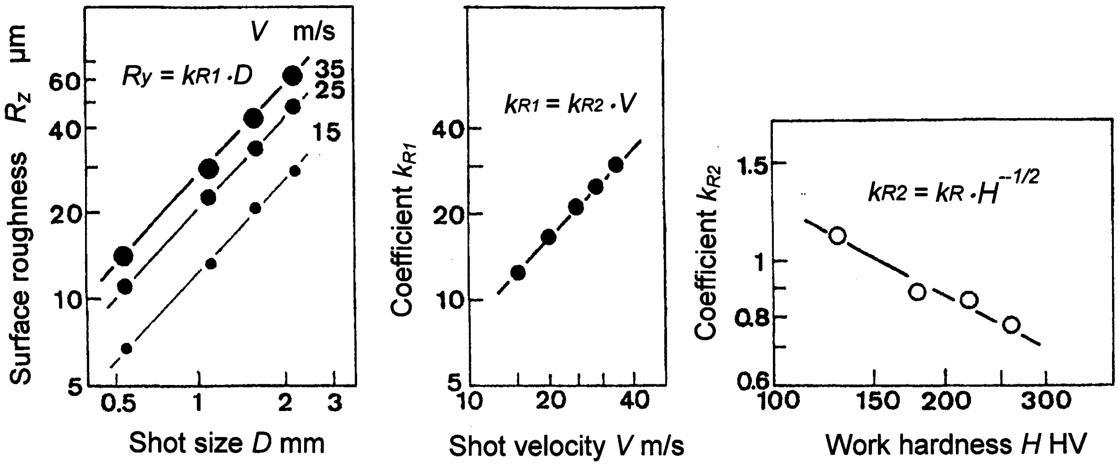


Fig. 5 Influences of shot size (D), shot velocity (V) and work hardness (H) on surface roughness (R_Z)

2. Surface Integrity

2.1 Affected zone

As illustrated in Fig.6, a blasted shot impacts on the surface, and produces a dent and an affected zone. The volume ratio of affected zone to dent is aproximatly from 250 to 300 as shown in Fig.7.

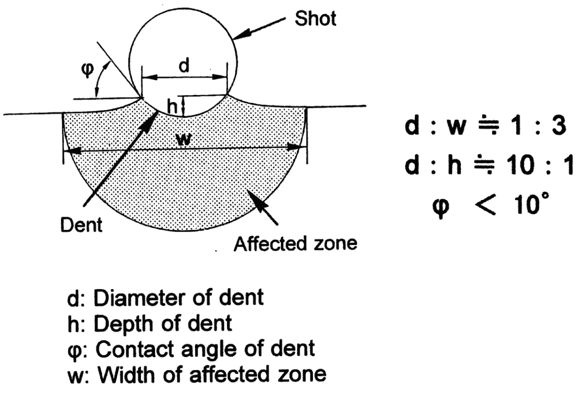


Fig. 6 Affected zone and contact angle

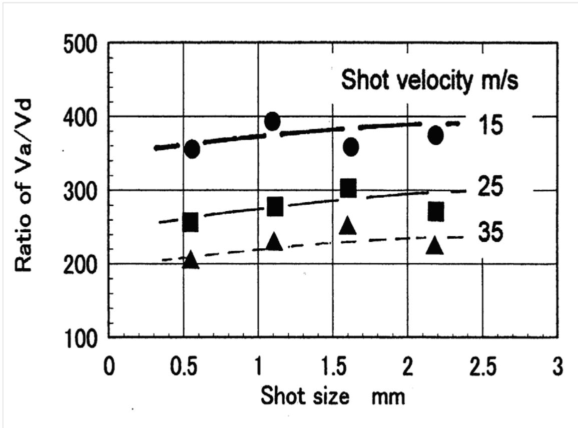


Fig. 7 Ratio of affected zone to dent volume

2.2 Hardness distribution

Although the hardness distribution produced by shot peening for an annealed steel is a work hardening type, the distributions for pre-strained steel shift to other types as shown in Fig.8.

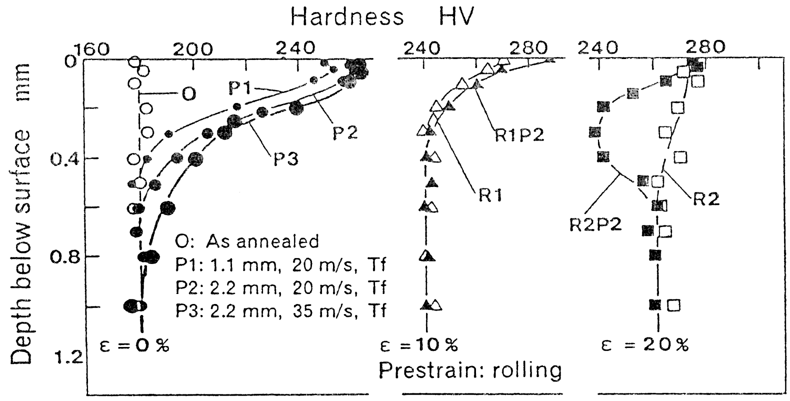


Fig. 8 Hardness distributions

The hardness distribution produced by shot peening changes from a hardening type to non-hardening and then to a softening one with an increase of pre-strain (ε), and the depth of the work hardened layer decreases as pre-strain increases. Thus it is, therefore, not sufficient to judge the depth of affected layer using only the hardness distribution.

2.3 Residual stresses

2.3.1 Influence of peening time, size and velocity of shot

Fig. 9 shows the influence of peening time on area coverage and surface residual stresses induced by shot peening. In the early stage, they increase rapidly, and then they approach saturated values when over 80 % of area is peened. Therefore, in the saturated case as shown in Fig. 10, surface residual stress is not sensitive to peening conditions,or the influences of both factors are negligible.

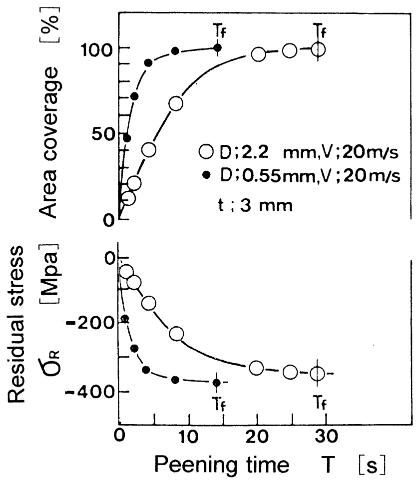


Fig. 9 Influence of peening time on area coverage and surface residual stress

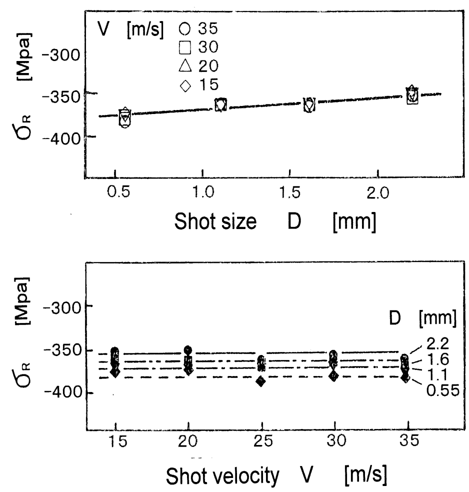
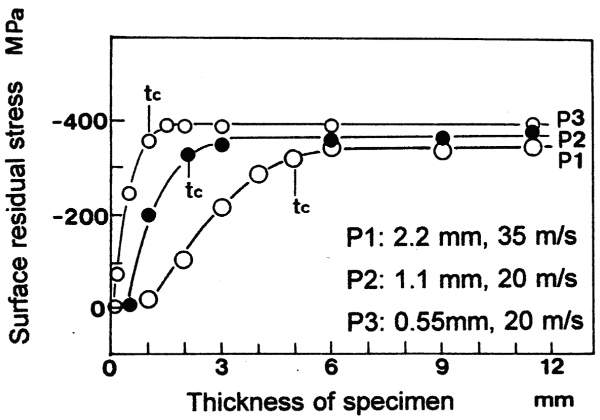


Fig. 10 Influence of shot size and shot velocity on surface residual stress

2.3.2 Influence of thickness of specimen

Fig. 11 shows the effect of the thickness of specimen on the surface residual stresses. Critical thickness (t_c) means the minimum thickness for efficient introduction of compressive residual stresses. Surface residual stresses fall to zero wherever the thickness of work material and those depths of work hardened layer are overlapped. Fig. 12 shows the relation between the critical thickness and the depth of work hardened layer.



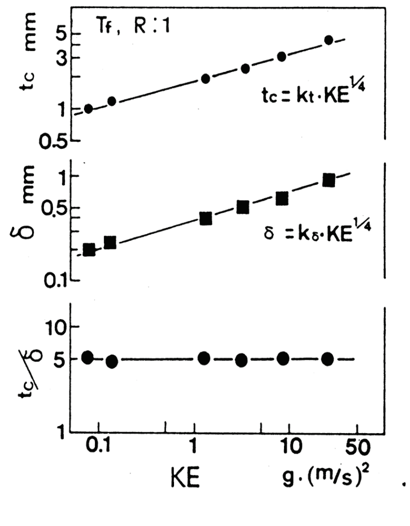


Fig. 11 Influence of thickness of specimen on surface residual stresses

Fig.12 Relation between critical thickness and the depth of work hardened layer(δ)

Conclusions

(1) The diameter of dent is in proportion to the shot size and the square root of the shot velocity, and in inverse proportion to the fourth root of the workpiece hardness.
(2) The contact angle of dent is in proportion to 2/3 power of the shot velocity, and the values were varied from 11 to 18 °.
(3) The surface roughness is in proportion to the shot size and the shot velocity, and in inverse proportion to the square root of the work hardness.
(4) The depth of work hardened layer increases proportionally to the fourth root of the kinetic energy of a shot.
(5) Residual stresses in the surface layer induced by shot peening are compressive, and the maximum value in this experiment was about -390 MPa.
(6) The ratio of critical thickness to the depth of work hardened layer is approximately 5.

References

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