A STUDY ABOUT DENT OF SHOT PEENING AND ITS APPLICATION IN RESIDUAL STRESS FIELD CALCULATION

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ABSTRACT

By pressing GCr15 steel balls with different diameters statically into 40Cr steel targets with different hardness, the relationship among diameter of dent, load, diameter of ball and mechanicall property of target material was studied. From the test results a method to determine the equivalent load during shot peening was proposed. Using the equivalent load, we can calculate the residual stress field in duced by shot peening according to an analytical model proposed by the authors. The calculated results were verified by experimental data quite well.

KEYWORDS

Shot peening, Residual stress, Dent

NOMENCLATURE

D	Diameter of ball or shot
F	load
S_b, ε_b	True stress and true strain at necking in tension
D_s	Diameter of dent after static pressing
D_d	Mean diameter of dents due to shot peening or impacting
E, υ	Young's modulus and Poisson's ratio
σ_s, ε_s	Yield stress and Yield strain
σ_b	Ultimate tensile strength
δ	Elongation
ψ	Reduction of area

INTRODUCTION

It is well known that formation of a favorable compressive residual stress field in the surface layer is an important strengthening mechanism of shot peening. An analytical model for calculating such stress field has been proposed by the authors [1]. But in order to calculate the stress field with this model, the equivalent load of peening should be correctly estimated firstly.

On the basis of rigid-perfectly plastic analysis, an useful equation to calculate average load of impact, F, was proposed [2]

$$4F/(\pi D^2 \sigma_s) = 0.6 + (2/3) \operatorname{Ln} (ED_d/\sigma_s D) \quad (1)$$

But when a work hardening target is considered, the equation should be modified. By falling diverse steel balls under gravity onto specimens, K.Iida gave [3]

$$F = K_1 D^{1.97} \cdot \upsilon^{1.10} \quad (2)$$

$$D_d = K_2 D \cdot \upsilon^{0.5} \quad (3)$$

Where F is the equivalent load of impact, υ is the velocity of the ball, and K_1 and K_2 are constant for material. From Eq.(2) and (3), the relationship between F and Dd is

$$F = K \cdot D_d^{2.20}/D^{0.23} \quad (4)$$

Where K is also constant for target material. Because only one kind of target material was used in that work, the rule of variation of K with target materials was not clear yet.

In the present work, systematical static pressing experiments were carried out with different balls and targets under different loads. From the test data, a new relationship between F and D_s was built and was used in calculation of residual stress field induced by shot peening.

EXPERIMENTAL PROCEDURE

The specimens of 20×20×10 mm used in this study were made of 40Cr steel, the chemical composition of which is 0.41C-0.72Mn-0.91si-1.0Cr-0.08Ni (weight %). Having been quenched at 840° C and tempered at 200℃, 400℃, 550℃ and 650° C, the mechanical properties of target materids were measured and are given in Tab.1.

Tab.1 Mechanical Properties of Targets

Sample symbol	Tempering temperature	σ_s, Mpa	σ_b, Mpa	δ, %	ψ, %	Hardness HRC
A	200℃	1420	1910	6.2	20.2	52
B	400℃	1270	1460	9.5	43.4	45
C	550℃	980	1120	13.7	50.5	35
D	650℃	700	750	23.4	67.7	21

In order to eliminate the residual stresses introduced by heat-treatment and machining operations, the specimens were annealed at 180° C for 48 hours and then a thickness of 50 μm was removed by electrolytic polishing.

Static pressing experiments were caried out by using GCr 15 steel balls which had hardness of HRC 63 and were 0.50、0.68、0.80、1.00 and 1.30 mm in diameter. The balls were pressed upon the specimens with different loads. The loading range was 45－450N and the interval of loading was about 25N. After unloading the diameters of dents, D_s, were measured on microscope. In order to study the effect of hardnesses of balls on dent diameters, the balls with diameter of 1.00 mm were tempered at 260℃ and 340℃ for two hours to get a hardness of HRC 56 and HRC 51, and then pressed upon specimens “A” and “C” under loading of 270N. The dent diameters were also measured.

Tentative shot peening was carried out on an air-blast machine at 0.2－0.4 MPa pressure. The cast steel shots used in peening had hardness of HRC 52－58 and average diameters of 0.55 and 1.10 mm. The specimens were peened at a given pressure for extremely short time. The diameters of 50 peening dents were measured under microscope for every peening condition and median dent diameters, D_d, were obtained. Full-coverage peening procedures were performed at the same conditions, but the peening times were properly changed to acguire 100% coverage rate. After full-coverage peeing the compressive residual stress distribution in the surface layer were measured on an X-ray diffractometer by using a step-by-step electrolytical method.

RESULTS AND ANALYSIS

The experimental results of static pressing with GCr15 steel balls of 1.30 mm and 0.80 mm in diameter are given in Fig.1, as example . From the test data in Fig.1, a relationship among D_s, F, D and S_b can be obtained

$$D_s = aF^n \quad (5)$$

$$a = (16.00 + 7.5D) + 1.66(1 + D)(2.30 - S_b/1000)^3$$

$$n = 0.482(1-0.1D)$$

Where D_s and D are in μm and mm, inspectively, and F and S_b are in N and MPa, respectively. Curves calculated according to Eq.(5) are also drawn in Fig.1, which shows a good coincidence with the experimental data.

The experimental results of steel balls of hardress HRC 56 and 51 are given in Tab.2 in which D_s are experimental values and F are calculated according to Eq.(5). It can beseen that, in the range of this work, the influence of hardness of steel balls on dent diameter may be neglected.

Tentative peening results are given in Tab.3,in which D_d is the diameter of peening dent. Substituting D_s in Eq.(5) by D_d, we may obtain the equivalent load F during shot peening . By using the calculated F values , compressive residual stress fields under eight kinds of peening conditions were calculated according to a analytical model and its program proposed by the authorw [1.4]. Some parameters inserted into the program are also listed in Tab.3 and calculated stress fields are drawn in Fig.2 . It can be seen that the computed curves show a good coincidence with experimental data.

DISCUSSION

In order to calculate compressive residual stress field produced by shot peening, the relationship between dent diameter D_d and equivalent load F must be determined

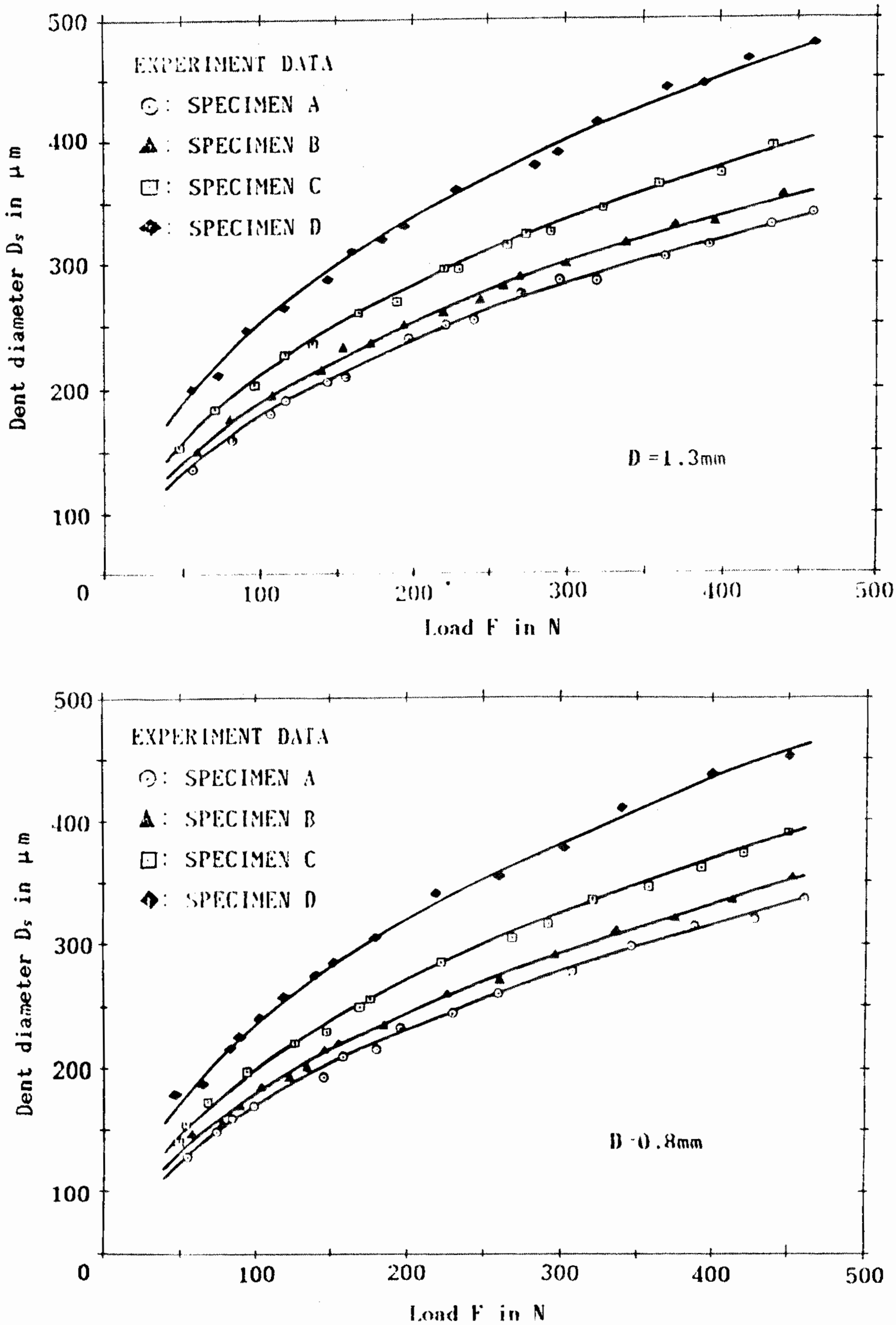

Fig.1 Relationship betwen dent diameter and load

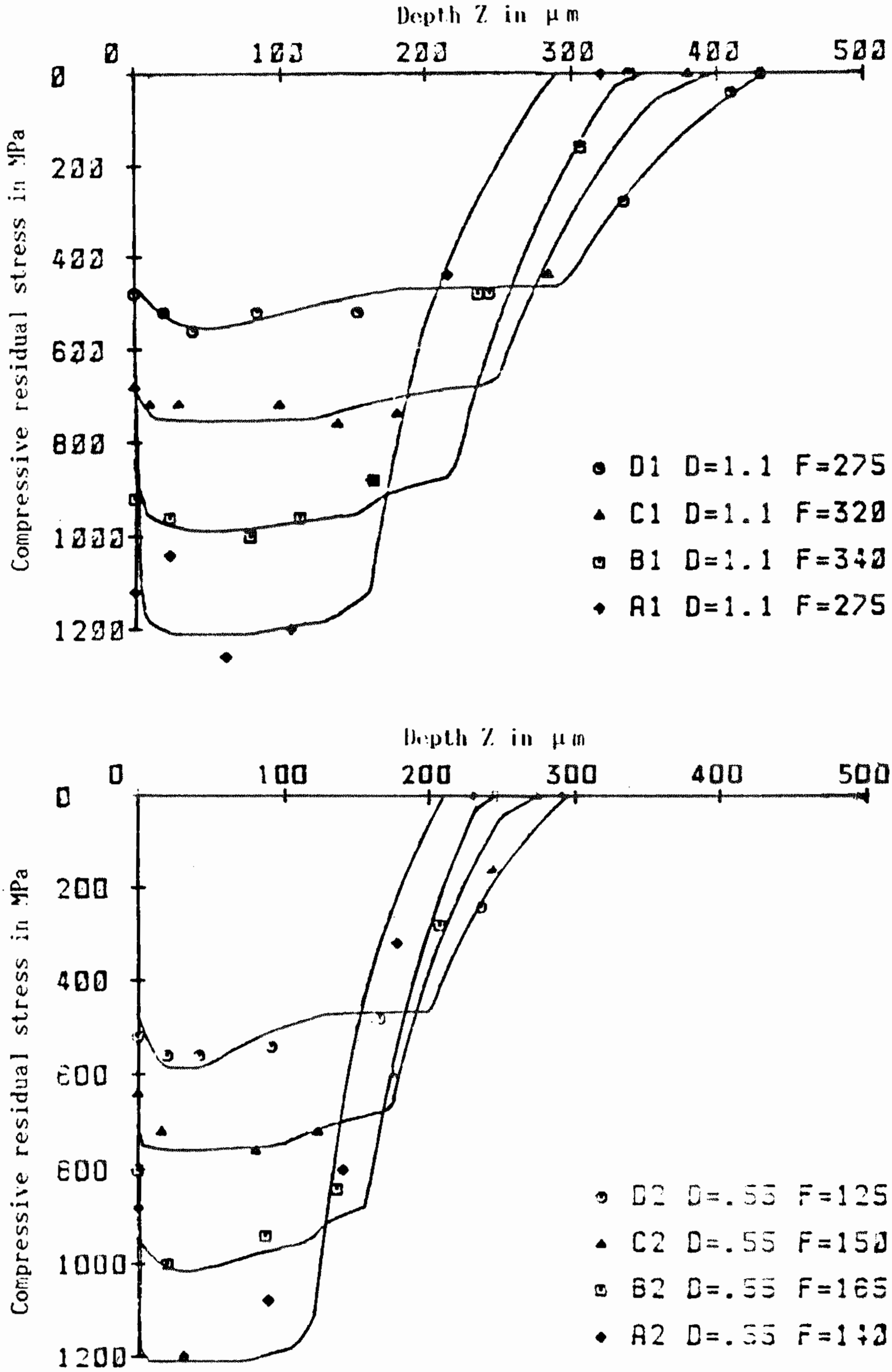

Fig.2 Calculated curves of compressive residual stress field and its experimental verification

firstly. But since the relationship is very complex and is effected by many factors, its accurate analytical equation could not be given by elastic-plastic mechanics at the present time. Therefore, experimental study was taken in this paper.

From the analyses carried above, it can be seen that, using D_d, we can determiine

Tab.2 Effect of Hardness of steel Ball on Dent Diameter
(Applied load F=270N, D=1.00 mm)

Hardness of slell ball, HRC	Specimen A		Specimen C	
	D_s, μm	F, N	D_s, μm	F, N
63	268	270	315	270
56	272	279	316	272
51	274	284	319	277

Tab.3 Some Parameters for Calculating Compressive
Residual Stress Field

Symbol of specimens	D, mm	D_d, μm	F, N	E, $\times 10^5$MPa	ν	σ_s MPa	ε_s $\times 10^{-3}$	S_b MPa	ε_b
A 1	1.10	272	275	2.0	0.3	1420	7.1	1950	35.0
A 2	0.55	192	140	2.0	0.3	1420	7.1	1950	35.0
B 1	1.10	314	340	2.0	0.3	1370	6.9	1540	45.0
B 2	0.55	218	165	2.0	0.3	1370	6.9	1540	45.0
C 1	1.10	341	320	2.0	0.3	980	4.9	1210	66.0
C 2	0.55	230	150	2.0	0.3	980	4.9	1210	66.0
D 1	1.10	380	275	2.0	0.3	700	3.5	885	140.0
D 2	0.55	247	125	2.0	0.3	700	3.5	885	140.0

the compressive residual stress field in the surface layer which is an important

DISCUSSION

In order to calculate compressive residual stress field produced by shot peening, the relationship between dent diameter D_d and equivalent load F must be determined firstly. But since the relationship is very complex and is effected by many factors, its accurate analytical equation could not be given by elastic-plastic mechanics at the present time. Therefore, experimental study was taken in this paper.

From the analyses carried above, it can be seen that, using D_d, we can determiine the compressive residual stress field in the surface layer which is an important factor governing the improvement effect due to shot peening. Furthermore, as proposed in Ref [4], D_d can be used to evaluate the surface roughness after peening, which also shows lavge influence on effectiveness of shot peening. In Ref [5], we have proposed a method for quantitatively estimate the effectiveness of shot peening in fatigue property, in this method D_d plays an important role.

Then D_d can be defined as a new parameter for evaluating peening intensity. As we know, Almen intensity is widely used in industry, but there are some very important problems that have not been solved yet. Because the Almen strips and mechanical parts are not made of the same material, Almen intensity could not exactly experss the compressive residual stress field formed during shot peening, and then, the strengthening effectiveness of peened parts. For different target materials, or even for the same target materials but peened under different combination of parameters, peening with the same Almen intensity may obtain different residual stress field. A typical example is given in Fig.3. The peening conditions of specimens used in Fig.3 are listed in Tab.4. It can be seen that although specimen A121 and A531 have the same Almen intensity of 0.34Amm, the thickness of compressive residual stress zone of A121 peened with larger shots is greater than that of A531. For specimen C the similar tendency also exists.

However, if D_d is taken as an intensity parameter, those problems will be solved well. Since D_d is measured from the peened parts, it can directly express the effect of peening on parts. Now it is worth offering that before peening practice, a tentative peening should be carried out to obtain D_d parameter, and to estimate residual stress field and surface roughness. If the D_d is suitable , then peening practice can be done with the same technical parameters and enough time; otherwise, the technical parameters should be changed to obtain suitable D_d and optimum

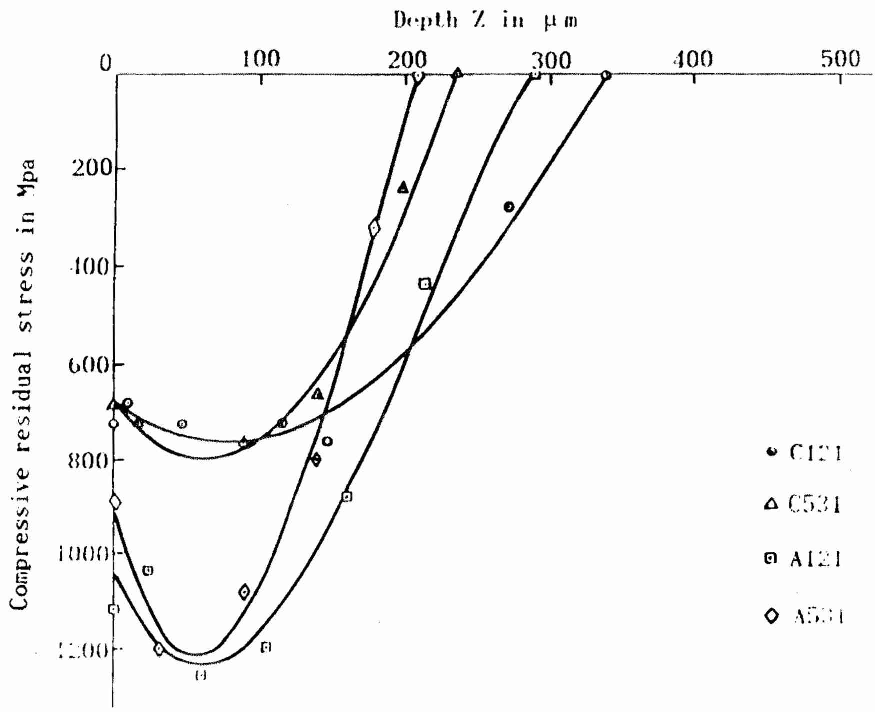

Fig.3 Different compressive residual stress field induced by peening with the same Almen intensity

Tab.4 Peening Conditions

symbol of sample	Median diameter of shots, mm	air pressure, Mpa	coverage rate, %
A121	1.10	0.2	100
A531	0.55	0.3	100
C121	1.10	0.2	100
C531	0.55	0.3	100

strengthening effectiveness.

CONCLUSIONS

In this paper change rule of static pressing and peening dents of 40Cr steel and its application in shot peening were studied, and some conclusions were drawn out

1. Diameter of static dent, D_s, can be expressed as

$$D_s = aF^n$$
$$a = (16.00 + 7.5D) + 1.66(1 + D)(2.30 - S_b/1000)^3$$
$$n = 0.482(1 - 0.1D)$$

where D_s and D are in μm and mm, respectively, F and S_b are in F and MPa, respectively.

2. Equivalent load F can be used to calculate compressive residual stress field produced by shot peening.

3. Peening dent D_d can be defined as a new parameter for evaluation of peening intensity.

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