A NEW CONCEPT FOR FATIGUE STRENGTH EVALUATION OF SHOT PEENED SPECIMENS

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ABSTRACT

In this paper, a new concept about the reason for improvement in fatigue property due to shot peening is suggested. It has been found that, for optimumly peened and/or peened and then ground specimens, fatigue failures nearly always start at some subsurface points where tensile residual stresses occur. Stress calculations show that the values of local fatigue strength at positions of fatigue source are about the same for these specimens, although their peening conditions are quite different. Then, it is reasonable to assume that, for a given material there should exist another kind of fatigue strength, namely, internal fatigue strength (IFS) which is different from fatigue strength in common sense (which should be called as surface fatigue strength (SFS) in our opinion). It has been established that the IFL of the steel used in our work is higher than its SFS for about 35%. This may be another important reason, besides compressive residual stress, responsible for improvement in fatigue property of shot peened specimens. Based on this concept, a method for calculation of fatigue strength of optimumly peened and/or peened and then ground specimens has been developed.

KEYWORDS: shot peening, residual stress, fatigue strength

NOMENCLATURE

Z_0	Thickness of compressive residual stress layer induced by shot peening
Z_s	Depth of point at which fatigue source occurs
FS	Nominal fatigue strength for a 5×10^6-cycle life under three-point bending test condition with stress ratio equal to 0.05
LFS	Local fatigue strength at the point where fatigue source occurs
IFS	Internal fatigue strength for a given material
SFS	Surface fatigue strength, i.e. fatigue strength for a given material in a common sense

INTRODUCTION

As a general consideration, it is believed that the improvement in fatigue property of metal parts after peening is due chiefly to the formation of residual stress and strain hardening effect in the surface layer. But in some cases, the fatigue sources are often located at points where only tensile residual stresses are present, but neither compressive residual stress nor strain hardening effect has occured. Therefore there must exist some other factors which are responsible for the improvement effect due to shot peening. In present paper, this problem will be discussed.

MATERIAL AND EXPERIMENTAL WORKS

A 40Cr steel with chemical compositions 0.41C-0.72Mn-0.91Si-1.0Cr (weight %) were used in this work. Having been quenched from 840°C and then tempered at 200°C, eight groups of specimen of $10\times15\times50$mm were shot peened with cast balls, different in diameter, under different conditions. The shot peening and test coditions were listed in Tab. 1.

Tab. 1 Shot peening and test conditions of specimens

Symbol of Specimen	Shot peening conditions			Test conditions
	Mean dia. of shots, mm	Air pressure Mpa	Coverage rate, %	
A000				As-heattreated
A512	0.55	0.1	200	As-shot-peened
A523	0.55	0.2	300	As-shot-peened
A121p20	1.10	0.2	100	Shot peened and ground off from surface for 0.02 mm
A143p50	1.10	0.4	300	Shot peened and ground off from surface for 0.05 mm
A166p50	1.10	0.6	600	Shot peened and ground off from surface for 0.05 mm
A121	1.10	0.2	100	As-shot-peened
A143	1.10	0.4	300	As-shot-peened
A166	1.10	0.6	600	As-shot-peened

Compressive residual stress fields formed during peening were measured on a X-ray diffractometer and are given in Fig.1
Three-point bending fatigue tests were carried out on an Amsler test machine with stress ratio of 0.05. The FSs of specimens for a 5×10^6 cycle life are given in Tab.2. In Fig.2, relationships between FS and Z_0 are shown. Z_0 is the thickness of compressive residual stress zone which can be used as a new parameter for evaluation of peening intensity [1]. The values of Z_0 are also given in Tab.2

Tab.2 Some experimental and calculated data of tested specimens

Symbol of specimen	FS, Mpa	Z_0 mm	Z_s, mm	Calculated stresses at fatigue source		
				LRS, Mpa	LAS, Mpa	LFS, Mpa
A000	1060	0	0	0	1060	1060
A512	1260	0.11	0.13	150	1230	1380
A523	1320	0.18	0.24	170	1260	1430
A121p20	1340	0.26	0.36	190	1240	1440
A143p50	1350	0.33	0.47	220	1220	1440
A166p50	1360	0.42	0.62	234	1190	1430
A121	1330	0.28	0.32	--	--	--
A143	1280	0.38	0	--	--	--
A166	1210	0.47	0	--	--	--

LRS--Local tensile residual stress
LAS--Local applied stress under nominal fatigue strength.

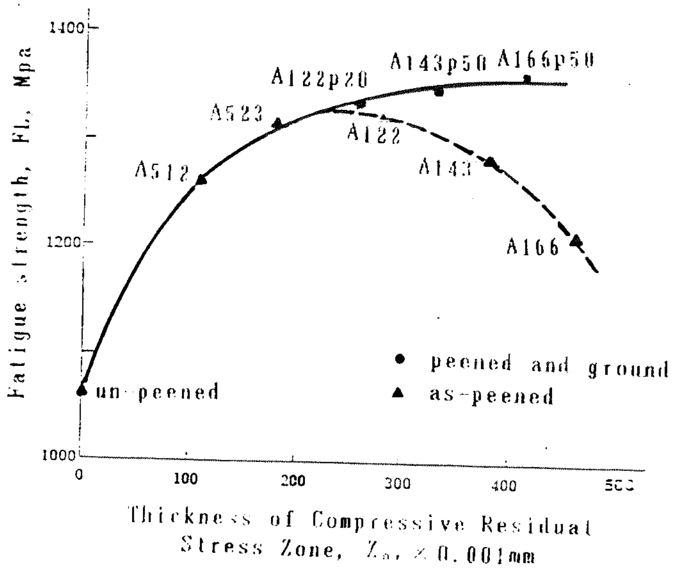
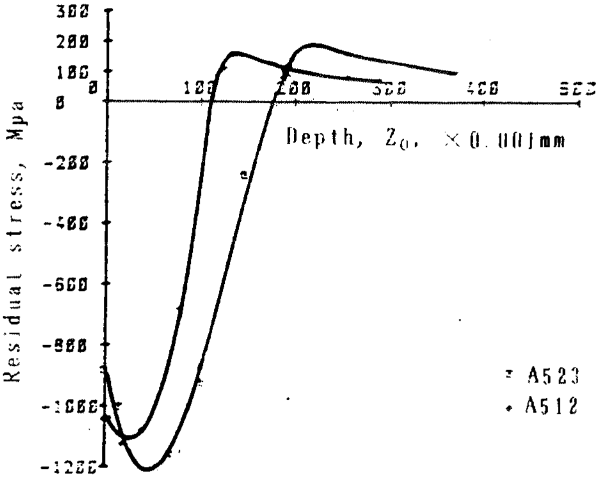
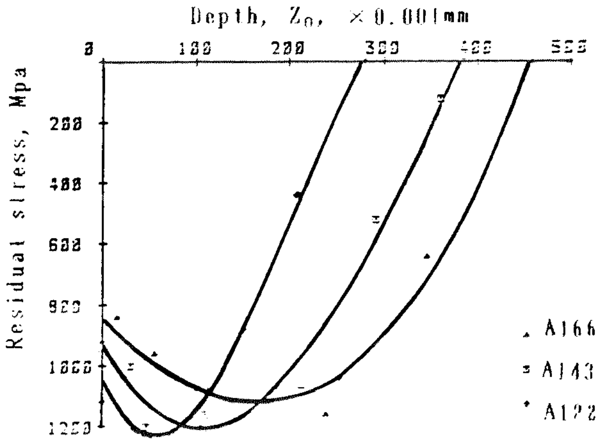


Fig. 2 Variation of FS with Z_0



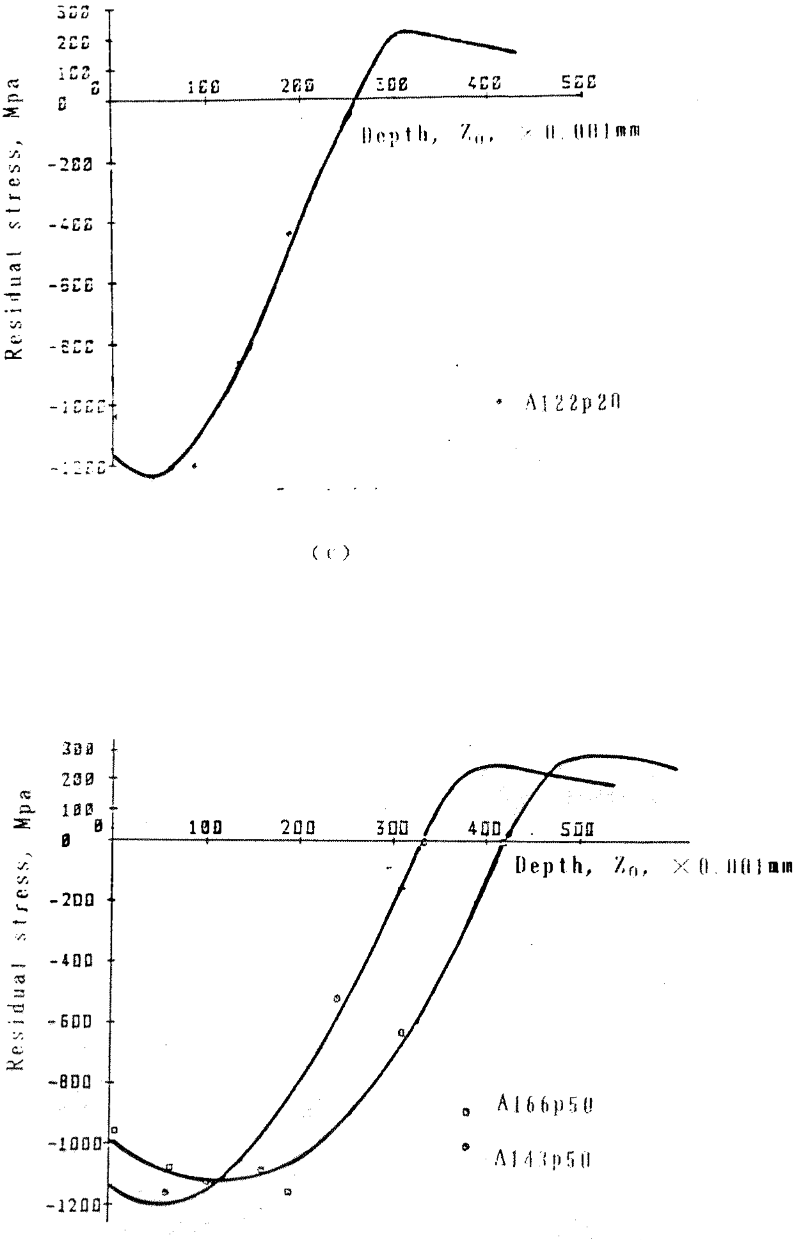
300
200
100
0
-200
-400
-600
-800
-1000
-1200
0
100
200
300
400
500
Residual stress, Mpa
Depth, Z₀, ×0.001mm
A523
A512

(a)



Depth, Z₀, ×0.001mm
0
100
200
300
400
500
200
400
600
800
1000
1200
Residual stress, Mpa
A166
A143
A122

(b)



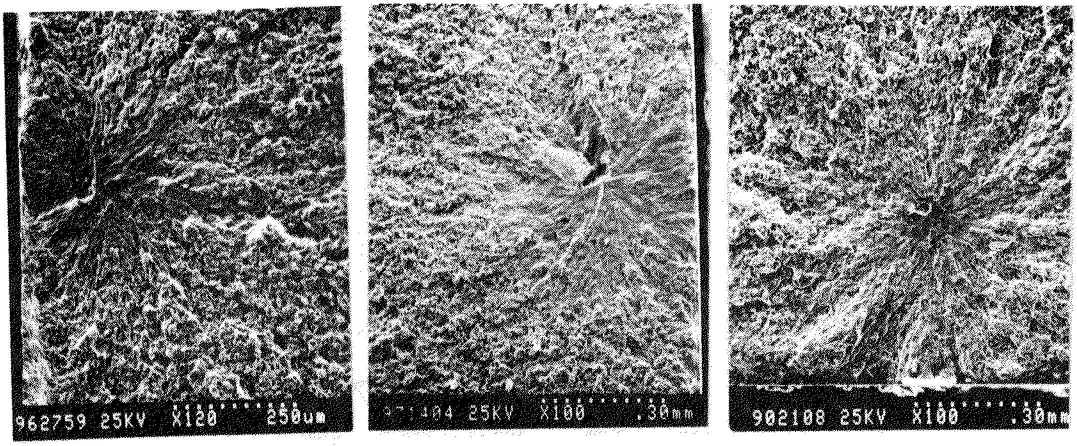
(c)

(d)

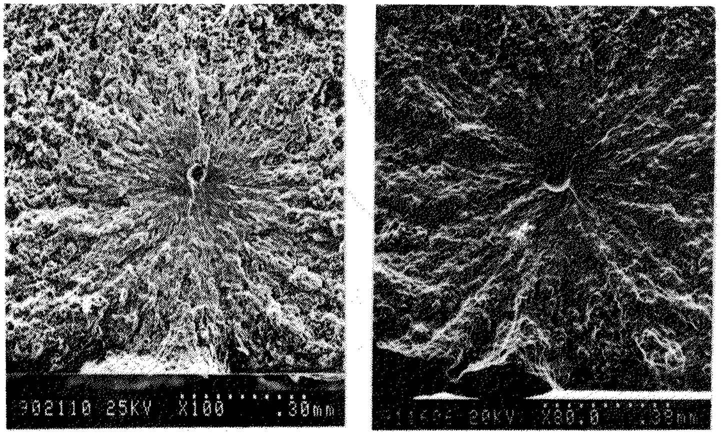
Fig.1 Residual stress stress field of investigated specimens

Fractographical SEM analyses were carried out for specimens broken at stress a little higher than FS. Some examples are given in Fig. 3. From these analyses, the depth of fatigue sources Z_S was measured and are also listed in Fig. 3.

It can be seen from Tab. 2 and Fig. 2 that, for as-peened (unground) specimens, the FS versus Z_0 curve can be divided into two segments: at lower Z_0 segment, the FS increases with Z_0 and the fatigue sources are displaced from the surface (for un-peened specimen A000) to the interior (A512, A523); while at the higher Z_0 segment (over-peened specimens A121, A143, A166), the FS decreases with increasing in Z_0 and the fatigue sources return to the surface again. But when the over-peened specimens are ground after peening to eliminate the damaged surface layers (A121p20, A143p50, A166p50), the fatigue performance will be “ recovered”, the fatigue sources will appear in the interior again and the FS will return to a high level and still increase (but slightly) with Z_0.



(a) A512　　(b) A523　　(c) A122p20



(d) A143p50　　(e) A166p50

Fig. 3 SEM fractographs of specimens in which fatigue source is in tensile residual stress zone

DISCUSSION

Comparing values of Z_0 and Z_S in Tab.1, we can find that, for those specimens, the fatigue source of which was located in the interior, Z_S were always higher than Z_0, that is to say, failures always started in the tensile residual stress zones, which were beneath the compressive residual stress layer. In order to clarify the critical fatigue stress or the local fatigue strength LFS at the fatigue source, the local resultant stress at there can be calculated as

$$LFS = LAS + LRS \tag{1}$$

where LAS is the local applied stress at the fatigue source which can be calculated from nominal fatigue strength FS of specimen,
LRS is the local tensile residual stress.

LAS can be determined from FL and Z_S

$$LAS = \frac{h - 2Z_S}{h} \cdot FL \tag{2}$$

where h is the thickness of specimen.

According to finite element calculation carriedout by authors[1], tensile residual stress introduced during peening can be expressed as

$$\sigma_t = \frac{(Z - Z_0)^{1.35}}{a(Z - Z_S)^2 + b} \tag{3}$$

where Z is the distance from surface,
a and b are constants depending on compressive residual stress field.

By substitution of Z_S for Z in Eq.3, LRS can be determined

$$LRS = \frac{(Z_S - Z_0)^{1.35}}{a(Z_S - Z_0)^2 + b} \tag{4}$$

The calculated LRS, LAS and LFS are also listed in Tab.2

It can be seen from Tab.2 that, except A512, for all other specimens, the fatigue of which starts in the interior, the values of LFS are about the same and approximately equal to 1430 Mpa. Then, it is reasonable to assume that, for a certain material, there should exist another fatigue strength, named "internal fatigue strength", which is also a characteristic parameter of material property and is independent of shot peening conditions. Fatigue failure will take place, when resultant stress of LAS and LRS at a certain point is over the IFS of target material. Since the fatigue failure of unpeened specimens always starts at the surface, their nominal fatigue strength should be called as "surface fatigue strength" SFS. The SFS of steel used in this work is 1060 Mpa. It can be seen that the IFS is higher than SFS and the ratio of IFS to SFS is equal to 1.35.

Now, it is clear that an important reason for improvement in fatigue performance of specimens after peening and grinding is that the existence of compressive residual stress in the surface layer displaces the crack initiation location from the surface into the interior where the higher internal fatigue strength makes the failure take place at higher applied stress.

It is believed[1]that the fact that the ratio of IFS to SFS is approximately equal to 1.35 is valid not only for particular material as used in this work, but also for other materials. Furthermore, a method for determination of compressive and tensile residual stress field after peening has been proposed[2]. Then, the nominal fatigue strength of peened and then ground specimens can be predicted, if the SFS, i.e. the fatigue strength of un-peened specimen is known. This problem will be discusses in another paper of authors[3].

REFERENCES

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