93073

A COMPREHENSIVE EFFECT THEORY FOR PREDICTION AND OPTIMIZATION OF FATIGUE IMPROVEMENT INDUCED BY SHOT PEENING

Li Jinkui Wang Shengping Shao Peige and Yao Mei*

Department of Metals Science and Technology, Harbin Istitute of technolgoy, Harbin, 150006, P. R. China

Wang Renzhi* and Li Xiangbin

Institute of Aeronautical materials Beijing, Beijing, 100095, P. R. China

ABSTRACT

A theory , in which the main influential changes induced by shot peening, the location of fatigue crack source and the fatigue properties of matrix metal are considered comprehensively , is proposed for evaluating the fatigue improvement of shot peened specimens. Two formulae are put forward to calculate the possible values of apparent fatigue strength of shot peened spencimens, by assuming the crack source is located either at the surface or in the subsurface region beneath the hardened surface layer. The apparent fatigue strength is related to different series of factors if crack source is located at different position. An "internal fatigue strength" of metal (which is about 35% higher than "surface fatigue strength" of the same meteal) is used in the case when the crack initiates in the subsurface region.

The actual value of apparent fatigue strength of shot peened specimens should be the smaller one between the two caculated ones. The optimum improvement is achieved when the predicted values get to maximum. This method for evaluating the fatigue improvement after shot-peening is verified by experimental results of a commmercial steel 40Cr, shot peened under different coditions.

KEYWORDS

Shot peening, Residual stress, Fatigue strength

* Correspondents

INTRODUCTION

The main changes produced by shot peening in machine parts are creation of a residual stress field and a change in surface roughness. But so far only the strengthening effect of the compressive residual stress field has been studied. Recently a comprehensive effect theory for shot peening strengthening is put forward[1] [2] [3]. This paper proposes a procedure for prediction and optimazation of shot peened machine parts based on this theory.

THE PROCEDURE FOR PREDICTING FATIGUE STRENGTH

To predict the fatigue strengths of shot peened parts, the knowledge of the laws according to which the fatigue strength changes with the peening parameters is necessary. The fatigue source of shot peened specimen may be located at the surface or in the subsurface region beneath the hardened layer. In these two cases the laws are different.

1. The Tatigue Strength Prediction when the Fatigue Source is Assumed to be at the Surface

When the fatigue crack initiates at the surface, three factors dominate the fatigue strength. One factor is the surface fatigue strength (σ_{ws}) of the material i.e. the fatigue strength of the unpeened specimen. Another factor is the compressive residual stress at the surface (σ_r^s) produced by shot-peening which can be regarded as a variation of the mean stress in the Goodman formula. σ_r^s can be measured by experimental methods or calculated approximately by an empirical formula, proposed in [2]. The last factor is the stress concentration produced by peening dents, which has been discussed in detail in [3] . When considering these factors together, the Goodman formula can be modified as:

$$K\sigma_a = m[\sigma_b - (K\sigma_m + \sigma_r^s)] \qquad (1)$$

Where $m = \sigma_{-1}/\sigma_b$, σ_{-1} is the fatigue strength under the stress ratio $R=-1$, σ_a and σ_m are the stress amplitude and the mean stress of the fatigue strength under a given value of R. From (1) we can get the maximum stress of the strength as:

$$\sigma_{max}^s = 2m(\sigma_b - \sigma_r^s) / \{K[1-R) + (1+R)m]\} \qquad (2)$$

Where R is the stress ratio of the fatigue test, and the superscript "s" indicates the surface source.

2. The Fatigue Strength Prediction when the Fatigue Source is Assumed to be Beneath the Surface Hardened Layer

It has been indicated[3] that the fatigue source is always in the tensile residual stress interval and we can postulate that it is located at the depth (Z_{mt}) where the maximum tensile residual stress occurs. Then the crack will initiate when the summary stress reaches the internal fatigue strength (σ_{wi}) of the metal, that is:

$$\sigma_s^A + \sigma_s^{rt} = \sigma_{wi} \tag{3}$$

where σ_s^A is the applied stress at the source (Z_{mt}); σ_s^{rt} is the tensile residual stress at the source, which can be caculated by a method put forward in [6]; and σ_{wi} is the internal fatigue strenth expressed by maximum stress which is related to the surface fatigue strenth σ_{ws} in the following form[3]:

$$\sigma_{wi} \cong 1.35\, \sigma_{ws} \tag{4}$$

Then we can derive as an expression for maximum applied stress (σ_{Zmt}^A) at the source (Z_{mt}):

$$\sigma_{Zmt}^A = \sigma_{wi} - \sigma_s^{rt} \tag{5}$$

In the case of three point fatigue test the nominal apparent fatigue strength σ_{max}^i is:

$$\sigma_{max}^i = \sigma_{Zmt}^A [h / (h - 2Z_{mt})] \tag{6}$$

Where the superscript i indicates that the fatigue source is internal, h is the specimen thickness and Z_{mt} is the depth where the maximum tensile residual stress occurs.

3. The Prediction of Fatigue Strength and Optimization of the Shot Peening Regimes:

Between the two possible values of the fatigue strength given by formulae (2) and (6), the smaller one is the actual apparent fatigue strength.
We define that:

$$\gamma = \sigma_{max}^s / \sigma_{max}^i \tag{7}$$

Then the fatigue source should be located at the surface if $\gamma < 1$; beneath the surface hardened layer if $\gamma > 1$. If $\gamma \leqq 1$, the source is either at the surface or beneath the surface hardened layer.

From formulae (2) and (6), we know that σ^{s}_{max} decreases with the shot peening itensity, because K increases and σ^{s}_{r} is nearly stable for the peened specimens; while σ^{i}_{max} increases with the shot- peening intensity because Zmt increases. So the optimum regime is that when $\gamma \leqq 1$.

Tab. 1. Mechanical Properties of 40Cr Steel and Shot Peening Conditions

Specimen symbol	Ground thickness μm	Peening conditions		
		Ball diameter mm	Air pressure MPa	Coverage rate ×100%
A000	—	—	—	—
A523	—	0.55	0.2	3
A121	—	1.10	0.2	1
A143	—	1.10	0.4	3
A166	—	1.10	0.6	6
A121P20	20	1.10	0.2	1
A143P50	50	1.10	0.4	3
A166P50	50	1.10	0.6	6
C000	—	—	—	—
C523	—	0.55	0.2	3
C143	—	1.10	0.4	3
C166	—	1.10	0.6	6
C523P20	20	0.55	0.2	3
C143P50	50	1.10	0.4	3

Specimen of Group A: Tempered at 200℃, σ_s=1420MPa, σ_b=1910MPa, m=0.32 [7] σ_{ws}=1060MPa

Specimen of Group C: Tempered at 550℃, σ_s= 980MPa, σ_b=1120MPa, m=0.48 [7] σ_{ws}=820MPa

EXPERIMENTAL VERIFICATION

To verify the prediction of the fatigue strength and the oiptimizatio method, 40Cr steel (0.4C and 1.0Cr) was used in this work. After quenched at 850℃ and temptered at 200℃ (group A) and 550℃ (grop C), specimens of 50×15×10mm were peened with a pneumatic machine and cast steel shots, under different conditions given in Tab 1. From some specimens, a thin layer was ground after peening, in which case the stress concentration coefficient $K \cong 1$. To abtain the fatigue strengths for 5×10^6 cycles, three point bending fatigue test were carried out under a stress ratio of R=0. 05. The predicted and experimentally determined fatigue strengths and the fatigue source location observed by SEM Fractography are listed in Tab 2. We can see the predicted fatigue strength are very close to the experimental ones with the errors less than 5% and most predicted fatigue strength values are a little less than the experimental ones. The optimization method is also successful for the nearer the γ value is to 1 , the higher the fatigue strength is .

Tab 2. Predicted and Experimentally Determined Values of Fatigue Strength for Peened Specimens of 40Cr Steel

Specimen Symbol	σ^{s}_{max} (MPa)	σ^{i}_{max} (MPa)	γ	Source position	Fatigue strength (MPa)	
					Predicted	Experimental
A000	—	—	—	S		1060
A523	1340	1300	1.03		1320	1320
A121	1270	1290	0.98	A	1280	1330
A143	1240	1300	0.95	S	1240	1280
A166	1190	1300	0.92	S	1190	1210
A121P20	1400	1290	1.09		1290	1340
A143P50	1400	1300	1.08	I	1300	1350
A166P50	1400	1300	1.08	I	1300	1360
C000	—	—	—	S		820
C523	1000	1020	0.98	S	1010	990
C143	930	1030	0.90	S	930	950
C166	910			S	910	920
C523P20	1180	1020	1.16	I	1020	1020
C143P50	1180	1020	1.15	I	1030	1040

• S-Surface fatigue source, I-Internal fatigue source, A-Either surface or internal fatigue source.

CONCLUSION

1. A procedure is proposed for predicting the fatigue strength of shot peened specimens. The procedure is proved successful by experiments.

2. A method is developed for determining the optimum shot peening regime which occures when $\gamma \cong 1$.

REFERENCES

[1] J.K.Li, Yao Mei, Wang Renzhi and LiXiangbin (1992) Comprehensive Effect theory For Shot-peening Strengthening, ACTA AERO.NAUTICA ET ASTRONAUTICA SINCA. (in Chinese) Nov. A670-677.

[2] Li Jinkui, Yao Mei and Wang Renzhi, Surface Layer Inducd by Shot-peening and Its Role in Improvrment of Fatigue Strength of 40Cr Steel, Proc. of ICM-6, vol. pp. 403-408

[3] Li Jinkui, Yao Mei and Wang Renzhi , A New Concept for Fatigue Strength Evaluation of Shot Peened Specimens, Proc. of ICSP4 (Fourth International Conference on Shot Peening), 1990, 225.

[4] J.K.Li, (1989) A Study of the Theory of the Shot-peening Ph.D. Dissertaion, Harbin Istitute of Technology (in Chinese).

[5] J.K.Li, Yao Mei, Wang Duo and Wang Renzhi (1992) , An Analysis of Stress Concentration Caused by Shot- peening and its Application in Predicti Fatigue Strength. Fatigue Fract. Engng. Mater. Struct. 12, 1271-1279.

[6] J.K.Li, Yao Mei and Wang Renzhi, Experimental Study about Compresive Residua Stress Field Induced by Shot-peening, Residual Stress-Ⅲ, Scince and Technol Proceeding of ICRS-3, 1991, pp. 750-757.

[7] X.T.Sun etal. (1979) Mechanical Properties of Metals, P116. Mechanical Industr Press, Beijing. (in Chinese).