PARAMETRIC STUDIES ON THE FATIGUE PERFORMANCE OF SHOT PEENED AISI 316L MATERIAL

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ABSTRACT

To keep pace with the competitive globalization market, it is benedictory to the shot peening industries in the improvement in applying statistical experimental technique in the investigations instead of using usual scientific method. In this paper design of experiment (DOE) technique was used in carrying out test, using air blast type shot peening machine. This investigation examines the influencing parameters such as pressure, shot size, nozzle distance and the exposure time at their two different levels on the fatigue performance of AISI 316L material. After going through confirmation test the analysis reveals the right combination of the parameters for better process control. An ANOVA was also carried out to find out the significant peening parameters. An expression correlating fatigue life, pressure, shot size, nozzle distance and exposure time has been developed. This technique set an example for the other applications in the industries to reduce the performance variation and to improve quality, performance, reliability and profits.

KEY WORDS: Fatigue, Surface hardness, Shot peening parameters, DOE, ANOVA

INTRODUCTION

Shot peening is widely used to improve the fatigue properties of the components and structures. Residual stresses, surface roughness and work hardening are the main beneficial effects induced in the surface layer obtained by shot peening, which depend on the correct choice of the peening parameters. Production processes, especially shot peening, lead to changes in the materials state close to the surface, which severely affect the success of the treatment, especially the resulting fatigue properties. Fatigue properties depends on various factors such as work hardening due to the cold work, compressive residual stress (Nakamura et al., 1990), surface topography and various other local fatigue properties (Schulze, 2002). To achieve the optimum benefit, the process variables must be identified and controlled.

Several authors have so far carried out shot peening studies on precision-machined steels with high strength to weight ratio; such steels are typically used for various components in aircraft, turbine and defense equipments (Wang et al., 1998; Torres and Voorwald, 2002; Yakuchi et al., 1984). Only a few authors have used design of experiment technique with specialized single-ball controlled shot peening machine (Neema and Pandey, 1981). Design for robust fatigue performance with the help of simulation technique has also been investigated (Marcos et al., 1996). It is observed that hardly any shot peening studies has been made for fatigue performance of the conventional materials using DOE technique (Mahagaonkar et al., 2007).

In this study, the experiments were designed using full factorial design of experiment (DOE) technique and an air blast type of shot peening machine was used for carrying out the experiments. Effect of process parameters such as pressure, shot size, nozzle distance and exposure time on fatigue performance for 316L materials was investigated. An ANOVA was carried out to identify the significant peening parameters. Empirical equations between the peening parameters and the fatigue performance for both the materials were developed, which would be useful in predicting the fatigue life. It is believed that this technique would prove beneficial to the industries to reduce the performance variation and cost and also to increase productivity

EXPERIMENTAL DESIGN

Experiments were conducted on turned specimens made of 316L material (Figure 1). The initial surface hardness for the 316L specimens in terms of Vickers hardness was 264 Hv respectively. The initial surface roughness (R_a) for the workmaterial was between 4 to 5 µm. The chemical composition is shown in Table 1.

Table 1 Chemical composition of 316L steel

Element	***Weight in %***
Carbon	0.03
Silicon	0.75
Manganese	2.0
Sulfur	0.03
Phosphorus	0.045
Chromium	17
Molybdenum	2.9
Nickel	14
Ferrous	Bal.

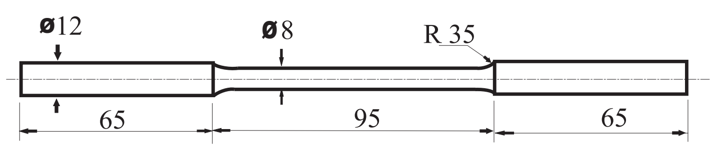

Figure 1 Fatigue test specimen

The experiments were conducted by using steel shots S-660 and S-390 having shot diameters 1.85 mm and 1 mm respectively. The selection was based on “MIL-S-13165B” specifications and the surface conditions of the specimen. According to the test certificates from the manufacturer these shots were completely tested and the sieve analysis was done as per IS 4606 of 1983. The design of experiment was based on full factorial design considering four factors each at two levels. In order to reduce process and product variability, sixteen runs of the experiment were replicated twice. After conducting pilot experiments, the levels for each factor were selected and are shown in Table 2. Factors that were held constant are: Jet obliquity equal to 90° and symphonic nozzle having orifice diameter 9 mm.

The fatigue life of the peened and unpeened, components were tested by using R. R. Moore rotating-beam fatigue machine, at a constant speed of 4340 rpm and a load of 19.62 N-m (200 kg-cm). In order to find the fatigue life of the components, average of the two closest values of the fatigue life of the components was considered. Fatigue life of the shot peened components was calculated in terms percentage of fatigue life. Percentage of fatigue life indicates the number of times of the peened component over the unpeened component. If N_p is the fatigue life for peened component in cycles and N_u is the fatigue life for unpeened component, then fatigue life enhancement factor (percentage for fatigue life) is given by the following formula.

Fatigue life enhancement factor, $N_f = (N_p/N_u)\ 100$

As per the guidelines given by Champaine (1989), the exposure time to achieve desired peening coverage for the material were determined by 10X-magnifying lenses. Almen strips were not used since Almen strip saturation time can be misleading due to the surface hardness difference between the Almen strip and the peening material.

The design matrix taking the average of two replicates is shown in Table 3. Tables 4, show the estimated effects for main factors and their interaction effects. These values were calculated based on the method as given by Lochner and Matar (1990).

Table 2 Factor levels for the experiment

Factors	Low level-1	High level-2
P: Pressure (kg/cm^2)	2	4
S: Shot type	S-390	S-660
T: Exposure time (seconds)	80	160
D: Nozzle distance (mm)	80	100

Table 3 Full factorial design matrix (replicated twice)

Expt No.	*P*	*S*	*D*	*T*	Fatigue life enhancement factor(N_f) for 316L
1	1	1	1	1	462.254
2	1	1	1	2	398.245
3	1	1	2	1	214.912
4	1	1	2	2	424.844
5	1	2	1	1	344.332
6	1	2	1	2	388.644
7	1	2	2	1	412.105
8	1	2	2	2	302.271
9	2	1	1	1	344.148
10	2	1	1	2	472.354
11	2	1	2	1	375.542
12	2	1	2	2	352.408
13	2	2	1	1	428.458
14	2	2	1	2	165.714
15	2	2	2	1	412.256
16	2	2	2	2	401.546

RESULTS AND DISCUSSION

Figure 2 gives the estimates for all the factors at their lower and higher levels. It also show the effects of four main factors (*P*- pressure, *S*- shot size, *T*- exposure time and *D*- Nozzle distance), as well as their two-way, three-way and four-way interactions on the fatigue performance. It was found that, contribution of pressure has the least significant effect on the fatigue life; however contribution of shot size and nozzle distance is more. The most dominating two-way interaction is *S*-*T*. The maximum and minimum response values for the fatigue life for both the materials were calculated by adding the individual contribution of the main factors to the grand mean (Table 4).

The maximum value of fatigue life from the Table 3 is 472.354, which occurred when pressure (*P*) and exposure time (*T*) were at higher levels and shot size (*S*) and nozzle distance (*D*) were at lower levels. From Figure 2, the sole effect of pressure alone is found to be negligible; one has to consider two-way interaction effects between *P*-*D*, *P*-*S* and *P*-*T* in setting the level for pressure. Since the interaction effect between *P*-*D* is more dominant than other, it is suggested that pressure be set at higher level. Similarly the nozzle distance can be set to its higher value. Considering the main effects of the shot size and exposure time, and also interaction effect between *S*-*T*, they could be set to their lower level in order to maximize the fatigue performance.
Confirmation tests were carried out by setting parameters *P* and *D* at higher levels and other two factors at their lower levels. The maximum fatigue life was found to be in the range of 382.157 to 472.354

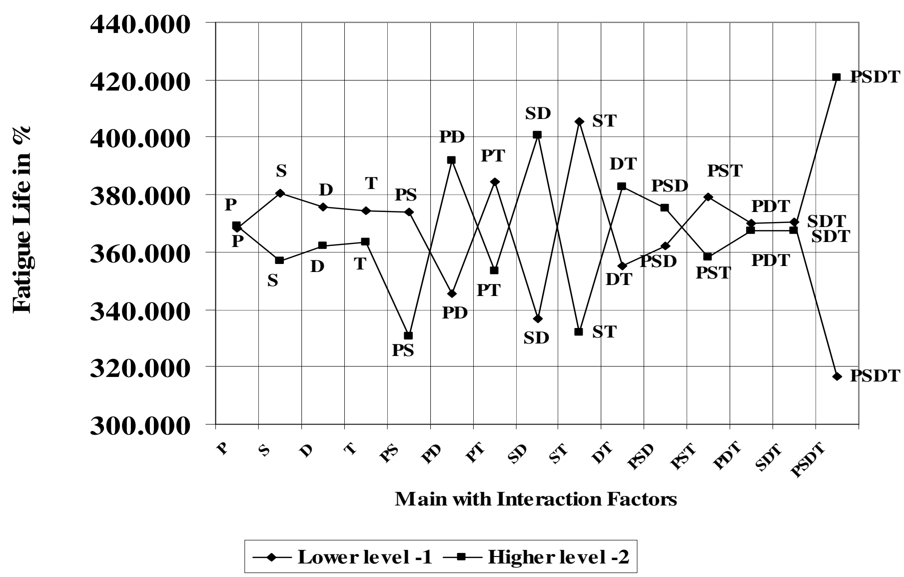

Figure 2 Graphical display of effect on 316L

ANALYSIS OF VARIANCE (ANOVA)

In this section MINITAB (software) is used to judge, whether the experimentally found significant factors are statistically significant or not. From the ANOVA (Table 4), it is observed that, the most dominating factors among the main factors is the shot size and the effect of pressure is very negligent as its *P*-value is greater than 0.05. Among the two-way interactions, the interaction between shot size and the exposure time

(*ST*) is more significant and the next interaction effect in the decreasing order are *SD*, *PD*, *PT*, *DT* and *PS*. The results from the ANOVA show that all the main and interaction effects except pressure are statistically significant, since the *P*-values for these parameters are less than 0.05.

Table 4 Effects and ANOVA for main and interaction factors

Main and interaction factors	Effects on fatigue life for 316L	ANOVA	
		F	***P*-Value**
P	0.602	0.58	0.458
S	-23.673	893.57	0.000
D	-13.533	292.03	0.000
T	-10.998	192.86	0.000
PS	-43.290	174.02	0.000
PD	46.303	3418.58	0.000
PT	-31.098	1542.04	0.000
SD	63.791	6488.56	0.000
ST	-73.746	8671.93	0.000
DT	27.561	1211.23	0.000
PSD	13.255	280.15	0.000
PST	-20.885	695.52	0.000
PDT	-2.388	9.09	0.008
SDT	-3.089	15.22	0.001
PSDT	103.933	17224.17	0.000

Maximum and minimum responses (Y)	
$Y_{average}$	368.752
$Y_{maximum}$	382.157
$Y_{minimum}$	355.347

REGRESSION ANALYSIS FOR FATIGUE PERFORMANCE

A regression model for fatigue performance was developed by using Analyze-it software. To have proper curve fitting following model was assumed.

$\ln (Y) = \beta_0 + \beta_1 \ln (P) + \beta_2 \ln (S) + \beta_3 \ln (D) + \beta_4 \ln (T)$

where β_1, β_2, β_3 and β_4 are the regression coefficients to be determined and Y is the fatigue performance.
the following correlation was obtained for the fatigue life in percentage (N_f) from the Table 7.16.

$\ln (N_f) = 6.5924 - 0.0185 \ln (P) - 0.1245 \ln (S) - 0.074 \ln (D) - 0.0685 \ln (T)$

The exponential form of the above equation is as follows:

$N_f = 729.53\, (P)^{-0.018}\, (S)^{-0.124}\, (D)^{-0.074} (T)^{-0.069}$

The resulting regression equation yields approximate values for the 316L material. However, it would serve as a useful guide for selecting proper values of process parameters for the above material so as to obtain desired fatigue life of the component.

CONCLUSIONS

To summarise, this study has, thus, brought out the effect of SP parameters on the fatigue performance of AISI 316 L materials. It is interesting to note that with the use of larger shot size in case of 316L material, the fatigue life increases with a decrease in pressure, but with smaller shot size it increases with an increase in pressure. It was found that the process parameters that have influence on fatigue performance are: shot size, nozzle distance, exposure time and pressure. Regression models correlating fatigue performance with process parameters have also been obtained. This equation would serve as a useful guide for setting proper values of process parameters so as to obtain desired fatigue life of the component.

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