THE EFFECT OF WARM SHOT PEENING ON THE FATIGUE PERFORMANCE OF A SAE 5160 SPRING STEEL

M. C. Ruy[1] J. R. Tarpani1[1], M. T. Milan[1], D. Spinelli[1] and W. W. Bose[1]

[1] Materials, Aeronautical and Automotive Engineering Department, Engineering School of São Carlos – University of São Paulo – Brazil

Abstract

Shot peening is a surface treatment commonly used in parts aiming to improve fatigue properties. The controlled plastic deformation caused by the impact of the shots introduces compressive residual stresses on the material's surface layer. Normally, this process is performed at room temperature, however, new studies present a possibility of perform this surface treatment above room temperature in order to increase the fatigue strength even further, due to a better association of higher plastic deformation with residual stresses. The purpose of this work was to study the effects of the shot peening process executed above room temperature, on the fatigue performance of a SAE 5160 leaf spring steel used by the automotive industry. Three point bending fatigue tests were performed in specimens with the same geometry of the original component. They were peened at 25, 100, 150, 200, 250 and 300ºC. Increasing temperature has caused an increase in surface roughness and reduction in residual stress levels. Generally, residual stress values increased up to 100ºC and decrease continuously above this temperature of shot peening. The highest fatigue performance was found for specimens peened at 200ºC. This was attributed to be due to an optimized association of residual stress level and hardening effects caused by plastic deformation. These results may directly affect the fabrication process of spring leaves and other mechanical parts.

1 INTRODUCTION

Zimerly and Almen first introduced the shot peening process prior to 1934 and during the years 1935 and 1945 Almen carried out the fundamental work. The residual compressive stresses in the wake of shot peening are a result of the locally occurring plastic deformation on the surface of the workpiece. The deformation processes or the generation of residual compressive stresses may be fundamentally explained in terms of plastic stretching and Hertz's Compression. Among other reasons, shot peening is mainly used to promote fatigue strength and diminish notch sensitivity. In general, the process is executed at room temperature, and since it has been used for the first time in springs fabrication process, several new steels have been developed attempting to increase the spring strength aiming vehicle mass reduction as well as increase in the fatigue life. Therefore, the shot peening process has needed shot with higher hardness, leading to both shot and equipment life reduction. Warm shot peening at or under the tempering temperature may be a solution to reduce or even avoid these effects. However, the effect of warm shot peening in improving fatigue strength has not been well established and not extensively studied. Recently, Totten et all (2002) and Tange et all (1999) studied the effect of warm shot peening of suspension coil spring. In this work, in order to get a better association of the strain hardening and residual stress as a function of shot peening temperature and its effect on fatigue strength of leaf springs, specimens of SAE5160 were penned at 25ºC, 100ºC, 150ºC, 200ºC, 250ºC and 300ºC and fatigue tested in three point bending.

2 EXPERIMENTAL

2.1 Material and test specimens

The material used in this work was a SAE 5160 steel plate with 750 mm length, 63.5 mm wide and 11.4 mm thick. The geometry is quite similar to one type of leaf spring produced for vehicles. The material's chemical composition is presented in Table (1).

Table 1. Chemical composition of the SAE 5160 steel.

Chemical Element	*C*	*Mn*	*Si*	*P*	*S*	*Cr*
% wt	0.59	0.96	0.22	0.016	0.018	0.86

2.2 Fatigue test

The fatigue specimens were divided in five groups, with four specimens each. The groups were placed in the furnace, heated at each previous established temperature, and remained in this temperature for 15 minutes. Once the specimens reached the required temperature they were one by one transferred to the shot peening machine.

As presented in Table (2), the groups were formed by specimens selected by its hardness after quenching and tempering heat treatments, as well as by the shot temperature.

The fatigue tests were carried in three point bending loading condition, 2 Hz frequency and load rate equal to zero. The test ended when the specimen was broken and the number of cycles was registered.

The main idea was to compare the fatigue life of the leaf spring, with the surface treated in one of the conditions presented in Table (2). Therefore, just for comparison, there was no need to get the S-N curve and all the fatigue tests were performed at a constant maximum flexural stress of 610 MPa, that was previously established by the spring maker and it was based on the maximum stresses that the component may be submitted in life.

3 RESULTS AND DISCUSSION

The fatigue results are presented in Table (3). As expected, there is a significant improving on the fatigue life when the leaf spring was shot penned at room temperature (from 8,400 to 46,154 cycles), an increase of approximately 5.5 times. This increase in the fatigue life is attributed to both the compressive residual stresses and the strain hardening introduced by the shot peening process, as proposed by Courtney (2000).

Table 2: Hardness after quenching and tempering treatments, and shot peening temperature.

Condition	**Hardness After Tempering [HV]**	**Shot Temperature [°C]**
A	528	25
B	491	25
C	491	100
D	491	150
E	491	200
F	491	250
G	491	300

It was also observed that for the same shot peening process conditions, the material's fatigue life is strongly affected by the material's hardness, since for high cycle fatigue case, higher is the materials strength to plastic deformation, higher is the number of cycles to nucleate a crack, since is more difficulty to create intrusion and extrusion on the surface. In this case, conditions A (528 HV) and B (491 HV) presented a fatigue life of 155,038 and 46,154 cycles, respectively.

Comparing the fatigue life results of specimens shot peened at room and higher temperatures, Table (3) and Figure (1), it can be observed that as the shot peening temperature increases, the fatigue life systematically increases, reaching to a maximum value at 200°C with 475,808 cycles, then decreasing continuously, it being at 300 °C equal to 46,154 cycles, approximately 10 times higher than the value obtained by the shot peening at room temperature.

Table 3: Fatigue life of shot peened specimens at different temperatures.

Condition	**Shot Peening Temperature[ºC]**	**Hardness [HV]**	**Mean life [Cycles]**	**Standard Deviation, SD**
As tempered	---------	491	8,396	3,253
A	25	528	155,038	2,070
B	25	491	46,154	20,327
C	100	491	73,996	23,861
D	150	491	162,554	41,388
E	200	491	475,808	62,698
F	250	491	155,800	60,119
G	300	491	97,575	34,019

Even though the fatigue life is dependent on many factors, in this work it was considered that the surface roughness, strain hardening and residual stresses would be the parameters to be considered affected by the shot peening temperature. Therefore, after the shot peening process, the roughness and residual stresses were measured on the specimen's surface. These results are presented in Figures (2) and (3).

These results show that as the shot peening temperature increased the roughness increased and the residual stress, after passing by a maximum at 100°C, decreased continuously. Nevertheless, as observed in Figure (1), the fatigue life reached a maximum at 200°C, which exhibited a higher roughness and lower compressive residual stresses when compared with room temperature. The reason for a maximum increased fatigue life at 200°C was attributed to be due to the maximization of the strain hardening effect that increased locally the yield strength, making difficult the intrusion and extrusion micromechanism of crack nucleation. This fact was proved by the Knoop microhardness test, carried out using a 100 g load at the shot peened region, as shown in Figure (5), whose values are presented in Table (4). As can be seen in this table, the maximum microhardness values were found for the shot peening condition at 200ºC.

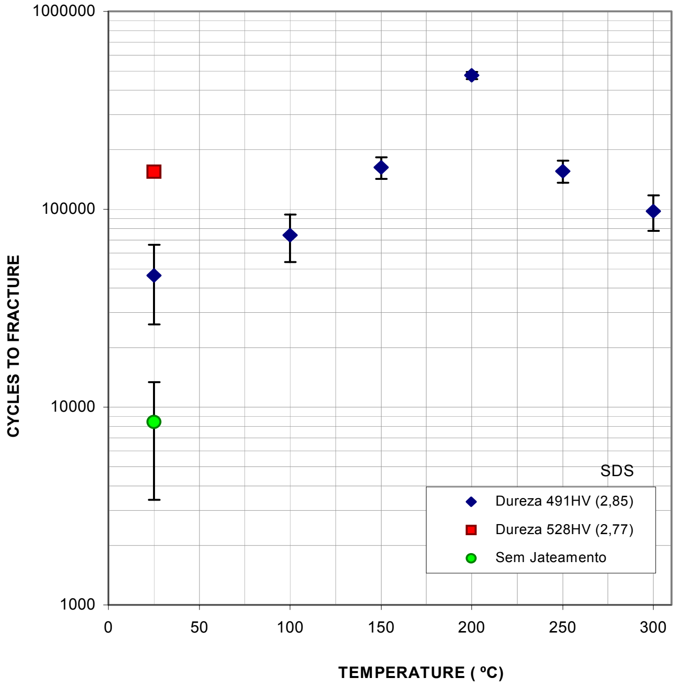

Figure 1. Mean fatigue life versus shot peening temperature.

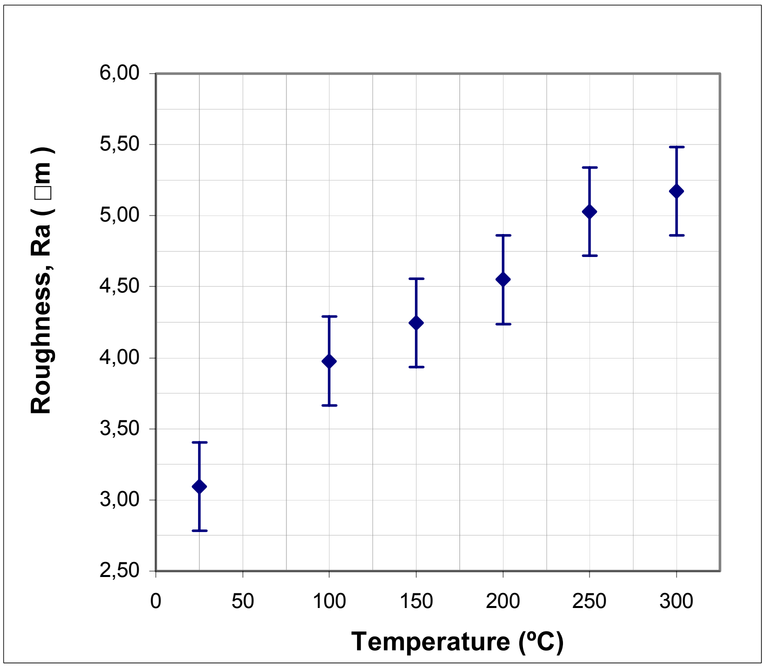

Figure 2: Roughness, measured in terms of Ra, as function of the shot peening temperature.

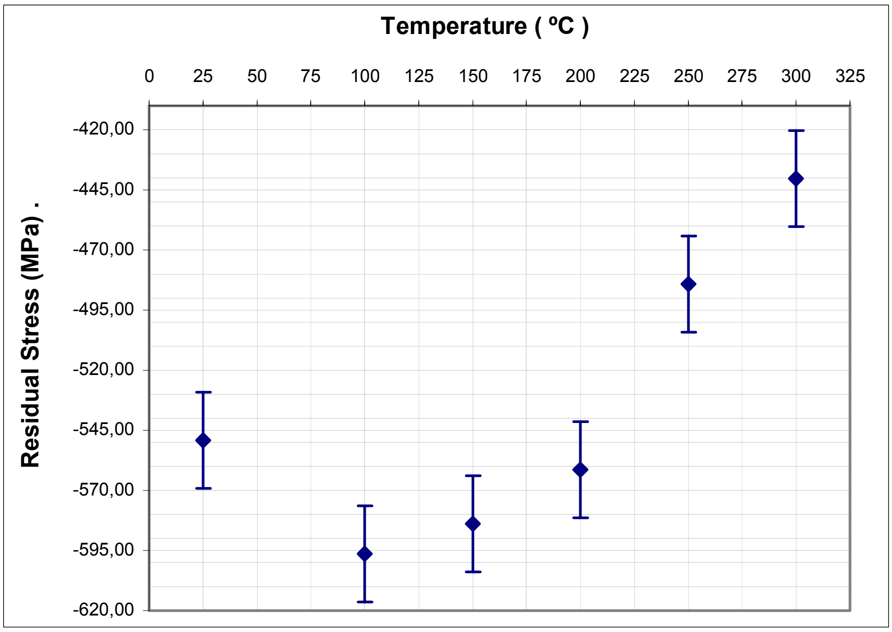

Figure 3. Residual stress mean value versus temperature of shot peening.

Figure 4. Knoop microhardness indentation close to the shot peened surface.

Table 4.: Knoop microhardness results, load of 100g.

Temp. [ºC]	*Level 2*		*Level 2*		*Level 3*		*Level 4*		*Level 5*	
	Mean.	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
100	444.2	8.8	467.1	42.4	511.2	16.5	497.1	5.2	429.3	13.1
200	549.3	11.1	541.7	4.5	575.70	36.3	527.7	45.9	494.3	30.3
300	338.5	13.4	483.6	37.8	487.9	24.2	456.5	49.5	444.5	78.6

4 CONCLUSIONS

The results from this work, allowed a very important conclusion related to the shot peening effect on fatigue life.

As well known for SAE5160 spring steel, the shot peening process at room temperature definitely improve fatigue life of leaf springs. However, as proved in this work, it can be further increased by execution of shot peening at approximately 200 ºC.

It was found that the main reason for the increased fatigue life at this shot peening temperature, relay mainly on the strain hardening effect that overcame the effect of the decrease in the compressive residual stress level and the increase in the surface roughness

5 REFERENCES

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