

Material Microcrack Failure Effects Based on Residual Stress Evaluations

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ABSTRACT

The leaf spring manufacturer must supply high quality raw material at required strength for ensuring endurance rig tests. It's very important to maintain both inside and surface cleanliness of raw material.

This study presents micro crack effects on material surface by evaluating residual stress values. Residual stress values on leaf springs are measured with X-ray diffractometer and different residual stress values are classified on the same raw material batch which have also the same material failures.

Finally, micro cracks are measured in metrics. Micro crack standardization is performed considering the residual stress values and rig tests. The outputs in metrics which correlated with endurance rig tests can be taken as reference by the manufacturers of leaf spring and original equipment manufacturers.

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INTRODUCTION

Residual stress is a highly effective method that increases the fatigue strength of the material and is used by the leaf spring manufacturers as well as the manufacturers of other areas. It is significant that the compressive residual stress distributions on the leaf spring are kept at a certain levels. To obtain compressive residual stress at desired levels increases the endurance of leaf spring. In order to ensure 100% product reliability, heavy vehicle manufacturers using leading edge technology in the world should lay the residual stress measurement controls of the products manufactured at certain residual stress values for each production lot with x-ray diffractometer (Figure 1) down as a condition. Residual stress amount to be generated on the product may vary in depending on the material type, material structure and the microstructure formed on the areas nearer to the material. In the event that the material determining the fatigue strength of the parabolic leaf spring, the heat treatment applied to the material and the compressive residual stress have proper values, the higher results could be achieved from the life time tests. After the comparison of these three facts with each other, it is seen that

residual stress values have stronger effect on life time than the others. Starting time of the crack formation in a leaf spring processed to shot peening will be delayed and crack propagation rate will slow down. Owing to the fact that cycling load starts to be applied to the metallic parts, that initiation of changes in microstructure will lead to crack formation. Shot peening parameters generating the compressive residual stress must be optimized.



Figure 1. X-Ray Diffractometer

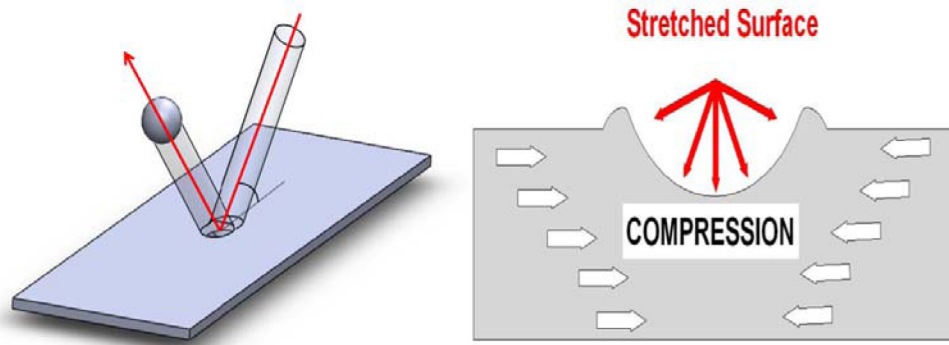


Figure 2. View of the influence area of the shot peening on part surface.

The motion of the shot and the form created on surface area during the shot peening process are given schematically in [Figure 2](#). Tension and compression graph depending on the depth of the profile as a result of the shot peening process which was applied by tension is shown in [Figure 3](#).

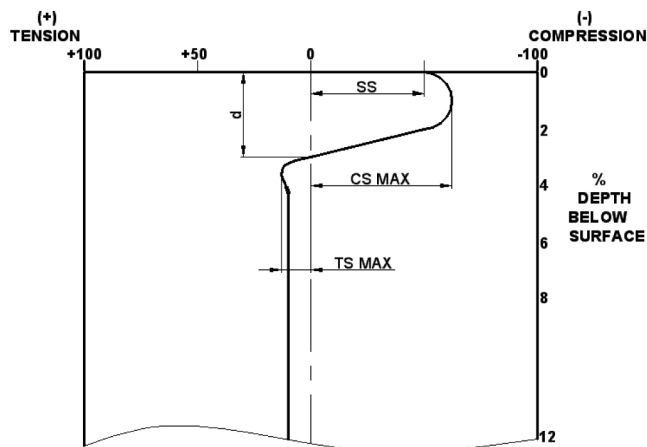


Figure 3. Residual stress profile generated by shot peening under tension

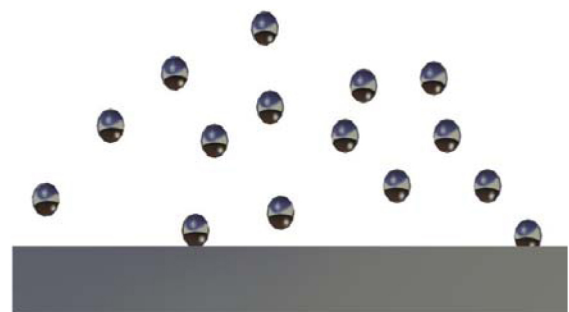


Figure 4. Start of shot peening

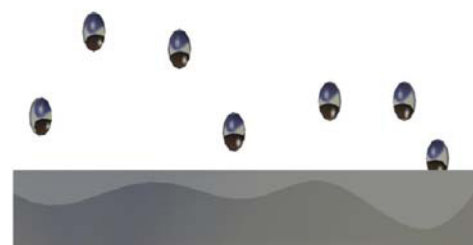


Figure 5. Steel ball - Surface contact

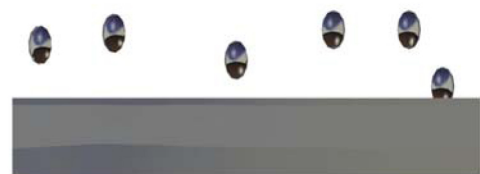


Figure 6. Surface alteration after the collision



Figure 7. Compressive stress on the surface

During the shot peening process, the hardness value of a steel shot is requested to be close to the hardness of the material to be shotpeened. Generally, it is preferred to be 5HRC higher than the hardness of the material to be shot peened. [Figure 4](#) shows the start of shot peening process; [Figure 5](#) shows the initial contact of steel shots with surface and [Figure 6](#) shows the energy release of the steel shots by hitting the surface and their effects on the surface in the end; [Figure 7](#) shows the completion of shot peening process by using the color differences of the compressive residual stress views generated on the surface and in the depth.

The bending behavior simulation of the compressive residual stresses - which are generated on the tension surface and the leaf section shot peened at the effective strain value applied to the leaf spring - for vertical rig test is shown in [Figure 8](#) and [Figure 9](#).



Figure 8. Pre-test unloaded condition



Figure 9. Operating at the time of test

Thanks to the compressive stress generated on the white colored areas in below figures, even if surface crack formation occurs, compressive residual stress occurred in depth prevents the propagation rate of the crack. And, fatigue cycle will be very high.

The behavior of leaf tension surface under dynamic loading conditions on the inner surface of the leaf spring which is not shot peened under the proper process conditions is shown in [Figure 10](#) and [Figure 11](#). An extremely small crack emerging on surface will propagate in a short time and result in fatigue on the part so the test will have been finalized after breakage event.

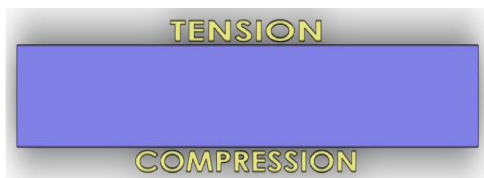


Figure 10. Pre-test unloaded condition

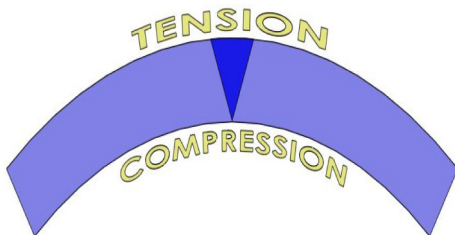


Figure 11. Breakage starting from the low cycle micro crack

REFERENCE STUDY

This reference study deals with the hardness of leaf spring, mean ball diameter that we determined as the parameters of strain and shot peening, time and intensity of shot peening, oxide layer sinking and permanent surface tensions, in other words compressive stresses generated on inner surface in response to tensile stresses on inner surfaces and the effects of all these parameters on fatigue performance of the leaf spring according to the variables.

Following the heat treatment, leaf springs were produced in 3 different categories between the hardness ranges of 1478 - 1513 N/mm², 1551 - 1591 N/mm² and 1630 - 1665 N/mm², respectively. 1400 N/mm² and 1600 N/mm² strain values were applied for each hardness range of the produced leaf springs during the shot peening operation ([Figure 12](#)). The view of the leaf spring after the application of strain values but before the shot peening process is shown in [Figure 13](#).



Figure 12. Before shot peening operation



Figure 13. The leaf spring exposed to strain during the shot peening process

After that 2 different stress values were applied to the leaf spring at the time of 3 different shot peening set up given in [table 1](#) and residual stress levels on the surface area and at different depths of the leaf springs made of the same spring material under 3 different hardness ranges are presented in the following graphs. For the strain values that were applied separately for each hardness level, vertical rig tests ([Figure 14](#)) in the range of F_{max} : 34.000N and F_{min} : 2800 N and at 3/4 Hertz were carried out and their results are presented below:

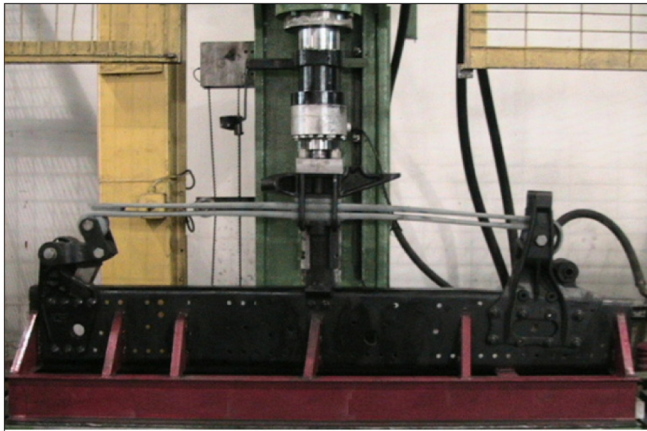


Figure 14. Vertical Rig Test

Table 1. Shot Peening Parameters

SHOT PEENING SET UP PARAMETERS				
Shot peening set up	Duration (m/sec)	Turbine currency (amper)	Almen intensity (A2 acc.to SAE J442)	Sieving (shot sizes)
1	5	60	33	$d \geq 1,0$; 97% $d \geq 0,8$; 3%
2	5	50	28	$d \geq 1,0$; 74% $d \geq 0,8$; 19% $d < 0,8$; 7%
3	5	40	23	$d \geq 1,0$; 40% $d \geq 0,8$; 43% $d < 0,8$; 17%

The measurements of oxide layer sinking that is an another parameter in the relationship of fatigue and residual stress were completed for each shot peening set up range and the achieved results were examined.

EXAMINATION OF THE RESIDUAL STRESS DISTRIBUTION OF THE LEAF SPRING - WHOSE HARDNESS WAS BETWEEN 1478 -1513 N/mm² (435 - 445HB) RANGE AFTER BEING HEAT TREATED - DURING THE THREE DIFFERENT SHOT PEENING PROCESSES

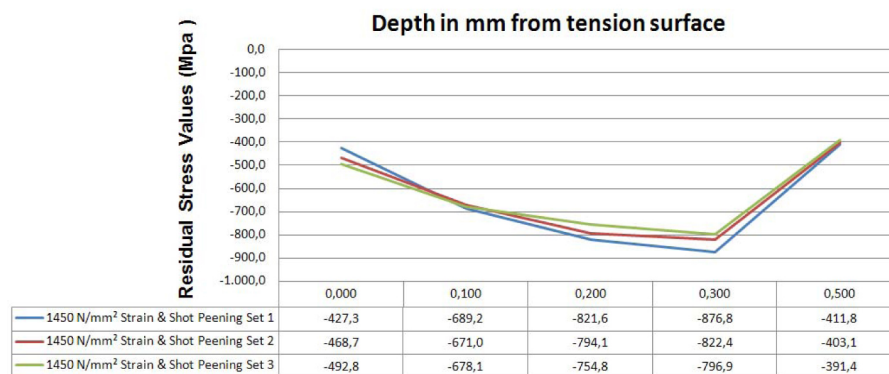


Figure 15. The graph shows the residual stress distributions occurring at different depth levels for each shot peening process of the 1450 N/mm² strain value-applied leaf spring which was subjected to shot peening process with three different methods by changing its parametric values.