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# The Effect of Heat and Surface Treatment on the Fatigue Behaviour of 56SiCr7 Spring Steel

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**Abstract**

Heat and surface treatments of spring steels can greatly affect fatigue life by increasing the number of cycles to failure. Heating, quenching and tempering of spring steel will increase its fatigue limit, as tempered martensite formation with an appropriate surface hardness is achieved from an initial ferritic/perlitic microstructure. This study deals with the parameters of the manufacturing process to transforming the initial microstructure of 56SiCr7 steel to tempered martensite, and increasing the surface hardness and fatigue resistance. Microscopy helps determine the decarburized surface layer thickness. Macro- and micro hardness measurements distinguish between core and surface microstructure hardness of the heat-treated steel. Shot-peening induces compressive residual stresses to the surface of the steel, therefore increasing its surface hardness and consequently the number of cycles to failure. This study shows significant hardness increase on the surface of the steel, and verifies how heat-treatment and shot-peening affect surface hardness. Experimental and analytically calculated (FKM guideline) S-N curves at 4-point cyclic bending quantify the individual effects resulting from the applied heat treatment and shot peening on fatigue life.


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*Keywords:* *Heat Treatmen; Shot-peening; Tempering; Spring Steel; Microstructure; Surface Hardness; Fatigue Life*

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## 1. Introduction

High strength steels are commonly used for load-carrying components such as axle suspension springs in the automotive industry. Changes in the microstructure demonstrated as nucleation sites followed by initiation and propagation of defects, are indicators of the degradation of a component's properties subjected to cyclic loading. One of the primary factors that affect a component's fatigue life is its microstructure, which is one of the designated performance parameters for leaf springs [1].

Both heat treatment and surface treatment processes, being among the most important steps in the leaf spring manufacturing process, have a direct effect on the fatigue life and strength of the end product [2]. It is these processes that form and define the microstructure and mechanical properties of the core and surface of the leaf. This paper examines the performance of 56SiCr7 leaf springs based on the microstructure and surface characterization of the steel, as a result of the leaf spring manufacturing process.

The heat treating process involved raising the steel to 850$^{o}$C, and then cooling it rapidly to 45$^{o}$C, through quenching in an oil bath. After quenching, the spring was tempered for 30 min at 500$^{o}$C. The ultimate goal of the heat treatment is the improved steel hardenability, which is achieved by creating a tempered martensitic layer below the leaf spring surface [3]. The step following heat treatment is shot-peening, which induces compressive residual stresses on the surface of the leaf.

## 2. Experimental Set-up

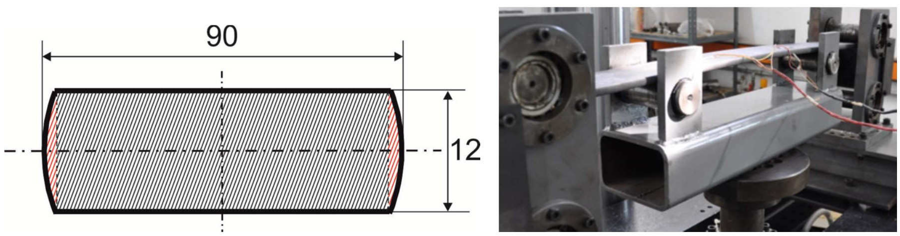


Fig. 1. Specimen's profile acc. to EN 10092-1:2003 (left), four-point test rig (right)

Eight specimens were subjected to fatigue tests on a servohydraulic test rig. The specimens had a length of 1200 mm and a rectangular profile 90x12 mm with rounded edges according to the European Standard EN 10092-1:2003, left hand side of Fig. 1. The loading condition selected was 4-point bending at a constant force ration of approximately R=0. Two cylindrical bearing supports were positioned at ±500 mm from the center point of the leaf, while the forces were applied from a hydraulic actuator via a hollow sectioned rigid bar with welded cylindrical load-introduction shafts at ±250 mm from the same point. The test rig designed for this investigation is shown on the right hand side of Fig. 1.

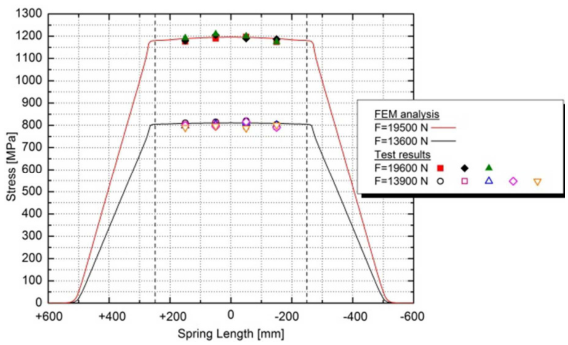


Fig. 2. Experimental and calculated stress distributions at two load levels

Strain gages have been applied to several positions of the highly stressed leaf area, i.e. the one at ±250 mm from the center of the specimens to measure the stress-strain response under monotonic and cyclic loading. Comparison of experimental and numerical (finite element) stress results at two different load values is shown on Fig. 2. The agreement is satisfactorily.

## 3. Results and Discussion

### *3.1. Microstructure*

Fig. 3 shows cross-sections of the steel at different microstructure compositions (raw material, only thermally treated material, thermally treated and shot peened material). A surface decarburization layer of approximately 100 μm can be observed.

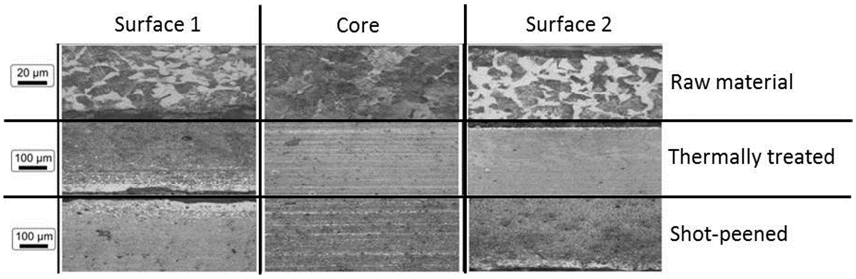


Fig. 3. Images of the Raw Material (top), Thermally Treated Steel (middle) and Shot-peened Steel (bottom). Left column represents surface 1, middle column the core and right column surface 2 of the leaf spring

### *3.2. Vickers Micro-Hardness*

Micro-hardness measurements in the Vickers scale were taken on cross-sections of the leaf spring, at different depths from the surface of raw material, only thermally treated, and thermally treated and shot peened specimens. A low speed diamond saw was used to prepare the metallographic samples, thus assuring minimum disturbance of the microstructure. The results are illustrated on Fig. 4.

The hardness levels of the surfaces of the thermally treated and shot peened specimens are similar, but as the distance between the measurement point and the surface increases the hardness value also increases, reaching a maximum of 650 HV at the core. Although, the only thermally processed material has a very low surface hardness due to decarburization, its core hardness is comparable to that of the shot-peened specimens with a maximum value of 600 HV. The core hardness of the latter specimens is almost double the core hardness of the raw material.

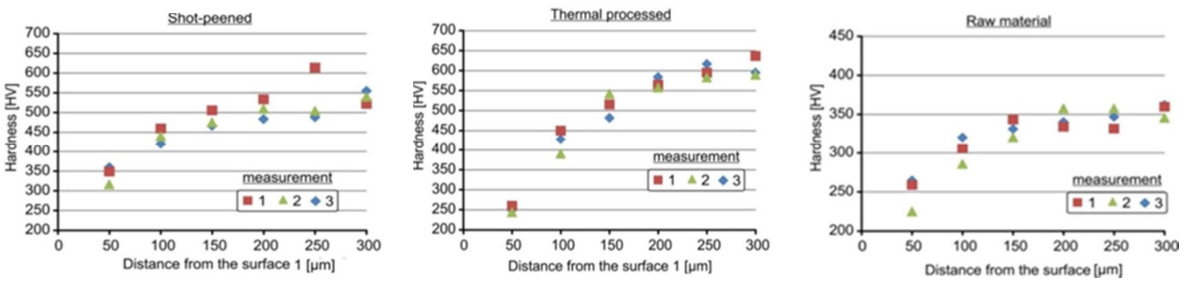


Fig. 4. Micro-hardness profiles measured on shot peened specimen surface areas (left), only thermally treated specimen surface area (center), and raw material specimen surface area (right)

### *3.3. Fatigue Assessment*

The Wöhler diagram of Fig. 5 illustrates the results of the fatigue tests. As expected, a significant difference between the stress amplitudes sustained by the shot-peened specimens and those sustained by specimens that have been subjected only to thermal treatment can be observed. In general, the specimens that have been subjected to both thermal and surface treatment show a significantly larger number of cycles to failure at the same stress level. The positive effect of the applied shot-peening in terms of fatigue life increase of 51SiCr7 spring steel can be easily quantified. The $S_a$-N relationship of Fig. 5 is fitted by a regression line of slope of 8.0, which is typical for shot-peened unnotched specimens.

The failure positions of the specimens examined lie within ±250 mm from the center of the leaf springs, in agreement with the experimentally and numerically determined high stressed area (Fig. 2).

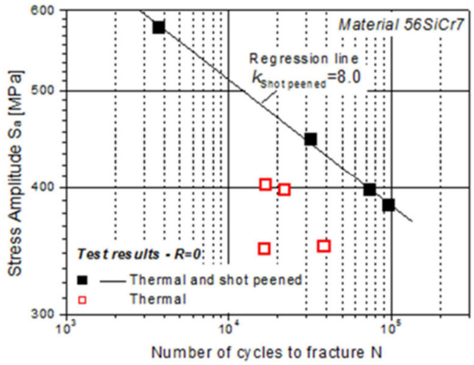


Fig. 5. Comparison of only heat treated (hollow symbols) and heat and surface treated (solid symbols) specimens in the Wöhler diagram

## 4. Conclusions

A tempered martensitic microstructure, resulting from the appropriate thermal treatment, will give the steel increased core hardness, when compared to the raw material. The surface hardness of the steel will be reduced due to decarburization of the tempering step from the thermal process. Shot-peening following heat treatment will induce compressive residual stresses on the surface of the steel, demonstrating a positive effect on the fatigue life of the leaf by an increase in the number of cycles to failure.

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## References

[1] S. Suresh, Fatigue of Metals, R.W. Cahn, E.A. Davis, I.M. Ward (Eds.), Cambridge University Press, Cambridge, 1991.
[2] R. Fragoudakis et al, Fatigue assessment and failure analysis of shot-peened leaf springs, Fatigue Fract Engng Mater Struct, 36 (2013) 92-101.
[3] D.A. Porter, K.E. Easterling, Phase transformations in Metals and Alloys, Chapman and Hall, 1992.