EVOLUTION OF THE RESIDUAL STRESSES BY STRESS ROLLING

Eckehard Müller
Fachhochschule Bochum (University of Applied Sciences), Department of Mechatronics and Mechanical Engineering, Lennershofstr. 140, D-44801 Bochum, Germany

Abstract
In this investigation, flat samples of spring steel (martensitic structure) with a tensile strength of R_m = 1420 N/mm² were rolled without load and stress rolled (preload: 300; 600; 1200 N/mm²). The samples were rolled with the help of a ball. The residual stress profiles are shown along and perpendicular to the rolling direction. In dependence of the preload (along the rolling direction) an increase of the compressive residual stresses is obtained. At a preload of 1200 N/mm² a nearly symmetrical angular state of the residual stress at the surface is reached at a level of −1000 N/mm². Perpendicular to the rolling direction the induced residual stresses are nearly independent of the preload. A comparison of the residual stresses with stress peened samples is made to show the higher quality of the stress rolling process in relation to stress peening.

Stress rolling, deep rolling, stress peening,

1. Introduction

Today reduction of weight or material is a current subject in wide areas of automotive and mechanical engineering. Several possibilities are available, like better utilization of the material by higher hardness or optimizing the construction by finite elements. Another possibility is inducing compressive residual stresses in the surface layers, especially used at tensile pulsating load to enlarge the dynamic life time or respectively reducing the weight. Two possibilities are deep rolling and shot peening, which have different advantages. Deep Rolling is more expensive but gives a higher amount of compressive residual stress. Shot peening is the other way round.

2. Basics

2.1 Deep Rolling

Deep rolling can be regarded as a continuously made plastic deformation of material near the surface. In this procedure a tool (ball, profile roll) is pressed against the work piece with a special pressing force. Here the important parameters are the pressing force and the overlap. This standard procedure is described many times, for example in (Bernstein, 1982; Finkelstein 1984; Kaiser 1984; Kloos 1988).

2.2 Stress Rolling

At the shot peening procedure sometimes the work piece has been loaded before peening, the so called stress peening to get after peening and unloading an higher amount of compressive residual stresses (Bonus, 1994; Müller, 1993). The same procedure can be done within the deep rolling process. The work piece is also loaded with a tensile stress before rolling. In addition, there is the original deep rolling process. Subsequently the work piece is unloaded and in the direction of the load an increase of the compressive residual stress can be expected, which has different effect, if the rolling and loading direction are the same or perpendicular.

3. Preparation of the specimens

The specimens were pieces of flat steel, which is normally used for leaf springs, with a length of 360 mm, a width of 75 mm, and a thickness of 11 mm . The edges were rounded in accordance with DIN 59145. The material was normal spring steel 55 Cr 3. The specimens were heated up to 880 °C and quenched in oil to get a martensitic structure. Then they were heat treated around 460 °C to obtain an tensile strength of R_m = 1420 N/mm^2. To avoid spreads of the hardness in the surface layer because of decarburazation, the specimens were ground to remove a layer of at least 0.3 mm.

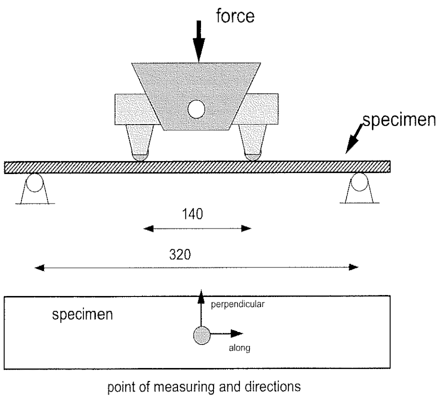


***Figure 1**. Mounting device and points of measuring for the stress rolled*

4. Experimental setup

4.1 Treatment of the specimens

The specimen were rolled with the help of a device type HG 6-9 from Ecoroll. It has a ball of 6 mm diameter, which were used to induce the residual stresses. The pressure against the ball by the liquid was p = 400 bar (380 bar without preload), which is equivalent to a force of around 1,1 kN. The optimal distance between the rolling tracks was always Δx = 0.15 mm , which was determined in a separate investigation (Müller, 2003). The rolling area was 55 mm * 55 mm and was rolled in the way of a meander.

In case of a preload the mounting device is shown in figure 1, in which the samples were fixed and loaded. Then the stress rolling was done under the different loads σ_{pl} = 300 N/mm²; 600 N/mm² and 1200 N/mm²

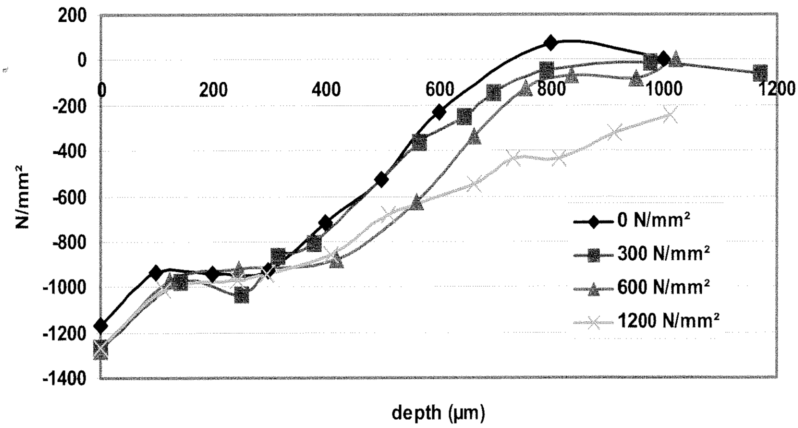
4.2 Measurement of the stresses

With the help of an x-ray diffractometer (type Rigaku Strainflex MSF-2M) the stresses were determined. It was used as an Ω-goniometer with Cr-K_α-radiation. In this case the distance between the [h,k,l]-layers [2,1,1] is measured. The diameter of the x-ray spot on the surface was 7-8 mm. The determination was done with the help of the $\sin^2\psi$ -2Θ -method (SAE, 1971; Noyan, 1987; Tietze 1982). To get a residual stress profile up to a depth of 1 mm the surface layers were removed electrolyticly.

5. Results

The residual stress was measured at two points at the meander. You find two different cases: In one case the rolling direction is perpendicular to the loading direction and in the other case the rolling direction is parallel to the loading direction respectively the load stress. At each point, the residual stress was determined along and perpendicular to the rolling direction. Per load and rolling force four different residual stress profiles are obtained. (Two will be shown for each load in this paper.)

Residual Stress Distribution (along)



Residual Stress Distribution (perpendicular)

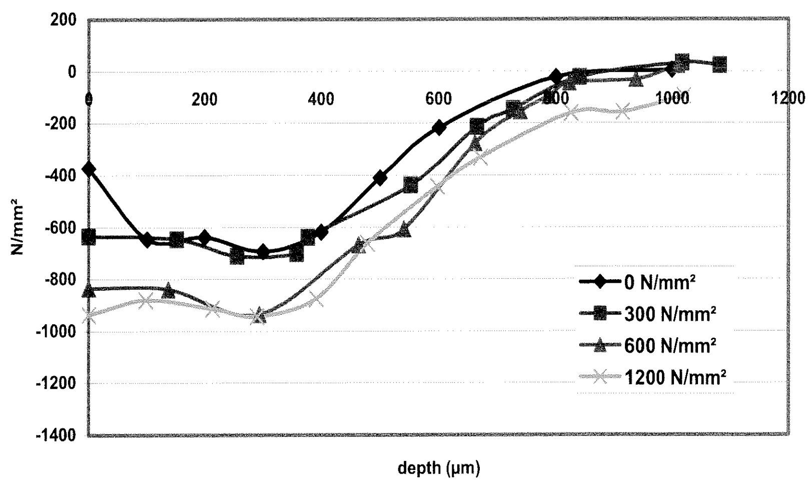


***Figure 2**: Residual stress distributions along and perpendicular to the rolling directions*

If the loading direction is perpendicular to the rolling direction, the enhancement of the compressive residual stress in dependence of the preload is not very strong. In the area between 400 µm and 800 µm depth a significant increase can be seen. If the preload is along the rolling direction in the region up from 600 µm depth the increase of the compressive residual stress is obvious.

If you look at the compressive residual stresses on the surface in dependence of the preload you obtain no independence of the preload if it is perpendicular to the rolling direction. If the rolling direction is along the preload the increase is linear in the beginning and has a saturation at high preloads. The same behaviour can be seen at stress peened samples (Müller, 1996; Zeller, 1991). One reason is the first non elastic micro deformations before the yield point, but does not explain the whole effect, because compressive residual stresses up to 1300 N/mm² are possible.

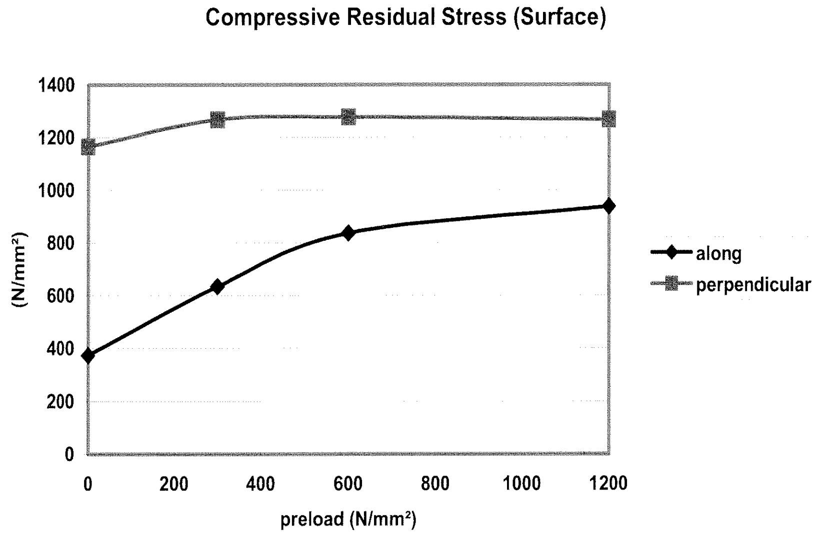
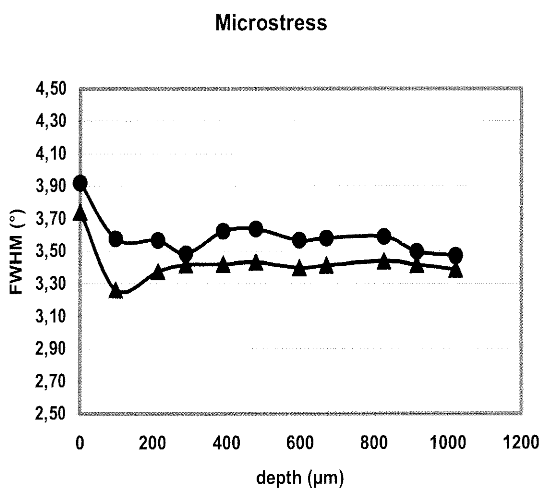


Figure 3: *The compressive residual stresses on the surface in dependence of the preload (rolling direction perpendicular/along bending direction)*



As an indicator for the micro stresses the full with half maximum of the scattered x-ray beam was measured. A typical distribution in dependence of the depth is shown in figure 4. A maximum is at the surface. At a depth of 100 µm there is sometimes an indication of a minimum.

Figure 4: *Distribution of FWHM in dependence of the depth*

5. Comparison with stress peening

Figure 5 shows the residual stress distribution at the surface. The axis called "along" is for stress peening the bending direction and for deep rolling the rolling direction and bending direction. As a result you get a nearly isotropic distribution of the residual stress (at the surface) at a high level, which can only be obtained at preload near the yield strength The compressive residual stress perpendicular is slightly reduced by stress rolling compared to normal rolled specimen. The same effect can be seen by stress peened samples (Müller, 1999).

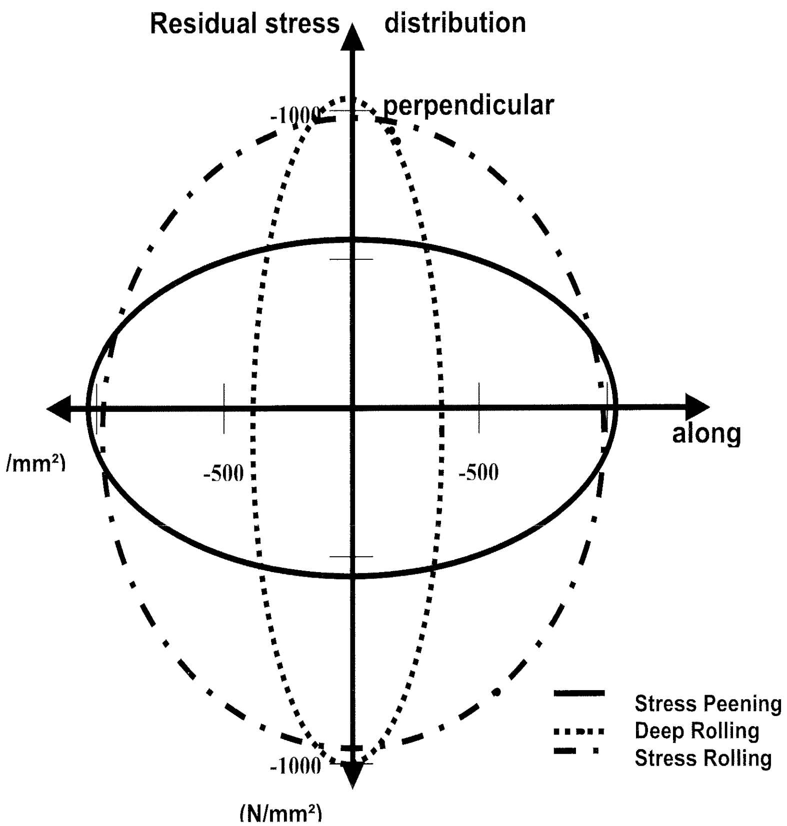


***Figure 5**: The angular distribution of the compressive residual stresses at the surface obtained by different surface treatments*

With normal peening, an isotropic distribution (not shown in the figure) of the compressive residual stresses at a level of σ = -600 N/mm² (Müller, 1999) can be achieved. With stress peening and deep rolling you obtain anisotropic stress levels at the surface (Müller, 2003). In both cases the maximums of the compressive residual stresses are comparable. The minimum of the compressive residual stresses is obviously lower after the deep rolling process. By stress rolling the mentioned isotropic distribution can be detected.

6. Conclusions

Equivalent to normal peening and stress peening a process of stress rolling can be defined as deep rolling under a tensile preload. Similar to stress peening higher compressive residual stress levels can be reached. The advantage is that a nearly isotropic distribution can be obtained.

7. References

Bernstein, G. u. Fuchsbauer, B.: Festwalzen und Schwingfestigkeit, Z. f. Werkstofftechnik 13 (1982), S. 103 - 109

Bonus L.: Auswirkung des Spannungsstrahlens auf die Eigenspannungen von hochvergüteten Bremsspeicher- und Torsionsfedern, Dissertation, TH Aachen, 1994

Finkelstein, v. E. u. Preckel, U.: Eigenspannungen beim Oberflächen-Feinwalzen, Stahl und Eisen 104 (1984), Nr. 14, S. 657 – 660

Kaiser, B.: Schwingfestigkeitssteigerung durch Randschichtverfestigungsverfahren, VDI-Berichte „Werkstofftechnik", Düsseldorf 1984, S. 26- 37

Kloos, K-H. u. Adelmann, J.: Schwingfestigkeitssteigerung durch Festwalzen, Mat.-wiss. u. Werkstofftechnik 19 (1988), S. 15 - 23

Müller E.: Spannungsstrahlen von Schraubenfedern, Draht 44 (1993) 1/2, S. 49 ff.

Müller, E.: Die Ausbildung von Eigenspannungen an Torsionsproben beim Spannungsstrahlen, Mat.-wiss. u. Werkstofftechnik 27 (1996), p.354 – 358

Müller, E: The Development of Residual Stress at Bending Specimens under the Influence of Setting and Stress Peening, Proceedings of the ICSP7, p. 88 f., Institute of Precision Mechanics, Warzaw 1999.

Müller, E.: Comparison of the induced residual stresses by shot (stress) peening and rolling in spring steel, in L. Wagner (Ed.): Shot Peening, p. 441 – 446, Wiley-VCH-Verlag, Weinheim 2003

Noyan I. C. u. J. B. Cohen: Residual Stress, Springer Verlag, New York, 1987

SAE (Ed.): Residual Stresses, Measurements by X-Ray Diffraction, SAE J 784a, Warrendale (USA), 1971

Tietze H. D.: Grundlagen der Eigenspannungen, Springer Verlag, Wien, 1982

Zeller, R.: Verbesserung der Ermüdungseigenschaften von Bauteilen aus Stahl durch optimiertes Kugelstrahlen unter Zugvorspannung, DVM-Band Betriebsfestigkeit „Moderne Fertigungstechnologien", p. 93-103, DVM, Berlin 1991