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THE DEVELOPMENT OF RESIDUAL STRESSES AT BENDING SPECIMENS UNDER THE INFLUENCE OF SETTING AND STRESS PEENING

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ABSTRACT

The development of the residual stresses at the surface at bending test specimens in dependence of several parameters was investigated. The specimens had two different hardnesses (R_m = 1530; 2000 N/mm²) and were setted before or after stress peening. They were shot peened under 4 different loads, which correspond to a stress of σ = 0; 600; 1200; 1600 N/mm². The residual stresses are shown in bending direction and perpendicular to it after every different step.

KEY WORDS

stress peening, strain peening, leaf spring. setting, plastification

1. INTRODUCTION

Today reduction of weight or material is an actual 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. Two further possibilities are the plastification of components and the shot peening or the later developed stress peening. Because it is possible to induce compressive residual stresses in dedicated amounts, it is used very often at tensile pulsating load to get a better utilization of the material. The two production steps peening and plastification influence each other, so that the correct sequence is very important. In this paper the different residual stresses in dependence of peening and plastification are described.

2. BASICS

2.1 Shot peening and stress peening.

Shot peening is a technology, which is a standard procedure. Peening (in the technical understanding) is the interaction between a particle (with the necessary hardness) with the surface of a working piece. If the particles have a round shape, you call it shot peening [Mü 93 a]. In the surface layer (up to 0.5 mm depth) compressive residual stresses are induced. At lower hardness of the working piece an additional hardening is achieved. In order to get better results by the peening process, the so called stress peening is used. Here the working piece or component is stressed in the direction of the later loading. After this step the original peening procedure is done and afterwards the unloading. The compressive residual stress profile, which now is achieved, is significant higher than that gained by normal peening. The result depends on the (torsional-) preload (τ_{ks}) σ_{ks} during peening [Mü 90, Mü 92, Bo 94, Mü 93a, Mü 93b, Mü 96, Mü 97a, Mü 97b, Ze 91, Ze 93].

2.2 Plastification

Under plastification or (pre)setting of a component is the loading (one or several times) in the later loading direction beyond elasticity [SC 67]. A positive change of the residual stress distribution is reached, which gives a better material utilization. In the plastified areas an additional hardening is achieved, which gives a better possible stress. Some examples of components are coil or leaf springs [Wa 66, Fi 87, Mü 94].

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 wide of 80 mm, and a height of 11 mm. The edges were rounded in accordance with DIN 59 145. The material was normal spring steel 50 Cr V 4. The specimens were heated up to 880 °C and quenched in oil to get a martensitic structure. Afterwards they were seperted in two batches for the heat treatment. At 460 °C you get a hardness of $R_m = 1530$ N/mm^2 and at 320 °C a hardness of $R_m = 2000$ N/mm^2. To avoid spreads of the hardness in the surface layer (decarburazation), the specimens were ground to remove a layer of at least 0.3 mm.

Afterwards the specimens were tempered at 250 °C for 1h to reduce the induced residual stresses.

4. EXPERIMENTAL SETUP

4.1 Treatment of the specimens

In fig. 4.1 the mounting device is shown, in which the samples are put for the further working steps. The sample could be loaded, which is not shown in the figure. The shot or stress peening was done with the help of this device. As shot conditional cut wire with a nominal diameter of 0.8 mm was used. The peening was done in a shot peener with four wheels in different directions.

In principle the steps of peening and plastification can be exchanged, as both induce compressive residual stresses with different distributions. Therefore different results are expected. Therefore two different sequences were examined at both hardnesses.

To verify the calculated loading stress in every sequence an additional step of loading/unloading is inserted. After each step the stresses at the surface were measured along and perpendicular to the axis of the specimens. The following basic sequence was carried out:

1. initial state, heat treated, ground, tempered at 250 °C, unloaded
2. loaded specimen with the calculated stresses σ_{ks} = 0; 600; 1200; 1600 N/mm^2
3. specimen unloaded
4. specimen loaded like step 2
5. specimen peened and kept loaded
6. specimen unloaded
7. specimen plastified at the calculated stress σ_b = 1800 N/mm^2

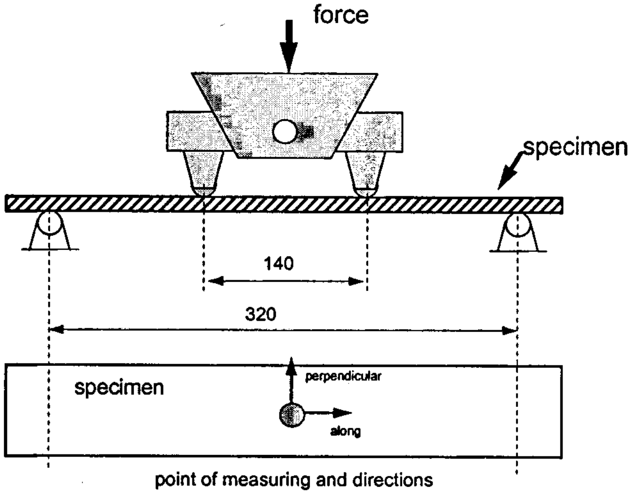


Figure 4.1: Mounting device and point of measuring

In this basic sequence plastifying followed by peening. In the other sequence the two steps were exchanged. All single steps were carried out under the same conditions.

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.

5. RESULTS

The results of the stress measurements at the surface are shown in fig. 5.1 - 5.4 . The length of the main axis of the ellipse shows approximately the amount of stress in this direction. The shadowing stands for compressive (dark) and tensile (bright) stress.

The initial state is the same for both hardnesses and sequences. The residual stress at the surface is the result of the grinding processes and lies between σ = +200 N/mm^2 and σ = - 200 N/mm^2. Looking at first at the basic sequence at the higher hardness (fig. 5.2) the calculated stress within the margin of errors is achieved. The following unloading and loading gives the same results. At the hardness R_m = 1530 N/mm^2 and the highest load sks the sum of loading and initial stress is not reached. It is smaller because at the surface the yield strength is more than reached. After the unloading along the sample a higher compressive residual stress is detected. There is also an indication at the load σ_{ks} = 1200 N/mm^2. The following reloading gives the exact sums of the stresses.

The shot peening creates a totally new residual stress distribution. Completely independent of the load σ_{ks} the same compressive residual stresses are induced, which gives an isotropic distribution. The unloading of the specimen is responsible for a strong increase of the compressive residual stresses along the specimen and a small decrease perpendicular to it. The increase is less than the total amount of load stress. This is caused at first by the compressive residual stress itself, which is verified by a slight bending of the specimen. Additionally because of the yield strength the amount of compressive residual stress is limited, which is around 1050 N/mm^2 for the lower hardness and 1600 N/mm^2 for the higher hardness. This fact is verified in fig. 5.3 and 5.4.

After plastification the compressive residual stresses along the specimen are slightly reduced. If it is plastified soon after tempering, compressive residual stresses are detected at the surface, which are very obvious at the lower hardness. The loading and unloading shows no strange behavior. In the next step (shot peening) the induced stresses are the same like the ones described above. During the unloading step the compressive residual stresses are increased. The amounts correspond with the other results. The amount of compressive residual stresses are kept, because the plastification has been done before and are higher in the final state.

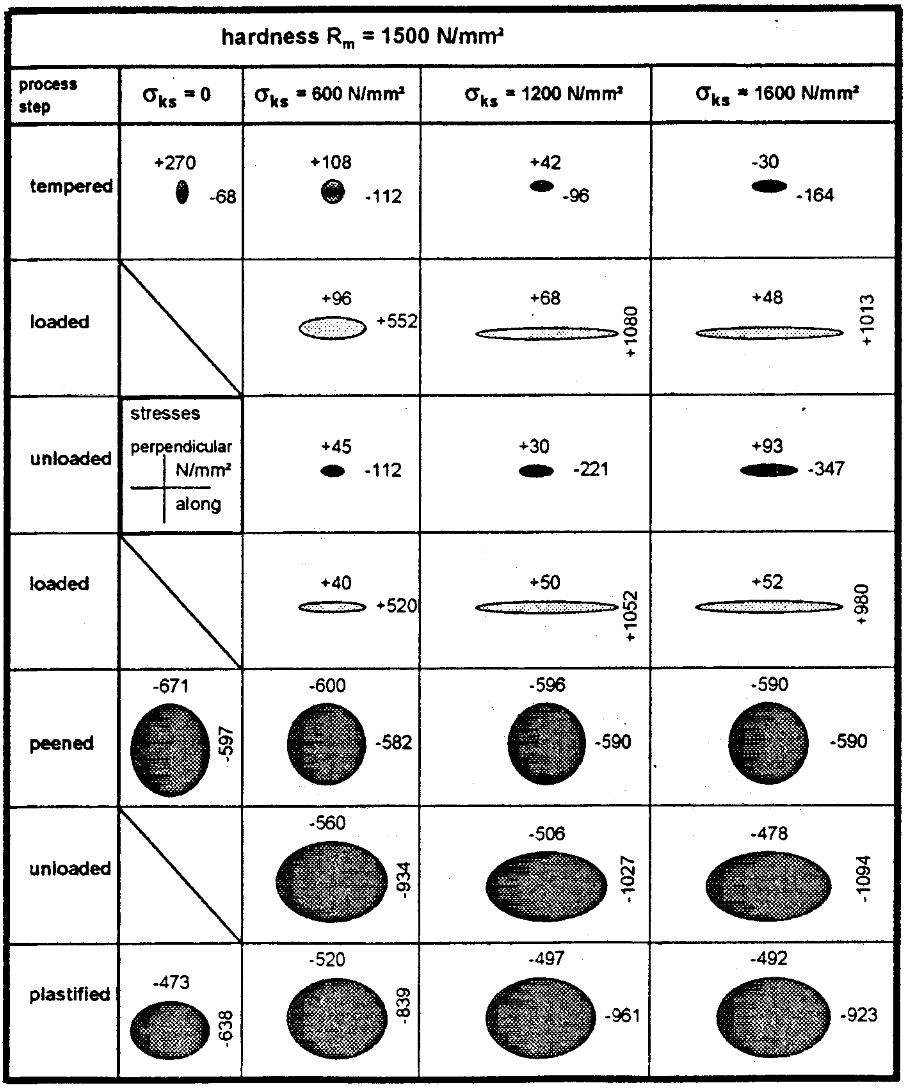
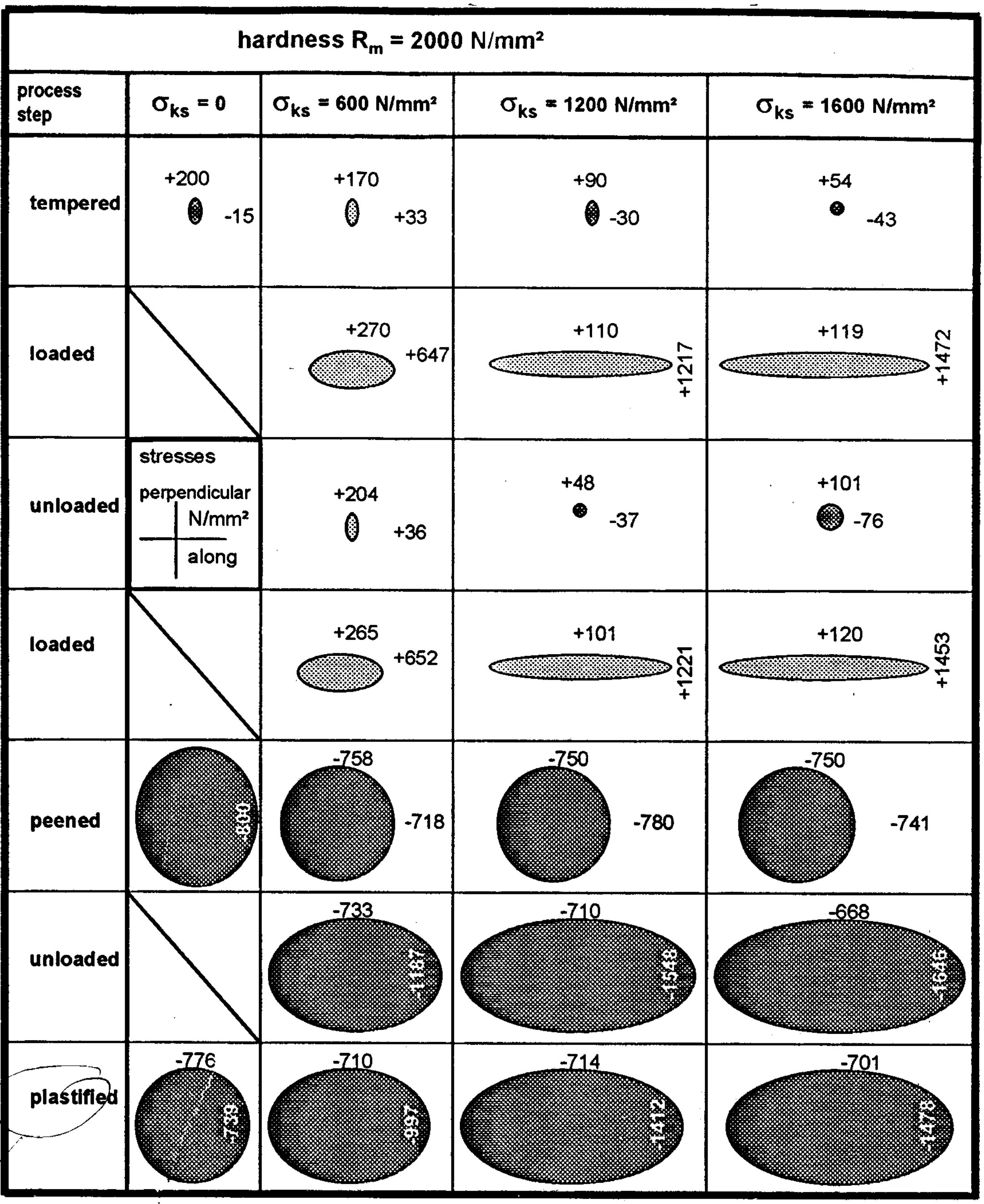


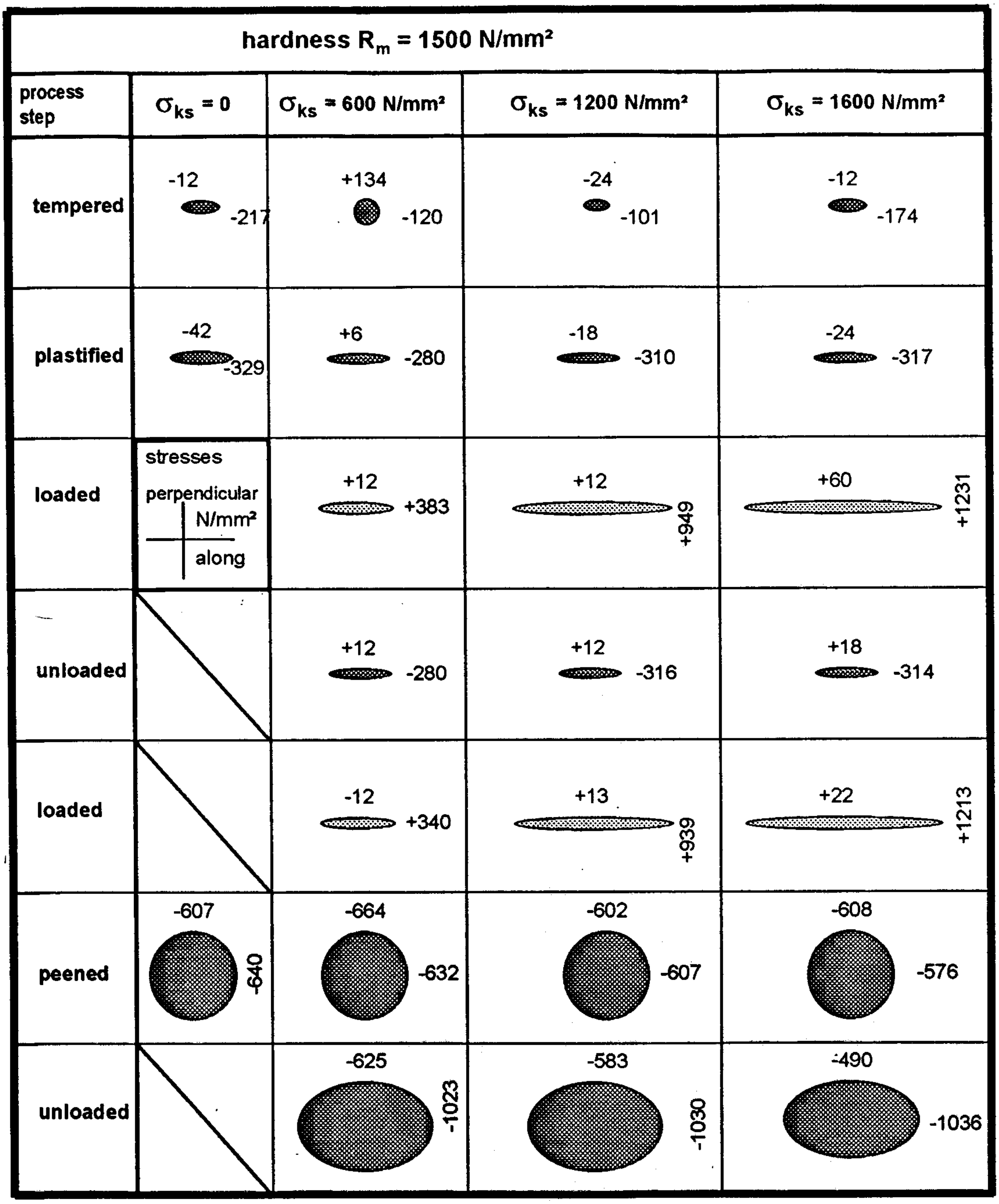
Figure 5.1: Stress distributions at the surface



hardness R_m = 2000 N/mm²				
process step	σ_{ks} = 0	σ_{ks} = 600 N/mm²	σ_{ks} = 1200 N/mm²	σ_{ks} = 1600 N/mm²
tempered	+200 -15	+170 +33	+90 -30	+54 -43
loaded		+270 +647	+110 +1217	+119 +1472
unloaded	stresses perpendicular N/mm² along	+204 +36	+48 -37	+101 -76
loaded		+265 +652	+101 +1221	+120 +1453
peened	-800	-758 -718	-750 -780	-750 -741
unloaded		-733 -1187	-710 -1548	-668 -1646
plastified	-776 -739	-710 -997	-714 -1412	-701 -1478

Figure 5.2: Stress distributions at the surface

reset shape of spring



hardness $R_m = 1500\ \text{N/mm}^2$				
process step	$\sigma_{ks} = 0$	$\sigma_{ks} = 600\ \text{N/mm}^2$	$\sigma_{ks} = 1200\ \text{N/mm}^2$	$\sigma_{ks} = 1600\ \text{N/mm}^2$
tempered	-12 -217	+134 -120	-24 -101	-12 -174
plastified	-42 -329	+6 -280	-18 -310	-24 -317
loaded	stresses perpendicular N/mm² along	+12 +383	+12 +949	+60 +1231
unloaded		+12 -280	+12 -316	+18 -314
loaded		-12 +340	+13 +939	+22 +1213
peened	-607 -640	-664 -632	-602 -607	-608 -576
unloaded		-625 -1023	-583 -1030	-490 -1036

Figure 5.3: Stress distributions at the surface

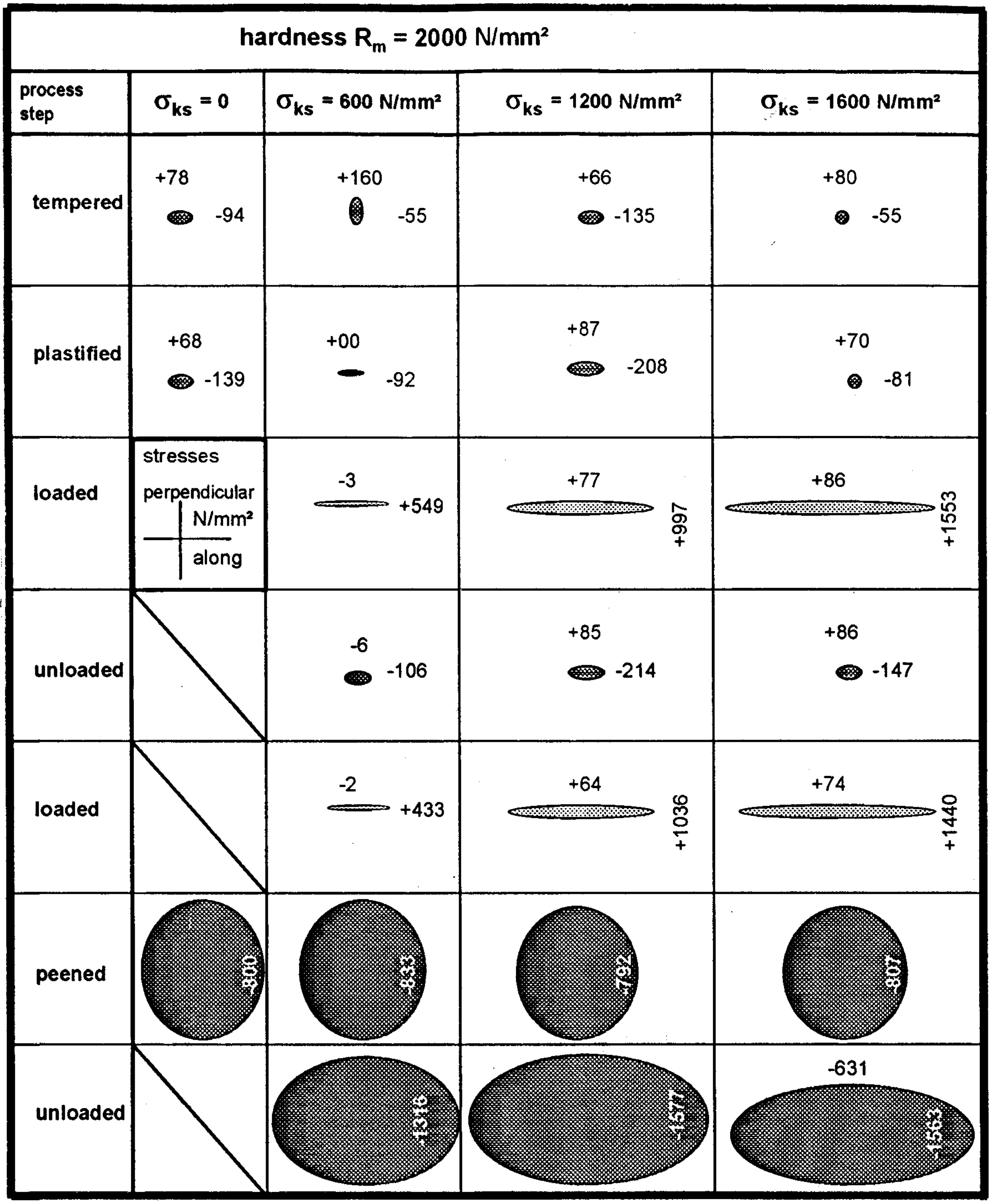


Figure 5.4: Stress distributions at the surface

6. SUMMARY

The maximum compressive residual stresses are achieved, when the plastification is done before shot peening. The induced residual stresses are independent of the stress distribution before peening. The compressive residual stresses can be increased by the unloading if it had been preloaded before. It is limited by the yield strength. The higher the hardness the more compressive residual stresses can be induced.

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