

Stress Peening—A Sophisticated Way of Normal Shot Peening

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Abstract: Stress peening is a special way of shot peening. The method is explained, and applications will be shown and discussed. These applications are seldom and mostly concentrated on spring industry. Here is the main process to increase the induced residual stresses to elongate the fatigue life. On the other hand, if no elongation is necessary, the weight of component can be decreased which is a basic question today. Also, the dimensions can be changed in a positive way.

Key words: Shot peening, stress peening, form peening, fatigue strength.

1. Introduction

Shot peening is a process used all over the world e.g. to increase the fatigue strength or is used for finishing surfaces or hardening it. It is used for many materials. If the aim of the shot peening process is to increase the fatigue strength the induced compressive residual stress is the main factor. The higher the stress is the higher the durability is. With inducing residual stresses, the shape of the component may change. This effect is primary used at sheets to bring them into a desire shape.

Stress peening is a special way of shot peening which is done under tensile stress. After unloading a higher amount of compressive residual stress is reached which increased the above-mentioned parameters. Normally it is done at components with high tensile strength ($R_m > 1,500$ MPa) and out of steel.

2. Basics

2.1 Shot Peening

At first shot peening should be defined to speak a

common language. A very general definition of peening is: Peening is an interaction of a sufficient hard blasting shot with the surface of a part or work piece. If the blasting shots have a round shape you call it shot peening.

The interaction has three aspects, which are described now:

- Work hardening
- Inducing compressive residual stress
- Giving a certain roughness

(1) The work hardening is unneglectable for high tensile strength, which is only discussed here. The main process is number two.

(2) The main reason for shot peening is to induce compressive residual stresses. The mechanism which dominates at high hardness is the so called Hertzian pressure, which is a consequence of the impact induced by the force perpendicular to the surface. The impact gives a dimple on the surface. A little bit of the material is pushed along the surface (Fig. 1.). The rest of the force gives a compressive stress, which can reach and be more of the yield strength. A local plastification of the material is the result. The generation of the shear stress is the important factor for inducing compressive residual stresses. The maximum of the shear stress is about half of the shot

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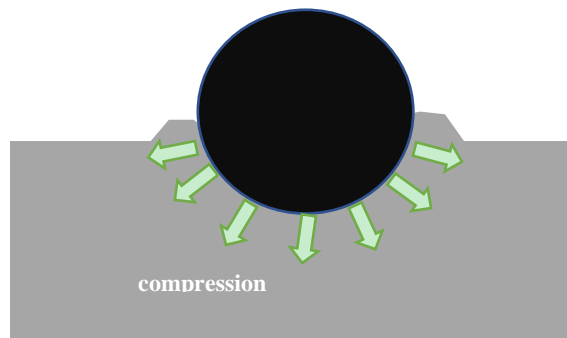


Fig. 1 Situation a shot hitting the surface.

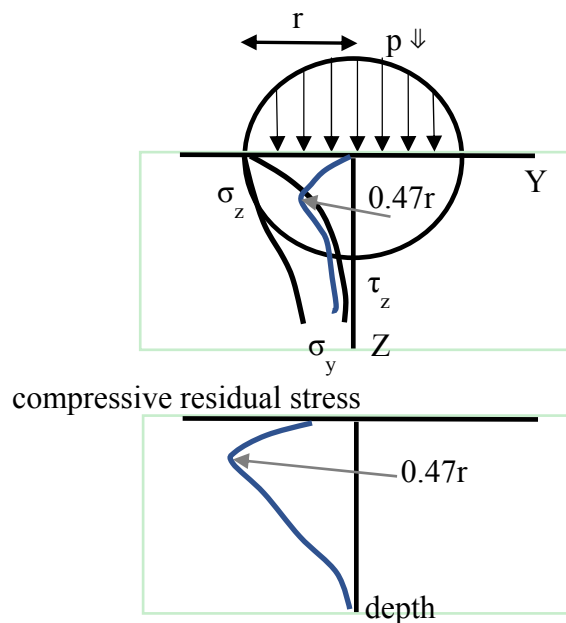


Fig. 2 Schematic situation of the Hertzian pressure (r = radius shots).

radius. Therefore, it is typical that the maximum is under the surface (If there is a strong hardening process, the maximum is at the surface). Fig. 2 shows all the stress distribution and the shape of the residual stress distribution. Normally at a depth of $300\text{ }\mu\text{m}$ the plastification of the material is ending, because the theory of the Hertzian pressure explains the shape and the depth of the profile. The kinetic energy gives only the amount of the residual stress up to the limit. For spring steel, the limit is $2/3$ of the tensile strength [1]. The hardness difference between the shot and the component to be peened should be significant. If you have too soft shots, you have only an elastic impact and no big plastification.

(3) The roughness increases with more velocity and size of the shot. Remember the velocity is squared in the kinetic energy and the diameter of the shot is to the third. The higher roughness induces a higher probability for crack initiations. Getting higher compressive residual stress gives higher roughness, that the effect of a better durability may be gone. For instant, the shot peening with a shot diameter of 0.6 mm and 1.4 mm gives the same durability. To get a better performance concerning durability two possibilities can be made. The first way is to make dual peening. That means to peen a second time with a small shot size to decrease the roughness. The second method is to peen at higher temperature (e.g. $300\text{ }^{\circ}\text{C}$).

The roughness will increase, but also the compressive residual stress is increasing significant. Additionally, the residual stresses (mean the dislocations) are longer stable at high dynamic loads. A simple picture is that they are a kind of frozen.

In the field of peening and residual stresses the concept of local durability is important [2]. It explains very well the crack initiations. For high tensile strength ($R_m > 1,500$ MPa) the compressive residual stresses enhanced the durability. The factor is $m = 0.33$ which means 100 MPa more compressive residual stress give 33 MPa more fatigue limit. The formula in total is

$$\sigma_{sfl} = \sigma_{fl} - \sigma_{ps} - m * \sigma_{sp} \quad (1)$$

where, σ_{sfl} = summarized fatigue limit with all influence factors, σ_{fl} = fatigue limit with no other stress in the component, σ_{ps} = additional stress, under load, σ_{sp} = stress induced by shot peening.

The compressive residual stress is not uniform in dependence of the depth. Concerning this fact, the concept of local durability was compiled. The consequence is that at high compressive residual stresses the probability of crack initiations will decrease or at lower loading stress it will disappear in this section. A typical example is described in the next section.

A very important aspect of shot peening is the following fact: If no higher durability is necessary, the load can be increased or respectively the weight of the components can be decreased. Many components in the automotive industry had a drastically weight reduction. Mostly there are only two ways to increase the durability respectively reducing the weight or increasing the hardness of the material and increasing the compressive residual stresses. For springs the so-called stress peening was performed (see Chapter 2.2).

All aspect of shot peening can be summarized in two definition:

“In general, shot peening is a cold working process. This treatment is used to strengthen the surface of

metallic components by increasing dislocation densities during plastic deformations. Furthermore near-surface residual stresses developed, and the surface topography is changed. In peening, the surface is impacted by round metallic balls, glass or ceramic particles.” [3]

DIN 8200 defines peening as mechanical surface treatment processes in which peening media with a specific shape and a sufficiently high degree of hardness are accelerated in peening devices of various kinds and interact with the surface of the treated workpiece. ...The creation of compressive residual stresses close to the surface is the main focus of the shot peening process, ...[4].

2.2 Stress Peening

Stress peening means the work piece or component is stressed in the loading direction under work. After this step, the normal shot peening process is done and subsequently the component is unloaded. As a consequence, parts which will be loaded in both directions (tensile and compressive stress) cannot be stressed peened. You distinguish three different types of preload for stress peening [5]:

- Pure tensile strength over the whole cross section
- Bending stress, which affects tensile stress at some section on the surface layer
- Torsional stress, which gives tensile stress over the surface in 45° direction to the torsional axis

All cases are applications, which will be described in Chapter 3.

Starting with the basics, for a better understanding, there is no residual stress in the component. The first is to load the component in the later loading direction. The amount of loading is important, because it is responsible for the height of the achieved compressive residual stress afterwards. Under loading conditions, the shot peening process is performed. Now a residual stress profile has been established like you peen under normal conditions. After unloading the compressive residual stress is increasing in the amount and in the

deepness. It is a simple process. The residual stress development during the process is shown in Fig. 3 [6, 7].

There are some very important aspects, which should be taken in considerations. The achieved amount of compressive residual stress is independent of the initial residual stress in the component. This means if there are high tensile stresses before the peening process in the surface layers afterwards you receive the same compressive residual stress distribution. The only requirement is, that the peening time is long enough, which must not be longer as under normal conditions [1].

If the loading stress is very high, which can be done for some components, you can reach the maximum compressive residual stress, which is limited from the material parameters. This can be seen at leaf springs (see Chapter 3.1).

Stress peening gives no higher roughness compared with normal peening. This is another big advantage. If you stress peen and you want to peen a second time e.g. with smaller shots, the preload has to be hold. Else the effect of stress peening is gone in the performance region. The effect of shot peening is independent of the prestress! Also, warm peening can

be done under stress. The achieved residual stresses with warm peening are more stable under high dynamic loads [8].

3. Applications

3.1 Springs

The oldest application is to stress peen leaf springs. This is an example for using bending stress. Since a long time, the leave spring has no constant thickness on the leaf. The thickness has a shape which is formed that the stress is constant on the whole leaf. The shape has a parabolic function of the thickness (if you take it exact the shape is like a square root function). Therefore, these springs are called parabolic leave springs. Every single leave is prestressed. At leaf springs, there is a very high limit concerning prestress. They were stressed over the tensile strength to plastify the spring into deeper regions and to get the maximum compressive residual stress to deeper regions (Figs. 4 and 5).

You can recognize it, if you have a compressive residual stress profile, which has constant amount of stress into deeper regions (Fig. 5). These causes are from the fact that for every material an elastic limit

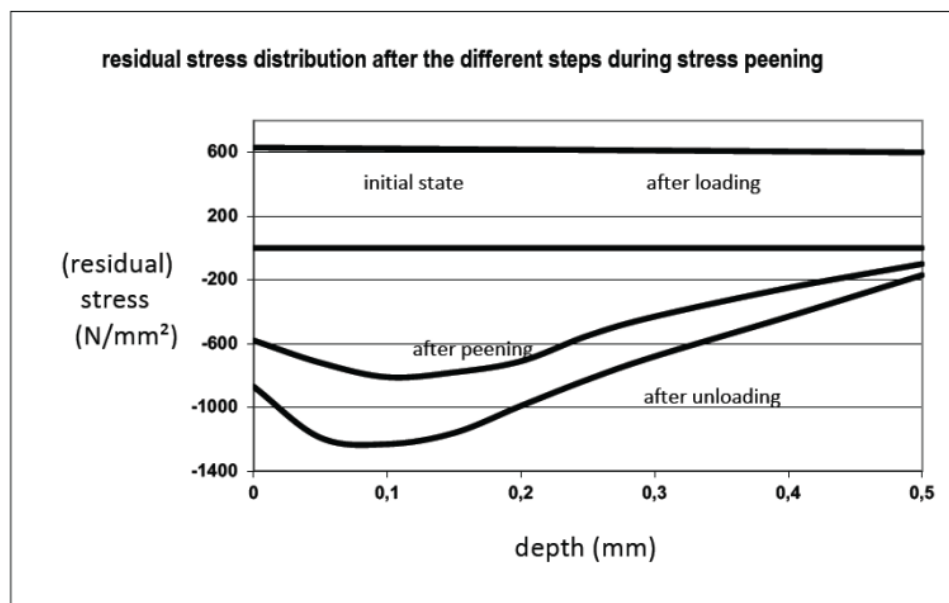


Fig. 3 The development of the residual stress distribution in dependence of the different steps.

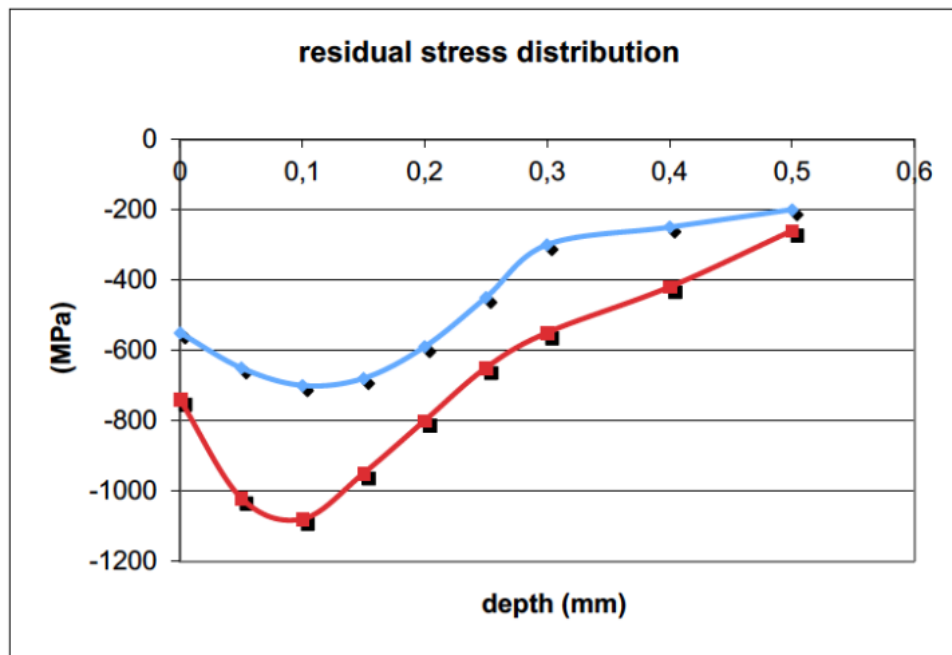


Fig. 4 Comparison of a typical residual stress profile for coil springs [9] (blue = normal peened).

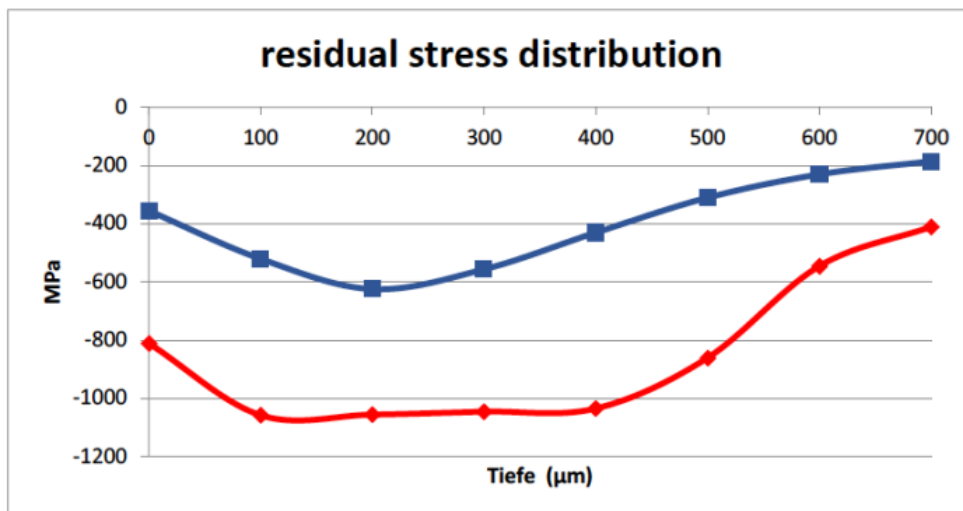


Fig. 5 Residual stress distribution measured at a leaf spring, which was normal (blue) and stress peened.

exist. For spring steel, it is two thirds of the tensile strength R_m [10]. In Fig. 5 the tensile strength was $R_m = 1,620$ MPa. This causes the plateau between 100 μm and 400 μm depth. The decarburizing at the surface is the reason for the lower compressive residual stress there

In Fig. 6 you see an S-N-diagram comparing normal leaf springs with high prestressed peened parabolic leaf springs. You can see the big increase of the fatigue limit.

Stress peened coil springs are today one normal step in a production line. This is an example for torsional prestress. The spring is compressed in a mounting device. The problems are the ending coils. Often, they were not peened very well, because of the mounting. There is the step to peen them without mounting before stress peening and not afterwards, because in the last case the effect of stress peening is gone.

The main problem at coil springs is the optimal

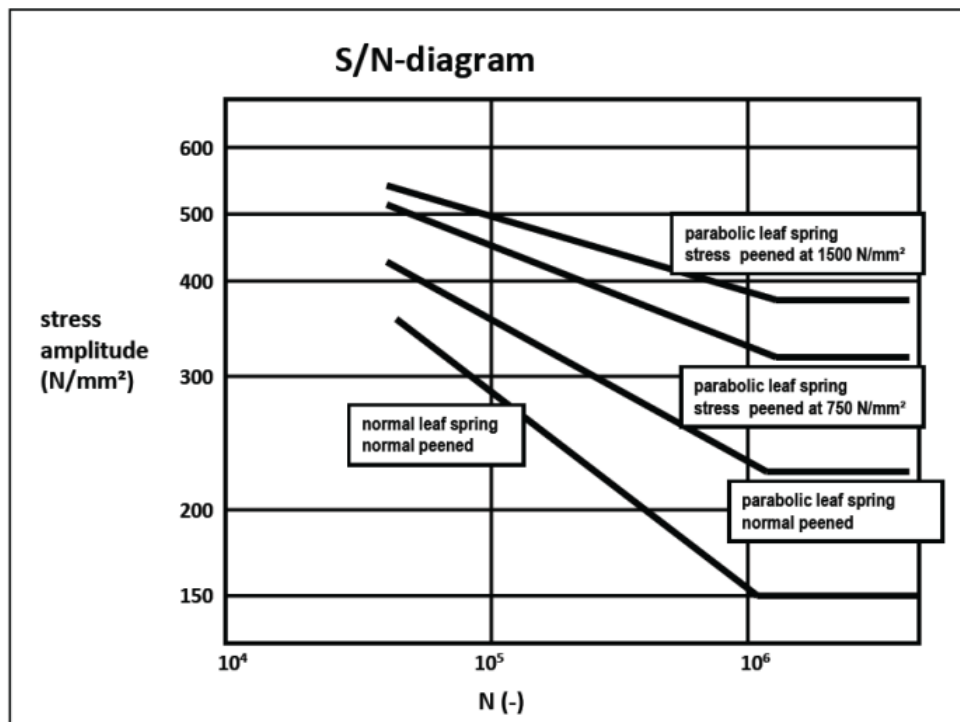


Fig. 6 Durability of leaf spring peened under different conditions [11].

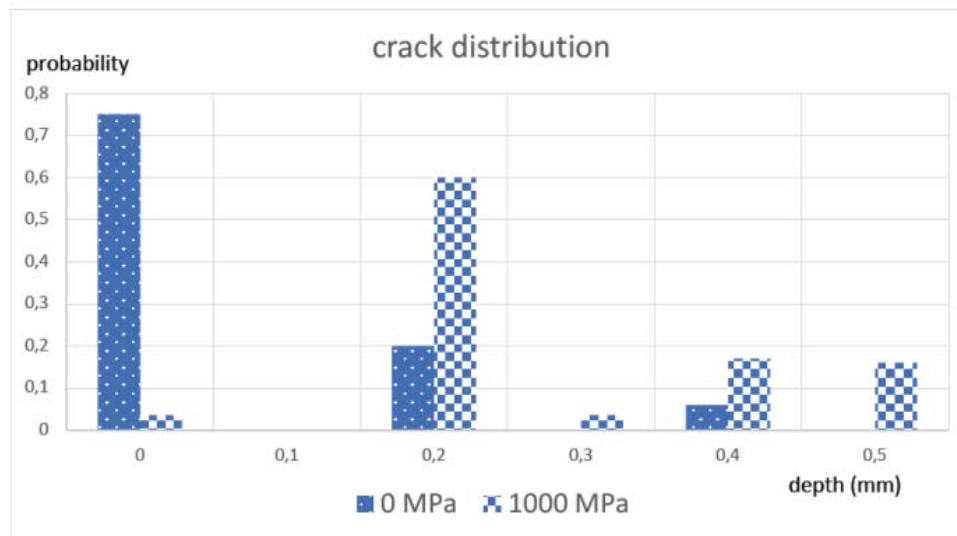


Fig. 7 Crack initiation in dependence of the prestress at stress peened torsion bars [5].

prestress. If it is too low the achieved compressive residual stress is not much more compared to normal peening. If the preload is too high, the coils shadow the inner surface of the coils with the consequence that there is a low intensity respectively compressive residual stress. The maximum of the later working stress is at inner side of the coils.

Because of experimental reason torsion rods were also stress peened. This has the big advantage that you can use more prestress compared with coil springs. In an experiment torsion bars were peened with a prestress of 0 MPa and 1,000 MPa. After a fatigue test the crack initiation in dependence of the depth was determined. Fig. 7 shows the result. In the region of

the maximum compressive residual stress out of the Hertzian theory no crack initiations were detected. The shot size was 0.6 mm diameter which means the maximum of the compressive residual stress is in around 150 μm depth.

Another application is disc springs, which mainly have an inhomogeneous tensile stress over the cross section, which will not further be described here.

3.2 Piston Rods

In some cases, piston rods were stress peened [12, 13]. The rods were stretched that you achieve a tensile the whole cross section. After the stress peening over the whole surface a high compressive residual stress is achieved as a consequence. In a fatigue test with high loads the crack initiations were not over a long area.

They were concentrated in a small section, where the highest loading stress under dynamic load is.

3.3 Peen Forming

The effect of form peening will occur in a significant way. If thin plates are shot peened on one side a compressive residual stress layer is established. The force depending on the intensity of the shot peening intensity respectively the amount of compressive residual stresses causes a bending of the plate to get an equilibrium of the internal forces. With different intensities of shot peening on a plate different curvature can be obtained [14, 15]. Normally this procedure is done by robotics. Aircraft wings [16, 17] and some metal sheets of the Ariane 5 rocket were formed this way [18].

To get a higher bending of the sheet it could be prestressed and in this shape the peening is done [14]. The gap between the amount of bending and not bending can be increased. It is another example for bending stress, which is used as prestress.

4. Conclusions

Stress peening is for a small range of components a well-established procedure. The equipment for

preloading must be individually built for nearly every different component. As a high sophisticated process, the durability can be increased by a factor two to three comparisons to normal peening.

A second application is a steering process for forming to get high different three-dimensional shapes of sheets, which cannot be manufactured in a normal way.

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