



THE EFFECTS OF SHOT PEENING ON THE FATIGUE LIFE OF MACHINE ELEMENTS

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Abstract: For increasing the resistance to fatigue and wear, different methods for improvement of contact layers properties are used. First of all, the improvement of properties is realized by heat treatment (induction and flame hardening), chemical-heat treatment (carburizing and nitriding) and plastic surface forming (surface forming by rolls, disks and balls, as well as shot-peening). The paper gives detailed explanation of the shot peening procedure, which involves the ejection of shots at high speed onto the forming object. The intensity of impact is the function of the kinetic energy and angle at which the shot hits the forming object. Thereat, smaller or larger increase of hardness occurs on surface layers, remaining stresses are made, surface topography is changed, and, in some cases, the structural changes are possible (disintegration of remaining austenite). This all leads to increase of fatigue life of elements subjected to shot-peening. The influence of specified effects on the increase of fatigue life depends on strength of material subjected to shot-peening but also on conditions at which the shot-peening process is performed. This paper will present the influence of shot peening on the increase of fatigue life of different parts.

Key words: Shot Peening, Fatigue Life, Machine Elements

1. INTRODUCTION

The shot-peening process involves the ejection of shots at high speed onto the forming object. Each shot which hits the object seems like the blow of a tiny hammer. The intensity of impact is the function of the kinetic energy and angle at which the shot hits the forming object. Thereat, smaller or larger increase of hardness occurs on surface layers, residual stresses are made, surface topography is changed, and, in some cases, the structural changes are possible (disintegration of residual austenite). This all leads to increase of dynamic strength of elements subjected to shot-peening. The influence of specified effects on the increase of dynamic strength depends on strength of material subjected to shot-peening, but also on conditions at which the shot-peening process is performed.

Unlike shot blasting, which is used for cleaning surface of parts by tiny sand particles, shoot-peening is used for strengthening part surface. It is performed with small hard balls, which can be made of steel, cast iron, glass or ceramics.

2. THE INFLUENCE OF SHOT-PEENING EFFECTS ON DYNAMIC STRENGTH

It is well known that forming by spray of balls can improve fatigue of metal materials. That improvement is reflected in one of the two possible ways: increase of stress for constant life or increase of life for constant stress, as shown in figure 1 [1]. However, it is also possible to reduce part mass for the same loading and life,

which can be extremely important, especially in airline, car and military industry.

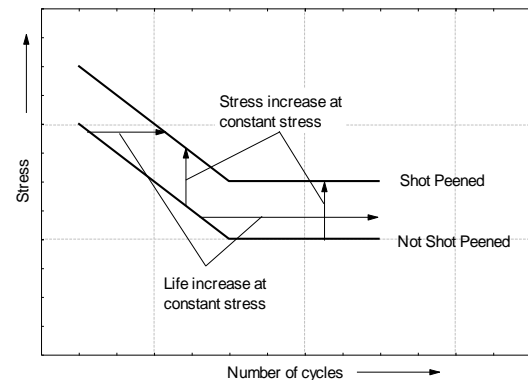


Fig.1. Influence of shot peening on material fatigue behavior

Hardening by shot peening can be done by variation of many parameters, enumerated in the first column in Figure 2, [2], which represents conditions in which the peening process is done.

The shot stream affects the condition of surface layers or the working piece. In certain cases the following changes can occur:

- breaking or removing of the protective layers, e.g., oxide layers,
- change of the surface topography ΔR_t ,
- hardening or softening of surface layers, represented as changes in hardness ΔHV ,
- changes of the residual stresses $\Delta \sigma^{RS}$ in layers close to the surface, due to creation of certain distribution

- of residual stresses in surface layer of relatively small thickness,
- phase transformations in layers close to the surface, e.g., transformation of the retained austenite ΔRA in quenched steels,

- formation of cracks in the case of the machining by the shot stream of high intensity.
- Intensity of changes of various characteristic parameters of material status depends also on initial values of these parameters before the shot peening, what is shown in the second column of Figure 2 by short symbols.

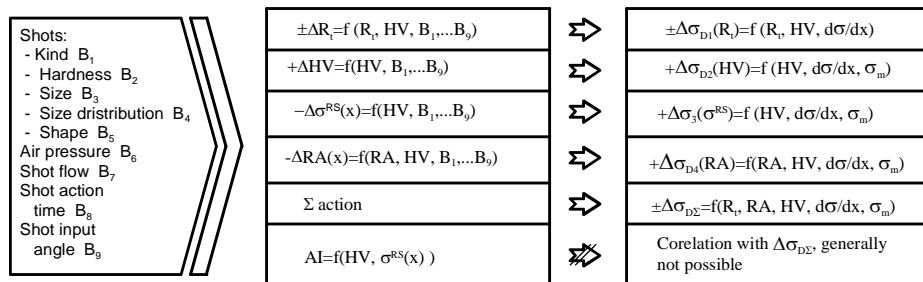


Fig.2. Mutual influence of shot peening conditions and fatigue strength

Each change of the surface conditions reflects, in some way, on fatigue behavior, for instance, the fatigue strength. In that the magnitude of influential parameters effect is different, depending on type and status of material, as well as on type of fatigue straining. These influences are shown in the last column of Figure 2.

Under the simplified assumption that changes of fatigue strength, due to individual influences of different factor, superimpose cumulatively, the total status can be represented by the following equation:

$$\pm \Delta \sigma_{D,\Sigma} = -\Delta \sigma_{D,1} (+\Delta Rt) + \Delta \sigma_{D,2} (+\Delta HV) + \Delta \sigma_{D,3} (-\sigma^{ZN}) + \Delta \sigma_{D,4} (-\Delta RA) \quad (1)$$

Now it is quite clear how the very complicated dependence of the fatigue strength increase due to multiple possible influences arises. Optimal conditions of shot peening, depending on type and status of material, shapes and size of element (part), as well as on type of stress, can be very different.

3. APPLICATION AND BASIC CRITERIA FOR APPLYING THE SHOT-PEENING PROCEDURE

The shot-peening procedure is widely applied for parts strengthening (dynamically loaded parts in car, airline and military industry). Shot-peening is performed on steel and non-ferrous metal parts. The percentage of increase of dynamic strength, i.e. fatigue life, can be various and depends on type of material, shot-peening conditions and machine part shape. The literature [3,4] includes a lot of data which indicate the effects of various parts strengthening. In figure 3, according to [4], the percentage of dynamic strength increase for different parts groups is shown. The increase is the largest for spring elements.

Compression coil springs are, most probably, the parts which are most often subjected to shot-peening. They are used not only in car industry, but also in other industry sectors; therefore, the annual production coil springs amounts to hundreds of millions. Coil springs should always be subjected to shot-peening from both the outer and inner side, because the largest fatigue life is obtained only in such a case [5]. In the course of shot-peening of springs, particular attention is given to the selection of

shot-peening intensity, because too intense shot-peening can cause the change of static properties of the spring [6].

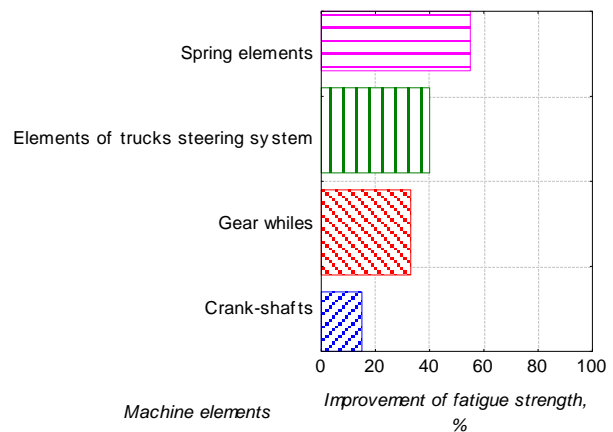


Fig.3. Increase in fatigue life of some machine elements as a result of shot peening [4]

For parts loaded only with direct variable loading, with the aim of increasing lifetime in relation to conventional shot peening, stress-peening, i.e. strain-peening is applied. This means that the part is shot in strained state, which provides higher compressive residual stress in relation to stresses obtained by normal shot-peening. Compression coil springs are very convenient for strain-peening. According to [5], if springs subjected to strain-peening are applied, it is possible to save about 25 kg of an airplane mass, which is not to be neglected in airline industry.

The initial material for manufacture of coil springs is hot rolled, drawn, peeled or abraded steel. Each of the surfaces obtained in such a way, especially on rolled material, has small errors (caused by rolling), boundary decarburisation and certain roughness. Anomalies in structure, caused by melting (segregation) and non-metal inclusions should also be taken into consideration. If located near surface, these anomalies can have negative effects on fatigue behaviour of springs. In such cases, shot-peening increases fatigue life for 30 - 180% [7].

Leaf springs, if loaded by one-sides bending, are subjected to shot-peening only from one side. If, in the course of performance, the spring is two-sidedly bent, shot-peening is performed on both sides.

One of the main causes of significant reduction of leaf and spiral steel springs life is the presence of decarburised surface layer, formed in the course of technological manufacture procedure. It was established that surface decarburisation leads to significant reduction of resistance to fatigue, due to both smaller strength of surface layer and the creation of tensile residual stresses in decarburised layer [8].

The procedure of strengthening by shot-peening is also often used for shafts and axes. Shot-peening is performed either on the entire surface or only on locations of grooves for the pins and transition radii. There are many papers [4,5] which indicate the significant increase of fatigue life of shafts and axes, caused by shot-peening.

Gears are the machine elements which are, also, often subjected to shot-peening. It has been determined that the procedure of shot-peening leads to formation of surface topography which enables creation of tiny oil tanks [5], which provides better lubrication and decrease of working temperature in the course of performance. Shot-peening of gears with low manufacture tolerance can lead to intrusion during the performance. In such cases, shot-peening is performed only in the area of tooth root, while gear tooth sides are protected.

Gears are also often subjected to shot-peening after cementation. Fatigue life of cemented gear, at maximal stress of 560 MPa, was increased from 270000 to 3 millions of cycles, after shot-peening [5]. It is recommended to use balls of increased hardness for that procedure, because they provide higher values of compressive residual stresses.

Heat zones made by welding are always under tensile stresses which reduce fatigue life of welded joints. The shot-peening procedure leads to creation of compressive stresses in surface layer and increase of fatigue life of welded joints.

Electrolytic coatings of soft metals, such as cadmium, lead, tin and zinc have minor influence on dynamic strength, unlike coatings of hard metals (nickel or chrome). Reduction of dynamic strength, in the course of coating by chrome and nickel, is the result of creation of tensile stresses in the surface layer. If a small crack appears in the coating, it continues to spread into the basic material. If the basic metal surface was subjected to shot-peening before coating procedure, the compressive residual stresses which arise prevent spreading of cracks in the coating.

The paper [9] has shown that shot-peening after chrome and nickel coating leads to increase of fatigue resistance. Coatings adhere much better to surface subjected to shot-peening than to abraded surface.

Shot-peening can also be performed only on one part of some machine element surface. Untreated surface is usually protected (masked) by stripes of good adhesion properties which are sufficiently elastic to absorb shots impacts. Masking is most often performed on points where dimensional accuracy and smooth surface are needed. This procedure is often used on crankshafts, where only radius is subjected to shot-peening, while sleeves for slide bearings are protected. One should bear in mind that masking increases the costs of machine element manufacture. That is why it is used only when it is necessary.

On materials such as stainless steel, manganese steel, stellites, nickel alloys etc., significantly higher hardness of surface layer is obtained by shot-peening procedure [5]. This is very important for parts which cannot be thermally treated, and which are required to have high resistance to surface wear.

In the course of shot-peening, it is possible to perform the correction of parts with relatively thin cross section. Such treatment annuls unfavourable tensile residual stresses which lead to machine element bending. According to data provided by Metal Improvement Company [5], it is possible to carry out, successfully, the correction of different parts, such as shafts, pipes, rings, ring gears, piston rods, discs etc.

Shot-peening can also be used for cleaning a metal surface (shot-blasting). Shot-blasting is much better than sandblasting, because during sandblasting, small notches, which represent stress concentrators, are made, which is not the case with shots.

Shot-peening procedure can eliminate the porosity of cast and welded junctions to a large extent. In many cases, shot-peening is much more reliable and economical than vacuum impregnation.

In addition to strengthening dynamically loaded parts, shot-peening procedure is also used for forming large dimension parts (peen-forming). This forming is used, almost exclusively, in airline industry and is based on the same physical foundations as the shot-peening focused on strengthening. Shot-peening intensity should be sufficient for change of macro-geometry of part being subjected to it.

In addition to strengthening parts made of steel, significant increase of dynamic strength is accomplished by using shot-peening on parts made of alloys of aluminium, magnesium, titan, as well as bronze and brass [5].

The endurance of machine elements can be increased by proper selection of materials, rational part construction, suitable technological forming procedures or combination of all those possibilities. Thereat, the main aim is to form the product of the highest quality level and acceptable price.

For parts subjected to variable stresses during the performance, material selection is based on fatigue properties. In practice, they selection is more often performed on the basis of static strength (flow limit and tensile strength). Up to a certain limit, the selection based on tensile hardness represents a satisfactory criterion. However, in some other cases (corrosion fatigue and strength at limited number of cycles) that selection does not give satisfactory results. Certain increase of tensile strength leads to limited increase of dynamic strength, because the material sensitivity to stress concentration and creation of fatigue cracks increases. In those cases, the selection of material should be made based on dynamic strength of the material.

Numerous factors, which can influence the resistance to material fatigue, should already be influenced in the phase of constructing parts, sets, devices etc. In most cases, the appearance of fatigue cracks can be prevented by adequate and optimal selection of the material and development of quality constructions. Such approach provides more possibilities for increasing the dynamic

strength compared with other available procedures. One of the most important tasks is the reduction of stress concentration. For complex shape parts, it is difficult to obtain theoretical solutions, and experimental analysis is often complicated and long. In those cases, it is more useful to rely on the results of fatigue investigations, because in that way the majority of loaded zones can be identified as well as the influence of additional factors (manufacture defects, residual stresses, corrosion and friction). For reduction of stress concentration, it is necessary to avoid sharp shifts of cross section, openings and notches. Sometimes, in order to make the entire construction functional, solutions which lead to dynamic strength reduction are used. In those cases, it is necessary to search for other methods and procedures for increasing dynamic strength.

The technological procedure of manufacture has a considerable influence on dynamic strength of machine elements. Machine forming procedures, in which considerable roughness and tensile compressive stresses are created in the surface layer, lead to significant reduction of parts resistance to fatigue. The increase of resistance to fatigue is accomplished by selection and adequate defining of technological manufacture procedures, especially of parts exposed to dynamic loadings in the course of performance. Some mechanical forming procedures (scraping, milling and grating) do not provide high resistance of parts to fatigue. Dynamic strength of parts is, to a large extent, increased by the grinding procedure, first of all by polishing. The procedures of surface plastic forming of parts can increase resistance to fatigue significantly. The procedure of shot-peening of surface by beam of balls is particularly convenient. Thermal and chemical-thermal surface forming can increase (induction hardening, cementation, nitriding) or reduce (normalisation, annealing, chrome-coating) dynamic strength.

Exploitation conditions, such as working temperature, type of loading and frequency, also have significant influence on fatigue behaviour of machine parts.

Parts of weapons and tools should provide functionality, be of small dimensions and be able to bear very high dynamic loadings. The increase of dynamic strength, i.e. the resistance to fatigue of such parts, cannot be achieved by increasing dimensions, but only by some other solutions and procedures. Procedure of shot-peening of critical points or complete parts offers the needed possibility for realising that increase. To that purpose, it is especially convenient to use, for example, the finite elements method or other ones, even experimentally, in order to carry out the stress analysis of the part, and only after that to perform the shot-peening procedure on points of largest tensile stresses. For a large number of dynamically loaded elements of weapons and tools, the value of limited dynamic strength is important, because those elements change during the exploitation, after particular exploitation period.

The proper selection and preservation of shot-peening parameters values throughout the forming process and improvement of resistance to fatigue life can be multiple. When selecting the procedure of part forming by shot-peening, certain limitations should be born in mind, such as:

- Impossibility to preserve tolerated dimensions after treatment,
- Impossibility to carry out shot-peening on locations with small opening and covered surfaces,
- At too intensive shot-peening of small cross section parts, permanent deformations may occur, which would disrupt part functionality etc.

Due to all this, it is necessary to be well aware of potential consequences, caused by shot-peening procedure and to have particular experience in practical application of this procedure.

4. CONCLUSION

The procedure of shot-peening by steel balls beam represents one of the methods for strengthening dynamically loaded parts by plastic surface forming which is applied on materials such as: steel, regardless of thermal treatment, cast steel and cast iron, copper alloys, aluminium alloys, titan alloys and some other metals. In addition to that, this procedure can also be applied for: cleaning machine elements, previous forming of elements for galvanisation and metallisation, protection against corrosion destruction, stress corrosion, pitting and erosion, sheet metals forming and correction of parts of small cross section.

During the shot-peening performance, quantitative and qualitative changes occur in surface layer. Those changes are: creation of compressive residual stresses in surface layer, change of surface layer hardness, change of surface topography and change of surface layer structure.

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