FATIGUE STRENGTH OF THE STEEL AFTER THE PERCUSSIVE BURNISHING PROCESS

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ABSTRACT: The percussive burnishing method, which can be used for treating the outer cylindrical surface of a shaft, was worked out in the Department of Manufacturing Process and Production Organization in the Technical University of Rzeszow. This method gives the possibility of the wide regulation within the range of the impact energy, impact traces arrangement on the workpiece surface and shapes of the single traces. We can use this method for processing both the soft and the hard materials. After the treatment we obtain the specific surface stereometry, which is characterized by the regular patterns. Depending on the kind of patterns, intensity of the treatment and other treatment parameters various changes in the surface layer are caused. With the use of this method we can increase fatigue strength of the steel component in order to know, what influence the percussive burnishing process has on the treated elements, studies using 42CrMo4 steel were done and their results are presented in this paper.

SUBJECT INDEX
Fatigue strength, percussive burnishing, steel elements

INTRODUCTION

Percussive burnishing process is a dynamic method of burnishing. We can also call it hammering. Most of the researches concerning dynamic methods are for shot peening (Nakonieczny, 2002, Przybylski 1987 and the others). Various methods of shot peening are used in the manufacturing for improving the functional properties of the machine parts. These are stochastic methods, where the shots (or other elements) hit on the surface of the treated elements causing changes in the surface layer. But these changes can be various at the various points of the surface, because on one point, a shot can hit twice, and at an other point of the surface it may not hit at all. It can cause making the places, which are overshot or not shot, and can be potentially weak points of the machine elements. The percussive burnishing method, which is described in this paper give us the possibility of designing the arrangement of the impact traces in the way we want to obtain. Besides, shot peening is usually long-term process and it takes much time to treat one component. These kinds of processes are often very expensive because, among others, the shots are crashed during the process. On the other hand with the use of shot peening we can treat the machine parts with various shapes. Percussive burnishing process is much faster than shot peening, as for example, to treat the shaft 100 mm long and 27 mm in diameter with the intensity 2,84 hits per mm^2 we need only 2 min. With the use of this method we can treat the outer surface of the shafts and also stepped shafts.

Studies were made to fond out which parameters of the treatment we should choose to increase fatigue strength of the elements with two chosen hardnesses.

MATERIAL AND SAMPLES

In the researches 42CrMo4 steel were used. The material composition is provided in Table 1 below. Samples for percussive burnishing process were prepared as Fig 1 shows.

Table 1. Steel composition in %

C	P	S	Si	Mn	Ni	Cr	Cu	Mo
0,39	0,016	0,002	0,25	0,63	0,12	1,0	0,26	0,15

Samples were quenched and tempered. Parameters of heat treatments were:

1) hardening: 840°C, reheating: 1 h, soaking: 30 min, oil cooled, tempering: 560°C, reheating: 1 h, soaking: 1 h, air cooled – after that the samples had a hardness of around 39 HRC,

2) hardening: 840°C, reheating: 1 h, soaking: 30 min, oil cooled, tempering: 640°C, reheating: 1 h, soaking: 1 h, air cooled – after that the samples had a hardness of around 31 HRC.

Mechanical properties of the steel after heat treatments are shown in Table 2.

Table 2 Mechanical properties of the steel

H	R_m	$R_{0,2}$	A_5	Z	LA_m
[HRC]	[MPa]	[MPa]	[%]	[%]	[%]
31	953,6	840,9	19,69	62,82	9,14
39	1091,4	985,6	13,8	53,95	5,77

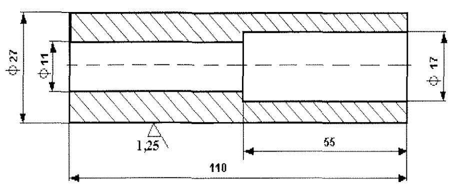


Fig. 1. Sample for percussive burnishing

PERCUSSIVE BURNISHING PROCESS

Percussive burnishing process was realized on the stand, which was designed and made in the Department of Manufacturing Process and Production Organization (Łunarski, Stadnicka, 2004). The stand consists of the percussive burnishing device (Fig. 2), fix workpiece system, head and cam driving system, feed motion system and control and registration system.

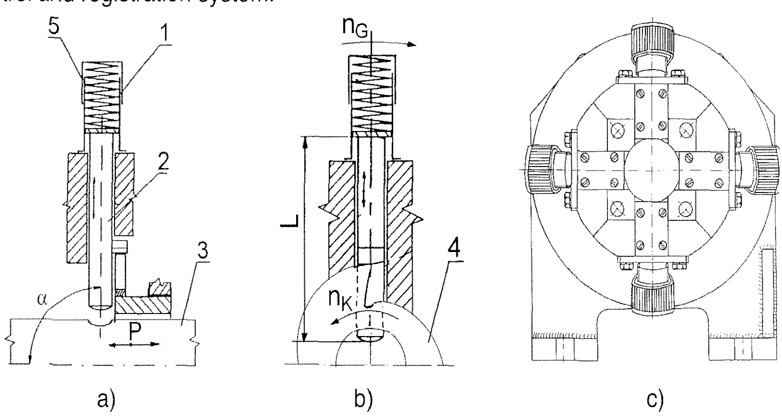


Fig. 2. Scheme of the percussive device for percussive burnishing process: a) mechanism elements and processed shaft, b) mechanism with the cam, c) percussive burnishing head;1 - spring, 2 – percussive element, 3 – processed shaft, 4 – cam, 5 - adjusting nut, n_K – cam rotation speed, n_G – head rotation speed, L – length of percussive element, α - striking angle

In the scheme shown in Fig.2, the working head with four percussive elements (Fig. 2c), which lean against the squeezed spring, rotates with stepless regulation. Percussive elements with ball tip are pulled away by the cam, which rotates in the opposite direction than the head. The cam is driven by the same motoreducer as the head, which ensures stable ratio of the head and the cam rotation speeds. The rotation speed of the head can be changed independently from the rotation speed of the cam in a certain range. The workpiece (the shaft) doesn't rotate, but does feed motion along the head axle. It is driven by the separate drive. Fig 3 shows some examples of the surface after the percussive burnishing process, treated with various parameters.

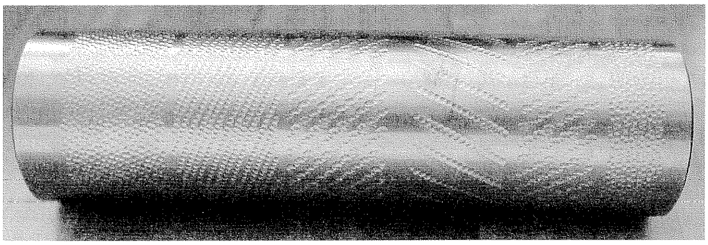


Fig 3. Photo of the surface after the percussive burnishing process

Using the described device, the samples (Fig. 1) were burnished with the use of the percussive elements with the ball tip and under the following conditions.

The researches had three stages. In the first stage the samples with 31HRC hardness were treated. The percussive elements with the ball tip 2,5 mm in diameter were used. The value of the impact energy (E_u) equaled 0,288 Nm. The intensity of the percussive burnishing (I_n) was of various values, such as table 3 shows.

In the second and third stages the samples with 39HRC hardness were used. And in the second stage the percussive elements with the ball tip 2,5 mm in diameter were used. The impact energy equaled 0,288 Nm. The intensity of the treatment had the various values as table 4 shows.

In the third stage the intensity equaled 1,1 hits per mm^2. Two various values of the impact energy and two different kinds of percussive elements were applied (Table 5: N^0 1 - percussive elements with the ball tip 2,5 mm in diameter, N^0 2 - percussive elements with the rounded tip of 2,5 mm in radius).

Table 3

Variant	I_n [1/mm^2]
1 - L	0,60
2 - L	0,84
3 - L	0,33
4 - L	0,46
5 - L	1,1

Table 4

Variant	I_n [1/mm^2]
1 - T	0,6
2 - T	1,1
3 - T	0,84

Table 5

Variant	E_u [Nm]	Percussive element
4 - T	0,288	N^0 1
5 - T	0,216	
6 - T	0,288	N^0 2
7 - T	0,216	

As the result of percussive burnishing process we obtained the various patterns on the samples' surfaces, depending on the taken parameters and hardness of the material. Table 6 consists the schemes of the impact traces after percussive burnishing process for the particular variants of the treatment. And the table 7 consists the values of the surface covering (S_p) by the impact traces. We can see, that the parameter S_p did not exceed 100%.

Table 6. Arrangement of the impact traces after percussive burnishing proces

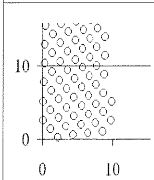
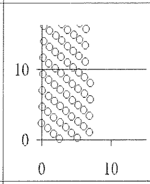
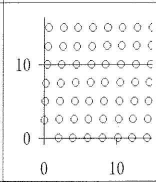
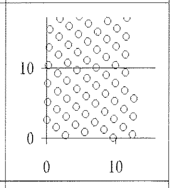
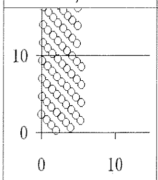
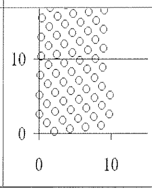
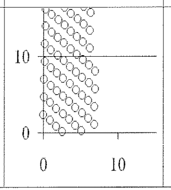
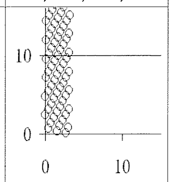
Treatment variants			
1L	2L	3L	4L
			
5L, 2T	1T	3T	4T, 5T, 6T, 7T
			

Table 7. Surface covering (S_p)

Variant	S_p [%]
1L	40
2L	50
3L	21
4L	30
5L	65
1T	35
2T	58
3T	45
4T	100
5T	91
6T	100
7T	91

FATIGUE STRENGTH RESEARCHES

Fatigue strength researches were made on the electrodynamics' vibrator. The main unit of the stand is an electrodynamics' vibrator, TiraWib 5142. The hydraulic holder, which is used for fixing the sample is fastened to the electrodynamics' table.

An optical system, which consists of the telescope, the camera and the monitor, is used for reading the resonant amplitude value of the investigated sample natural frequency. Electrodynamics" inductor is controlled by the beat frequency generator in the range 5Hz ÷ 10 kHz. The value of the table vibration amplitude can be regulated in the range ± 3 mm. Above the sample the condenser microphone is fixed.

The signal from the microphone goes into the input X of the oscilloscope, through the microphone amplifier, with which the cycle counter and the frequency meter are collaborated. The cycle counter switches off the control system after the fixed number of the cycles is reached. The sensor is fixed directly onto the hydraulic holder and it measures the amplitude and the forced vibration frequency of the electrodynamics' table. The signal from the sensor is sent by the vibration meter into the input Y of the oscilloscope. At the same time, with the vibration meter the frequency meter is collaborated.

After the percussive burnishing the samples were prepared for fatigue researches, as Fig 4 shows.

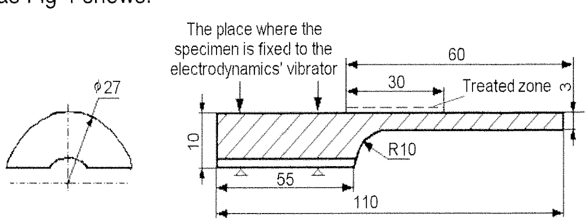


Fig 4. Shape and dimensions of the samples for fatigue strength researches

The samples, as shown in Fig 4, were fixed with the thicker end in the hydraulic holder. Then they were put under vibration at the sample's free end, with resonance frequency. The needed load was obtained by setting the specified value of the vibration amplitude. The value of the amplitude meets the specified load value, which was determined before the researches, by the sample scaling.

In the researches the Locati method was used, and two samples for every variant of the treatment were investigated. To ensure more exact results the Wöhler curve was determined differently than traditionaly. The tests were not made on the three specified levels, but with the use of the stepped method (16 samples). Additional tests of four samples on the much higher stresses levels were done to get exactly inclination angle of the Wöhler curve. The range of the stresses was 339 MPa - 507 MPa. The equation of the Wöhler curve, which is shown in fig 5, is σ = -33,311 lnN + 843,46 [MPa].

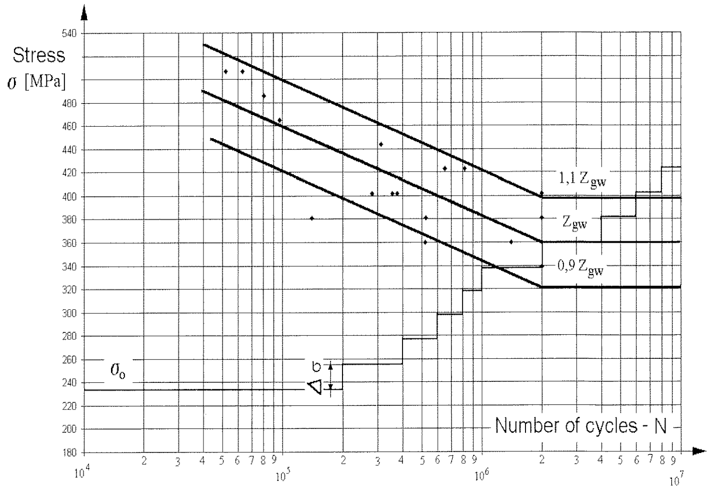


Fig. 5. Wöhler curve; σ_0 = 234 MPa, $\Delta\sigma$ = 21 MPa, n_i = $2{\cdot}10^5$ cycles

The samples (fig 4) were subjected to a oscilatory bending. The researches were made according to the scheme, which is shown in the fig. 5. During the researches the individual samples were put under load, which were incresed step by step, from one level to another. On the each level the samples were tested at the same number of cycles $n_i = 2 \cdot 10^5$. The difference between the levels was constant, i.e. $\Delta\sigma$ = 21 MPa. In the researches, the conventional criterion of the failure was established. It was agread that the beginning of the fatigue failure was when the enohance frequency of the sample dropped by 1%. The test was continued till the resonance frequency of the sample dropped by 5%, then it was stopped. The test was continued till the sample was cracked or reached 2 000 000 cycles.

RESULTS

The results of the studies were calculated with the use of the failures summation rule and they are shown in table 8. Values of the true endurance limits for the samples after percussive burnishing process were compared to the values of the true endurance limits for the samples before percussive burnishing, but after the heat treatments.

As we can see for the samples with the hardness of 31HRC the increase of the true endurance limit value reached 29%, but for the harder samples the increase was not much or almost zero for an intensity less than 1,1 hits per mm^2.

We can also notice that decreasing impact energy yielded greater increases of the true endurance limit.

Table 8. True endurance limit values (z_{gw}) for specified treatment variants

Variant	z_{gw} [MPa]	Increase of z_{gw} [%]	Variant	z_{gw} [MPa]	Increase of z_{gw} [%]
42CrMo4 steel – 31 HRC			42CrMo4 steel – 39 HRC		
C - L	329,5	-	C - T	436,0	-
1 - L	393,5	19	1 - T	391,5	-
2 - L	425,5	29	2 - T	437,5	-
3 - L	336,0	2	3 - T	435,0	-
4 - L	333,0	1	4 - T	440,5	1
5 - L	410,0	24	5 - T	451,5	4
			6 - T	466,5	7
			7 - T	460,0	5

The application of percussive elements with the rounded tip of 2,5 mm in radius gave better results.

Increase of the true endurance limit is caused by the changes, which are created after the percussive burnishing process in the surface layer. The most important is hardening of the surface layer. Degree of hardening is greater for steel with the hardness of 31 HRC and depends on treatment's intensity: degree of hardening is greater when the intensity of the treatment is grater. So, in these cases we could obtain greater increase of the true endurance limit.

CONCLUSION AND IMPLICATIONS

Presented method of the percussive burnishing process can be used instead of shot peening to increase the fatigue strength of the machine parts. The main advantage of this method is the possibility of arranging the impact traces in various ways, for example, to get a certain surface covering by the impact traces. Thanks to that, we can obtain the regular patterns and uniform arrangement of the impact traces on the surface. The other advantage is a short time of treatment. The most exploited parts in the device are percussive elements, but if we use bearing balls for making their tip we can increase their life. The treatment is not expensive, but need fixture for fixing the workpiece. We can make the device in various ways to adapt it for treating various machine parts, for example outer surface of the stepped shafts (where the percussive elements hit on the workpiece surface at an angle different than 90^0) or inner surface of the sleeves. We can also use different number of percussive elements.

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