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Research Article

IMPACT OF VIBRATORY AND ROTATIONAL SHOT PEENING ONTO SELECTED PROPERTIES OF TITANIUM ALLOY SURFACE LAYER

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ABSTRACT

This study presents the results of tests on impact of vibratory and rotational shot peening of the Ti6A12Mo2Cr titanium alloy onto the processed object surface roughness and surface layer microhardness. The external surfaces of ring-shaped samples were shot peened. The preceding process consisted of turning with a cubic boron nitride blade knife. Steel beads, having a diameter of 6 mm, were used as a processing medium. The variable parameters of shot peening were vibrator amplitude and shot peening time. The range of recommended technological parameters for vibratory and rotational shot peening was determined. As a result of shot peening, the surface roughness could be reduced by approximately 4 times and the surface layer could be hardened to the depth of approximately 0.4 mm.

Keywords: shot peening, titanium alloy, surface layer, surface roughness, microhardness.

INTRODUCTION

Titanium alloys feature high strength, small density, high corrosion- and resistance to high temperature. These properties make titanium alloys a valuable structural material used in various branches of industry, and particularly in aviation industry. Titanium alloys are used for production of components that are exposed to changing loads during operation. Fatigue strength of such components can be increased by shot peening.

Titanium alloy components are most often shot peened by dynamic jet method, which consists of blow effect of a shot or bead jet ejected mechanically or pneumatically onto the processed object surface. The tests performed by the authors of this study [1] showed that shot peening with a jet of glass beads having the diameter of 55–100 µm within 40 seconds increase the fatigue strength of WT3-1 titanium alloy by 40%. The use of glass beads having the diameter of 40–150 µm in shot peening process proved to be even more effective (fatigue strength increased by 50%) than use of steel beads with diameter of 3 mm (fatigue strength increased by 20%) [2]. The study [3] presents the results of jet shot peening impact onto low-cycle fatigue strength. It was found that jet shot peening of an aircraft engine compressor rotor, made of WT3-1 titanium alloy, increased its durability three times. Shot peening allowed to increase fatigue strength of the components operating not only at room temperature but also at an elevated temperature. It was found that shot peening of the Ti-6A1-4V titanium alloy samples with a cast steel shot jet resulted in almost identical increase of fatigue strength, both during tests at room temperature as well as at 150°C [4].

The fatigue strength of machined elements increased also as a result of vibratory shot peening with free beads. This method consists of attachment of machined objects in a working chamber to which a charge of loose beads is poured, after which the working chamber is set in oscillating motion. The surface strain hardening effect is obtained as a result of loose beads hitting against the machined objects. Application of the controlled shot peening method enabled to evaluate the effect of beads energy, while hitting against the machined surface and density of these impacts onto the Ti-6A1-4V titanium alloy fatigue strength [5].

The increase of fatigue strength of shot peened elements is related to the shape of advantageous properties of the surface layer of such elements during the dynamic shot peening process. The test results of Ti-2.5Cu titanium alloy surface layer properties after surface treatment conducted by various methods are presented in the study [6]. It was found that due to shot peening, the surface layer microhardness in the vicinity of the surface increased by approximately 40% and the own compressive stresses of about 460 MPa were formed. The study [7] presents the test results of impact of shot peening with a jet of 70 µm beads within 8 seconds onto properties of the Ti-6A1-4V titanium alloy surface layer. This process caused a significant increase of surface roughness (value of Ra parameter increased 8 times), increase of microhardness by approximately 18% and forming of compressive residual stresses of about 900 MPa. Increase of surface layer microhardness and shaping of compressive residual stresses were obtained as a result of controlled shot peening of the Ti-6Al-4V alloy [8].

Shot peening by means of free beads may be performed on objects of various shapes. The objects whose shape is approximate to solids of revolution may be shot peened by vibratory and rotational method that consists of joining vibratory shot peening with rotational motion of the object being processed. The existing testing proved a beneficial effect of vibratory and rotational shot peening onto properties of the bearing steel surface layer in a quenched condition (62–64 HRC hardness) [9]. The purpose of this study is to evaluate the effect of vibratory and rotational shot peening onto the titanium alloy surface roughness and strain hardening degree.

TESTING METHOD

Tests were performed on the Ti6Al2Mo2Cr titanium alloy (per WT3-1 Russian standards), whose chemical composition was specified in Table 1. This is an alloy for plastic working, of the a+b structure, used widely for industrial purposes, especially for manufacturing parts for the machines working at changing loads, what justifies the usefulness of shot peening in these parts.

The samples prepared for tests had a ring shape with external diameter D = 56 mm, internal diameter d = 50 mm and length l = 10 mm. The process that preceded shot peening the external surface of samples was turning with the PCLNR2020K12 turning tool with the CNMA120404 inserts with cubic boron nitride blades. The machining parameters were as follows:

- depth of cut a_p = 0.5 mm,
- feed f = 0.07 mm/rotation,
- cutting speed v_c = 140 m/min.

The external surface roughness of samples after turning was Ra = 0.88 to 1.23 mm.

Vibratory and rotational shot peening was carried out on a special stand whose diagram is shown in Figure 1. The tested samples 7 were fixed to the spindle 4, which revolved in a slide bearing 9, seated in side walls of the working chamber 5. The working chamber 5 was set in oscillating motion by means of a vibrator 11. Due to vibration, the beads 6 inside the working chamber were hitting against the external surfaces of samples 7. Uniformity of shot peening on the entire circumference of samples was assured thanks to rotational motion of the spindle 4 with the samples attached. The special nuts 8 and 10 were

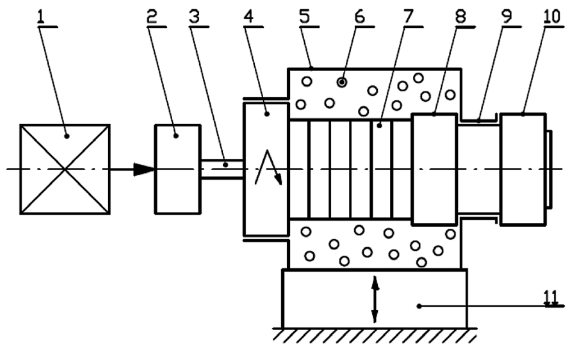

Fig. 1. Schematic illustration of the stand for vibratory and rotational shot peening: 1 – electric motor, 2 – reduction gear, 3 – flexible coupling, 4 – spindle, 5 – working chamber, 6 – bead, 7 – sample, 8, 10 – special nuts, 9 – slide bearing, 11 – vibrator

Table 1. The chemical composition of the Ti6Al2Mo2Cr alloy

Chemical element	Al	Mo	Cr	Fe	Si	C	N	Ti
Percentage	5.8	2.4	1.5	0.4	0.3	0.05	0.04	rest

used to secure the spindle 4 against displacement in axial direction. The spindle 4 was driven from the electric motor 1 via the reduction gear 2 and the flexible coupling 3.

The following constant parameters were applied for vibratory and rotational shot peening:
- vibrator frequency v = 7 Hz,
- bead diameter d_k = 6 mm,
- sample rotational speed n = 2 rpm.

The variable parameters of shot peening were as follows:
- vibrator amplitude,
- shot peening time.

The vibrator amplitude was changed within a = 36–60 mm for the constant shot peening time t = 10 minutes. Also, shot peening time was changed within t = 1–40 minutes at the constant amplitude a = 60 mm.

After shot peening, the tests of selected surface layer properties were performed, which covered:
- surface roughness test,
- surface layer microhardness distribution test.

Roughness of external surface of samples was measured using the Surtronic 3+ instrument of Taylor Hobson production. The measurement direction was parallel to the sample axis.

Microhardness measurements were made using the LM700AT microhardness tester of LECO production, by the Vickers' method, with the load of 981 mN (the 100g weight). The surface layer microhardness distribution was determined on perpendicular microsections. Based on the microhardness distribution, the surface layer strain hardening degree was determined using the following formula:

$$e = \frac{HV_{max} - HV_0}{HV_0} 100\% \qquad (1)$$

where: HV_{max} – maximum microhardness,
HV_0 – microhardness of material core.

TEST RESULTS AND THEIR ANALYSIS

The effect of vibratory and rotational shot peening onto the processed surface roughness is presented in Figures 2 and 3. The Ra roughness parameter value is approximately 2–4 times smaller as compared to the surface before shot peening (after turning). Along with the increase of vibrator amplitude within a = 36–52 mm, the Ra parameter value reduced visibly which means that along with the amplitude increase, the energy of shot peening beads hitting against the processed surface increased and, as a result, microunevenness shaped after the process that preceding shot peening was leveled more effectively. In the scope of bigger amplitudes (a = 52–60 mm), it was observed that the amplitude increase was accompanied with the increase of Ra parameter, which probably resulted from the fact that the beads hitting with high energy made dents in the processed surface.

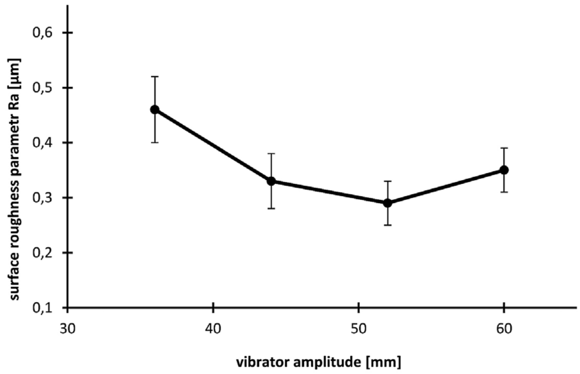

Fig. 2. Effect of vibrator amplitude onto Ra surface roughness parameter

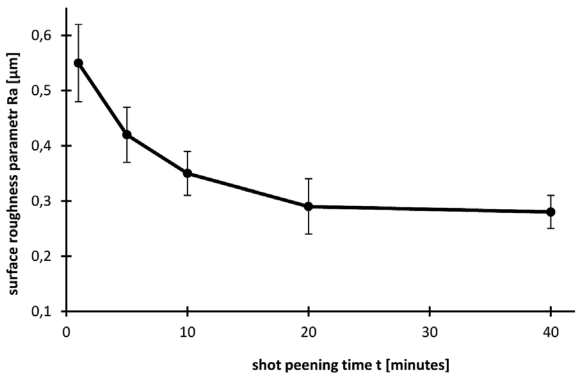

Fig. 3. Effect of shot peening time onto Ra surface roughness parameter

Along with the increase of shot peening time, the Ra roughness parameter value decreased (Figure 3), which was related to the increase of hitting density of burnishing beads onto the surface processed. Besides, along with prolongation of shot peening time, the surface layer of samples got hardened, which resulted in reduction of depth of impression due to beads impacts, and thus reduction of surface roughness. Prolongation of shot peening time above 20 minutes had no effect onto roughness of the surface processed.

The effect of vibratory and rotational shot peening onto microhardness of the processed sample surface layer is presented in Figures 4–8. The surface layer strain hardening degree, calculated per formula (1), and the depth of strain hardening layer g_h (Figure 4) were accepted as the indices that feature the microhardness distribution.

The strain hardening degree was changing along with the change of shot peening parameters and its value was from 6% to 23%. Both vibration amplitude increase and shot peening time had effect onto the surface layer strain hardening degree and such an increase was more visible in the scope of smaller values of shot peening parameters (Figures 5 and 6). The increase of shot peening time above 20 minutes caused only an insignificant increase of strain hardening degree.

Also the depth of hardened layer depends on the burnishing parameters and its value changes within the range from 0.17 mm to 0.42 mm. The curves showing the effect of vibration amplitude and burnishing time onto the hardened layer depth (Figures 7 and 8) have a similar shape as the curves of consolidation degree versus burnishing parameters.

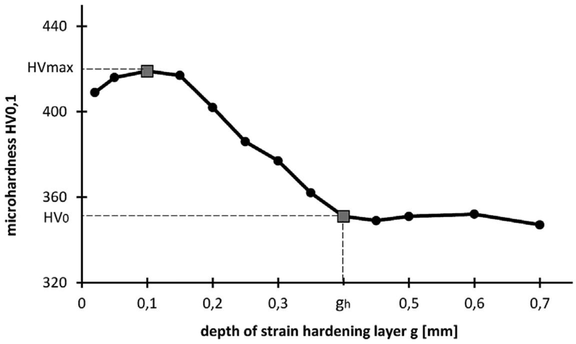

Fig. 4. Typical surface layer microhardness distribution after vibratory and rotational shot peening

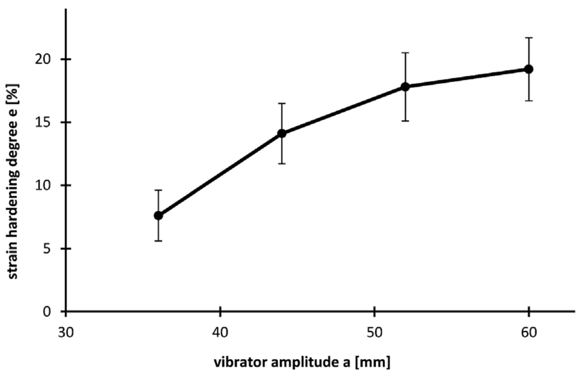

Fig. 5. Effect of vibrator amplitude onto strain hardening degree

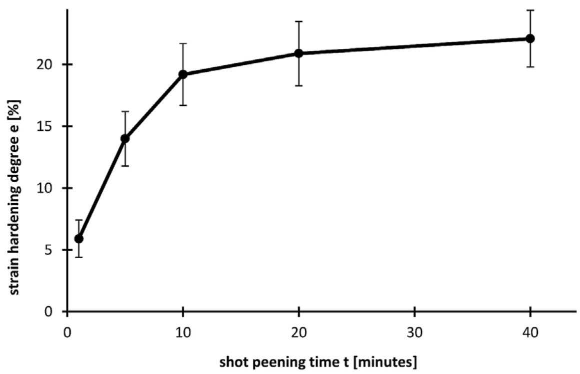

Fig. 6. Effect of shot peening time onto strain hardening degree

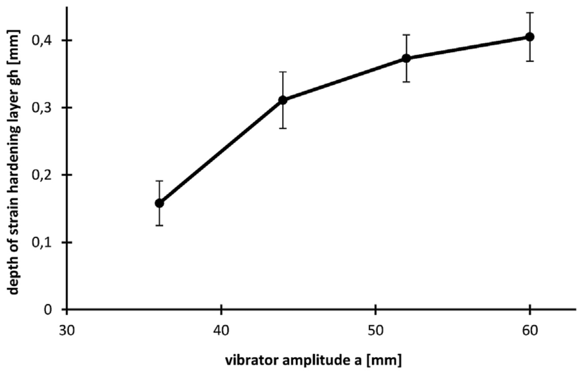

Fig. 7. Effect of vibrator amplitude onto depth of strain hardening layer

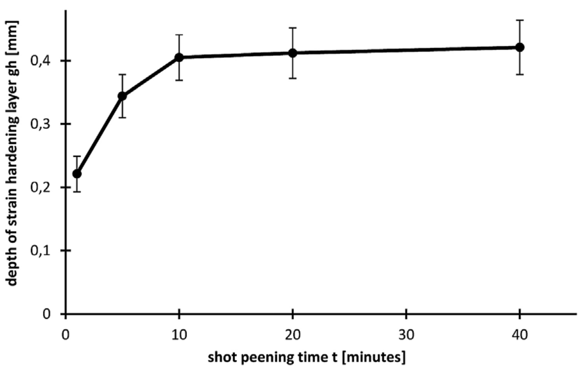

Fig. 8. Effect of shot peening time onto depth of strain hardening layer

CONCLUSIONS

Significant difficulties that occur while grinding titanium alloys (intensive wear of grinding wheel, high roughness of the machined surface) are the reasons for which it is required to search for alternative methods of finishing of machine components made of such alloys. The conducted tests proved that in case of the components of a shape approximate to solids of revolution, such a method may be vibratory and rotational shot peening.

Having analyzed the test results, it can be stated that the vibrator amplitude a = 52–60 mm, and the shot peening time t = 10–20 minutes (it is pointless to increase the shot peening time over 20 minutes due to economic reasons) should be applied. Upon application of the shot peening parameters specified above, it is possible to obtain the surface roughness of approximately Ra = 0.3 μm, the surface layer strain hardening degree of about 20%, and the hardened layer depth of about 0.4 mm.

The changes of processed titanium alloy surface layer properties obtained as a result of vibratory and rotational shot peening are advantageous due to durability of the machined components.

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