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Influence of Cold Work on the Efficiency of Vibratory Machining

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Abstract

The aim of the article was to determine the impact of crushed condition (work hardening) on the effectiveness of the vibratory machining. The vibratory machining processing was carried out in two steps. The first step consisted of mechanical abrasion and remove oxides from the surface of the workpieces with abrasive media. While in the second step, smoothing - polishing with metal media was performed. Vibratory polishing also strengthened the treated surfaces. The test results were compared for samples in the crushed state (work hardening, plastic processing) and samples subjected to recrystallization annealing heat treatment. Mass losses, changes in the geometric structure of the surface and changes in the hardness of the machining surfaces were analyzed. Samples subjected to recrystallization, as compared to the samples in the state after work hardening-plastic working, are characterized by a slightly higher arithmetic mean surface roughness and lower surface hardness than for analogous processes for samples not subjected to heat treatment. Heat treatment of annealing allows to remove the effects of crushing and thus it is possible to obtain larger mass losses. Smaller burrs dimensions were obtained for samples after the heat treatment – annealing than after work hardening.

Keywords: Vibratory machining, Brass, Recrystallization, Crushing, Burrs removing

1. Introduction

M63 brass is a two-component alloy used in plastic working to produce different shapes, in particular cartridge cases. Machining of this material is difficult; therefore, it is recommended to use the low cutting speed adjustment [1]. M63 brass is an alloy characterized by technological assessments - it is polished, suitable for soldering, has good electrical and thermal conductivity. Moreover, it has corrosion resistance, its resistance to stress corrosion cracking after forming, and it is advisable to use annealing stress-relief in order to eliminate this cracking phenomena. It is not suitable for use under the influence of acidic conditions (acetic acid, hydrochloric acid and acidic acid). Due to the wide range of applications of this alloy, it is widely used in the engineering industry, automotive, electrical components, stamped parts as well as mechanics and construction.

The vibratory machining method is an efficient method of smoothing and polishing surfaces. It is widely used in the foundry production of mass-produced elements which require repeatability of results [2, 3]. These objects are often small, with relatively small dimensions and have complicated macro geometry [4]. The great advantage of container processing is the possibility of processing many items at the same time [5]. Process parameters such as the type of media - abrasive parts, machining time, vibration frequency of the tumbler is experimentally determined and it is difficult to clearly determine the machining time needed to achieve the required final results [6, 7] such as basic parameters of the surface geometric structure (e.g., arithmetic mean height of the surface - Sa), directivity of the geometric structure of the surface, etc. The authors made an attempt to assess the impact of the hardening of the material resulting from plastic working (drawing) and after its recrystallization on the final effects of the surface smoothing process by vibratory machining.

Microstructure of the brass after recrystallization at 580°C on 30 minutes are shown in Figure 1. Figure 2 presented microstructure of the brass after recrystallization at 580°C on 30 minutes and rolling with 50% crush (plastic deformation).

Fig. 1. Microstructure of annealed brass, magnification 100x

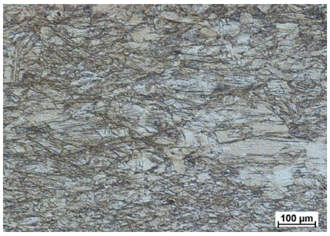

Fig. 2. Microstructure of annealed brass and then crushed (50% deformation), magnification 100x

2. Methods

The authors used vibratory machining to remove the influence of the effect of heat treatment on the surface layer, to smooth and shine the surface. Devices for container processing have been known since the 1850s [8]. Simple containers, such as available barrels or drums, were then used for container machining. With the development of the industry, the demand for fast and repeatable methods of surface treatment of small items grew. The use of container treatments with loose abrasive gained practical importance after the introduction of vibratory machine tools. This contributed to the spread of this type of treatment. Currently, container processing is widely used in many industries. The use of vibrating devices as compared to rotary machine tools allows for a significant reduction of machine times, required to obtain the assumed parameters of the geometric structure of the surface [9, 10].

Vibratory machining is a finishing process based on chemical-mechanical surface treatment [11, 12]. The type of media used - shapes - determines the nature of the process: deburring, grinding or polishing. They can be made as abrasive media with a ceramic or resin binder, e.g. polyester, porcelain, metal, but also in the form of shapes made of materials of natural origin such as, for example, granules from nut shells, corn, rice, shavings, or shapes or wood chips [13, 14]. The use of appropriately selected machining fluids allows to increase the effectiveness of the processes of mechanical abrasion [15], smoothing or polishing. The entire working load, i.e. media, abrasive pastes and fluids, is placed in the working tumbler, which, depending on the type of device, may be subjected to vibrations with a frequency of 30 Hz to several hundred Hz.

Experimental studies by J. Domblesky [16] on vibration machining as a finishing treatment of brass, aluminum and steel showed that brass had the highest material removal efficiency, while aluminum had the lowest level, and steel showed an intermediate degree of material removal efficiency. The ratio of material density to specific energy (specific energy is a critical factor in metal machining) for each workpiece material included in the study was similar, indicating that the material properties alone do not account for the differences in stock removal rates for the three materials in question. Further research revealed that for the considered materials, the multiplication of the mass of the object and the speed of the object has a greater influence on the changes in the speed of material removal than on the properties of the material itself. Bańkowski [17] investigated the effect of the addition of abrasive pastes on changes in mass losses. It was found that the addition of abrasive paste to the machining media causes more intense mass losses and slightly lower parameters of geometric structure of the surface than in the case of processes carried out without abrasive paste additives [17]. Vibratory machining with the addition of abrasive paste results in a lower arithmetic mean deviation of surface ordinates - Sa [17]. The greatest effects are observed in the case of a two-stage treatment. First step deburring and then followed step of polishing.

The analysis of the available literature shows that the influence of material hardening as a result of plastic working (eg. drawing) has not been determined so far on the technological effects of vibratory machining, such as: efficiency (changes in mass losses), parameters of the geometric structure of the surface and surface hardness.

3. Experiments

A Rollwasch SMD-25-R (Rollwasch Italiana S.p.a. Albiate (MB) - Italy) vibratory machine with a tumbler volume of 25 dm^3 and 20÷50 Hz frequency range of the tumbler was used for the tests. To the experiments used samples made of a M63 Z4 brass, illustrated on Figure 3. Samples in form of pipe with a diameter of 12 mm, a wall thickness of 1 mm and a length of approx. 45 mm were tested. The M63 Z4 alloy is a semi-hard brass which, according to the standard, should have a tensile strength of min. 350 MPa and elongation about 28 %.

Brass was chosen for testing because it is an easily machinable material. The aim of the work was to assess the influence of crush (deformation) on the effects of vibratory machining. The samples used were cold forming) and heat treated by recrystallization annealing at a temperature of 540 °C for 60 minutes. In this way, samples with the same density, weight and dimensions were obtained, but differing in mechanical properties, including hardness.

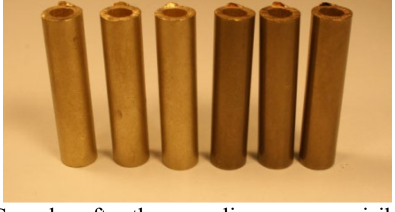

Fig. 3. Samples after the annealing process, visible burrs

In the first step, the prepared samples were processed with machining vibrators using abrasive media based on polyester binders - PB 14 KR – Figure 4a). The treatment times were 30, 60, 90 minutes. In the second stage, the samples were subjected to work hardening a strengthening treatment using metal media - SB 3.1 lotto – Figure 4b). The duration of the "burnishing" vibratory machining was 30, 60 and 90 minutes, respectively. The first stage of treatment was carried out with the addition of 200 ml of ME L100 A22/NF liquid to increase the effect of mechanical abrasion, etching and deoxidation of the surface. The second part of the research was carried out with the addition of approx. 200 ml of FE L120 B32/R fluid having anti-oxidation properties and ensuring effective smoothing and crushing with metal media. The rotational speed of the engine driving the working tumbler was 2400 rpm, which corresponded to the vibration frequency of 40 Hz. The degree of filling of the working tank - tumbler was set at 50%.

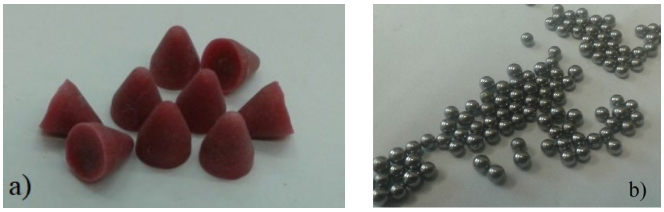

Fig. 4. Tumbler media used in vibratory machining a) polyester media, cone with dimensions: diameter 14 mm, height 14 mm, b) polishing media SB 3.1 lotto (round)

4. Results and discussion

The study analyzed the mass loss and changes in the parameters of the geometric structure of the surface. The 3D surface roughness parameters were determined with a Taylor–Hobson Talysurf CCI Lite non-contact 3D profiler.

The hardness of the M63 brass was measured at a load of 200 grams with an Innovatest Nexus 400 tester (Innovatest, Maastricht, The Netherlands). The test results are included in Table 1.

In the case of vibratory machining, higher mass losses were obtained for samples with lower hardness. In order to determine the percentage weight loss the vibratory machining performance was evaluated based on the material mass remove coefficient MMR (‰):

$$MMR = \frac{(m_1 - m_2) \cdot 1000}{m_2} \quad (1)$$

where:
m_1—specimen mass before vibratory machining, [g],
m_2—specimen mass after vibratory machining, [g].
The calculated values of mass losses and MMR are presented in Table 1.

During recrystallization annealing, the hardness is reduced and the plastic properties are increased, i.e. elongation, reduction. The analysis of the obtained test results presented in Table 1 shows that the recrystallization annealing caused a reduction in hardness - Figure 5. The average hardness of brass pipes after plastic working - forming was approx. 95 HV. After the heat treatment - recrystallization process, the hardness significantly decreased to approx. 60 HV.

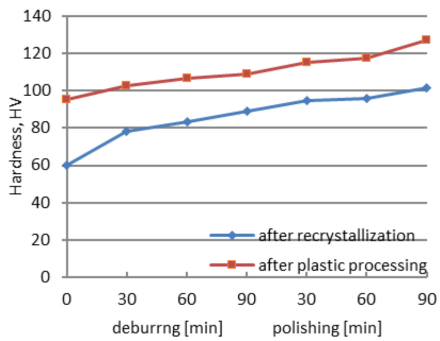

Fig. 5. Effect of recrystallization on the hardness of the surface

Table 1.
Test measurement results

	Type of vibratory machining and time	Δm, μg	MMR, ‰	Isotropy	Sa, μm	Sz, μm	Sv, μm	Sp, μm	Sq, μm	HV
recrystallization	0 min	-	-	55.0	0.403	11.377	6.381	4.995	0.582	62.0
	deburring 30 min	21.9	1.69	87.6	0.620	8.989	5.542	3.447	0.819	78.0
	deburring 60 min	29.3	2.26	87.8	0.642	16.144	10.035	6.108	0.851	83.5
	deburring 90 min	31.7	2.44	90.4	0.616	10.625	6.518	4.107	0.817	88.9
	polishing 30 min	32.5	2.50	86.1	0.491	11.244	7.152	4.092	0.649	94.6
	polishing 60 min	33.2	2.56	89.1	0.428	9.879	5.638	4.241	0.601	95.7
	polishing 90 min	33.7	2.60	89.9	0.415	8.064	5.625	2.438	0.628	101.5
cold forming	0 min	-	-	53.4	0.319	11.685	6.674	5.012	0.843	95.3
	deburring 30 min	16.1	1.31	39.6	0.757	8.504	5.483	3.021	0.755	102.9
	deburring 60 min	22.3	1.81	74.1	0.577	7.325	3.547	3.778	0.957	106.5
	deburring 90 min	24.4	1.95	82.9	0.554	6.785	3.770	3.015	0.755	108.8
	polishing 30 min	25.1	2.00	83.3	0.439	7.321	3.527	3.793	0.628	115.5
	polishing 60 min	25.7	2.09	68.6	0.396	6.477	3.481	2.995	0.512	117.9
	polishing 90 min	26.4	2.14	67.1	0.365	4.652	1.949	2.703	0.464	127.2

Analyzing the results of hardness tests, it can be observed that vibratory machining workpieces consisting in surface deburring, after recrystallization annealing (78-89 HV) causes about 22 to 32% lower hardness than samples after forming (plastic treatment) (103-109 HV). On the other hand, vibratory polishing with reinforcing - steel media is also characterized by surface lower hardness after recrystallization (95-102 HV) from about 22 to 25% than samples after forming (115-127 HV). The largest difference of 58% can be distinguished in the case of the sample after recrystallization compared to the sample after forming, not subjected to vibratory machining.

Comparing the mass losses for vibratory machining with abrasive media (deburring), in the case of samples subjected to recrystallization annealing treatment, the loss of mass was greater by about 30-36% than for samples only after plastic processing (forming). The largest losses can be observed for the first period, i.e., for the first 30 minutes of deburring treatment. For samples after recrystallization, this loss is 21.9 µg, and for samples after cold forming was about 16.1 µg. Extending the treatment time by another 30 minutes results in lower weight losses about 7.4 µg and 6.2 µg, respectively. Dependencies of weight loss on the duration of the process and the type of samples are shown in Figure 6.

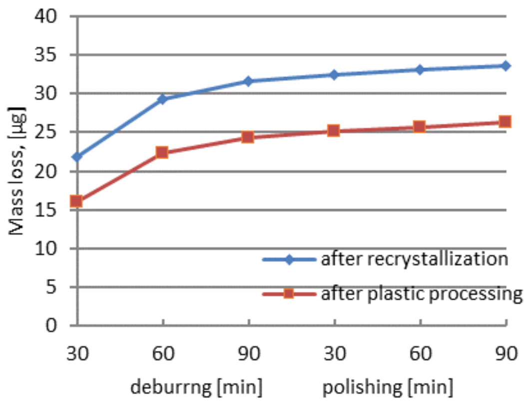

Fig.6. Effect of recrystallization on the mass loss

Vibratory strengthening machining - with polishing steel media, causes much smaller weight loss of smoothed details than in the case of vibratory deburring machining. A 30-minute treatment with metal reinforcements media only translates into a weight loss of less than 1 µg. It can therefore be concluded that the polishing treatment has a very small effect on the mass loss, which translates into a negligible loss in volume. The virtually negligible loss in volume is a factor that does not cause the loss of the treated samples, but their further smoothing and strengthening.

Analyzing the results obtained for the study of the geometrical structure of the surface, it can be concluded that the annealing process causes a significant increase in the arithmetic mean high of the surface unevenness from the reference plane - the *Sa* parameter [18] from about 0.3 µm after plastic working (forming) to about 0.4 µm after heat treatment - recrystallization annealing. This is mainly due to the oxidation of the surface, as the heat treatment was carried out without a protective atmosphere. The graph of changes in the *Sa* parameter - the mean of the arithmetic high of the surface roughness from the reference plane - the parameter depending on the time and type of treatment is shown in Figure 7.

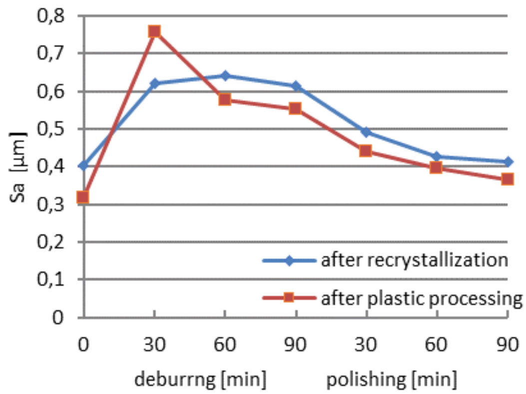

Fig. 7. Effect of vibratory machining time on the arithmetic mean high of the surface

Vibratory machining – deburring with the use of polyester abrasive media increases the arithmetic mean high of the surface unevenness from the reference plane - the Sa parameter from about 0.4 µm to 0.7 µm. By analyzing the measurements of the geometric structure of the surface, it can be clearly stated that the extension of the machining time causes the stabilization of the arithmetic mean surface roughness parameter - Sa about to 0.6 µm after 90 minutes of machining. Longer machining times do not cause significant changes in the parameters of the geometrical structure of the surface, but increasing mass losses.

Vibratory machining - smoothing, with the use of reinforcing (steel) media, translates into a further reduction of the arithmetic mean height of the surface from the reference plane - the *Sa* parameter after recrystallization from about 0.6 µm to 0.4 µm after 90 minutes of treatment. However, in the case of samples after plastic treatment (forming), even up to 0.36 µm.

Considering the results of geometric structure of the surface measurements, and in particular the *Sa* parameter, it can be concluded that in the case of details immediately after the plastic working process - forming, the first 30 minutes result in obtaining a larger arithmetic mean height of the surface unevenness from the reference plane - the *Sa* parameter than in the case of the sample after recrystallization annealing. Components with higher hardness are more difficult to machine than soft materials, therefore longer machining times are required for them. Extending the machining time only stabilizes the surface roughness parameters, as mentioned in Hashimoto [19] and Marciniak [20] - Figure 8. In the case of both conditions (i.e. after annealing and in the hardened state as a result of forming), the sampling should be compacted, especially in the first minutes of vibratory machining - which may be an idea to further explore this topic.

Looking at the obtained results of the maximum surface height *Sz*, which is the roughness height according to 10 points, analogous conclusions can be drawn as for the arithmetic mean height of the surface roughness height from the reference plane - the *Sa* parameter. It should only be noted that after forming processes (plastic working), the maximum surface height was about 11.6 μm, after recrystallization annealing was close the same about 11.4 μm, and deburring treatment (mechanical abrasion) led to a value of *Sz* equal to 10.6 μm after annealing and 6.8 μm in the cold forming conditions. The polishing treatment with the metal media reduced the maximum surface height to 8.0 μm after recrystallization annealing and to 4.7 μm after forming.

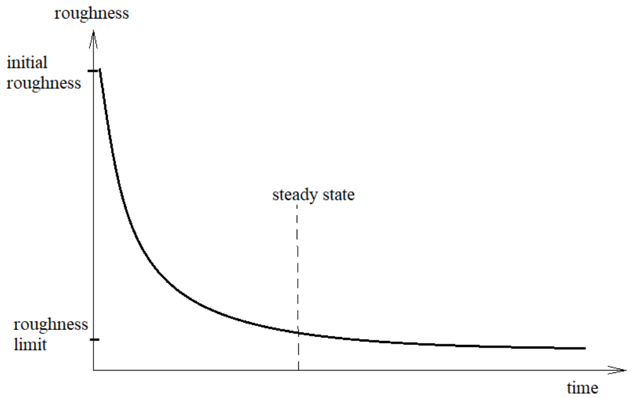

Fig. 8. Basic principles of vibration treatment

Based on the data contained in Table 1 and literature [4, 9, 11], it can be confirmed that vibratory machining results in an isotropic structure.

The surface of workpieces before vibratory machining characterized with about 53-55% isotropy index. Vibratory machining results in an isotropic structure, the isotropy index was approx. 90% when examining the geometric structure of the isotropy surface.

5. Conclusions

The initial condition of the surface has a huge impact on the final results of vibratory machining.

In the case of machining the same material with the same density, hardening the surface by cold forming – drawing processes of plastic working translates into much higher hardness than samples in the normalized state (after recrystallization annealing). In the case of testing the M63 brass alloy, these differences range from 22 to 32%. Mass losses and material mass remove coefficient MMR (‰) are similar - the harder the surface, the smaller the possible losses of the processed details. The samples in the normalized state were characterized by 27 to 36% greater weight losses than the samples in the crushed state.

Moreover, samples in the crushed state (after plastic forming) are characterized by a higher arithmetic mean height of the surface unevenness height from the reference plane - *Sa* parameter as compared to the surface in the normalized state. The only exception is the case for the processing time of 30 minutes, where the situation is different.

The analysis of changes in the effects of vibro-abrasive machining in the first 30 minutes of the research is a prospect for further research. In this case, the sampling should be concentrated and the obtained results analyzed.

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