VIBRATORY TUMBLING OF ELEMENTS MADE OF HARDOX400 STEEL

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Abstract

This article discusses experimental results obtained for elements made of a wear - and abrasion-resistant steel, Hardox400, finished using a non-conventional method. The analysis focused on the relationship between of the tumbling time and the radius of rounding. The effect of the angle of the cut was also taken into consideration. The surface of the finished items was examined with a Nikon MA200 microscope equipped with a NIS-elements viewer (version 4.20). The study also involved determining the influence of the tumbling time on the relative mass loss and the basic surface texture parameters. The surface texture of the finished elements was examined using a Taylor Hobson Talysurf CCI Lite optical 3D profiler.

Keywords: Tumble finishing, vibratory tumbling, fine machining, Hardox

1. SURFACE CONDITIONING

The requirements concerning the aesthetics and corrosion resistance of final products have increased considerably in recent years. To improve the quality and surface properties of goods, many manufacturers have had to use labour- and cost-intensive methods. From the technical and economical points of view, tumble finishing seems an appropriate solution to obtain the required surface quality. Since the technique is becoming increasingly common in automated manufacturing systems, it is essential to select the process conditions such as the kinematic parameters properly, the type and size of the tumbling equipment, the type and size of the finishing media and the type of compound or fluid to achieve different goals [1, 2]. This article discusses the use of vibratory tumbling for long time surface finishing of Hardox steel.

2. VIBRATORY TUMBLING

Vibratory tumbling, alongside the cutting and processing of erosion, is one of the production techniques of the finished products with low surface roughness [3]. Electrical Discharge Machining is often included in the "non-traditional" or "non-conventional" group of machining methods together with processes such as electrochemical machining [4], micro-welding [5], laser cutting [6], water jet cutting (AWJ) [7] and opposite to the "conventional" group milling, drilling, turning, grinding [8-10] etc. Vibratory tumbling is a mechanical and chemical surface conditioning process during which elements are polished with abrasive media [1-3, 11, 12]. The whole load of the parts to be finished and the finishing material is set into motion by the vibration of the container; they rub against one another until the required surface is obtained. The helical motion about the tumbler axis causes the tumbling material to micro-machine the workpieces [13-16]. If metal media are used, the parts may be surface conditioned by micro-kneading [1, 17]. All the processes taking place inside the tumbler change the surface texture of the parts [18]. The principle of operation of the vibratory tumbling equipment used for the experiments is shown in **Figure 1.** Tumble finishing is commonly used, for example, in jewellery to polish metal items with a complex macro-geometry and semi-precious stones or in medicine to polish implants and natural bones [3, 8, 19]. It is also suitable for brightening plastic elements, deburring or degreasing.

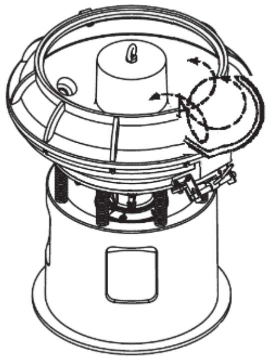

Figure 1 Diagram of vibratory tumbling [20]

The abrasive material placed in the tumbler helps:

- remove burrs or flash and round sharp edges (deburring, de-flashing and radiusing, respectively) [16],
- clean the surface and removing oxide layers or scale (descaling) [21],
- smooth the surface (reduce surface roughness),
- produce uniform surface texture [22],
- prepare the surface for electroplating
- polish the surface to a high shine (brightening),
- change the residual stress after heat treatment and welding,
- strengthen the surface layer, introduce compressive stresses and increase the hardness of the surface layer.

3. EXPERIMENT

The elements under study were made of a wear - and abrasion-resistant steel, HARDOX 400. The hardness of the material ranges from 370 to 430HB [23]. Hardox steel plates, characterised by high hardness, high strength and high impact resistance, have a large number of applications, for instance, forestry, earthwork, asphalt paving and underground mining [23]. The specimens were in the form of triangular wedges. They were prepared using abrasive waterjet (AWJ) cutting so that the edges to be rounded were inclined at 30^0, 60^0 and 90^0.

Table 1 Composition of Hardox 400 [23]

C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Ni [%]	Mo [%]	B [%]	CEV [%]	CET [%]
0.150	0.700	1.600	0.025	0.010	0.300	0.250	0.250	0.004	0.330	0.230

The tests were performed using plastic media in the shape of triangular-based pyramids (PB40 KT) According to the manufacturer's specifications this type of media is the most effective [23]. It is designed for roughing and deburring. FE-L120-B32/R was added as a liquid lubricant (approximately 250 ml). The finishing was carried out in a Rollwasch SMD-25-R vibratory tumbler with a 25 dm^3 bowl. The tumbling times were: 2, 5, 10, 15 and 20 hours.

4. RESULTS

Before finishing, the triangular workpieces were marked and weighed. Then, they were placed in the tumbler and processed for 2, 5, 10, 15 or 20 hours. After the finishing process, the specimens were weighed again. The results are shown in **Table 2**. The relative mass loss, expressed in ‰, was calculated from the mass loss relative to the mass (of the part) before the smoothing operation. The results of the measurements obtained with a Talysurf optical profiler are also included in **Table 2**. According to ISO 25178 defining the 3D areal surface texture parameters, *Sa* is the arithmetic mean height of the surface. Parameters *Sz* is the maximum height of the surface, *Sv* is the maximum height of valleys and *Sp* is the maximum height of peaks (difference between *Sz* and *Sv*) [24, 25] - see also **Figure 3**.

Table 2 Material removal rate (MRR) and the surface texture parameters

Tumbling time, hours	m_1, g	m_2, g	*MRR*, mg	*MRR*, ‰	*Sa*, µm	*Sv*, µm	*Sp*, µm	*Sz*, µm
0	60.6225	60.6225	0.0	0.00	3.41	21.03	19.13	40.72
2	60.6225	60.5417	80.8	1.33	2.96	14.03	9.27	23.30
5	60.6108	60.4975	113.3	1.87	2.57	20.34	7.13	27.46
10	60.5353	60.3715	163.8	2.71	1.98	15.37	7.59	22.96
15	60.8328	60.6234	209.4	3.44	1.56	13.97	3.73	17.70
20	60.5796	60.2916	288.0	4.75	1.33	16.91	5.81	22.72

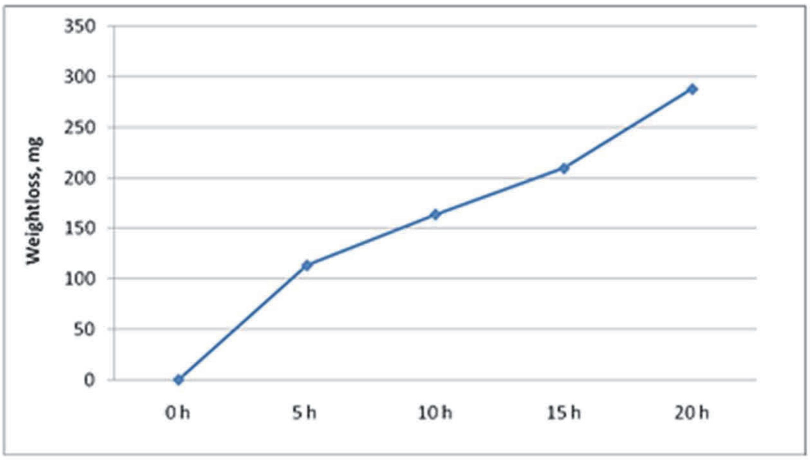

Figure 2 Rate of material removal versus tumbling time

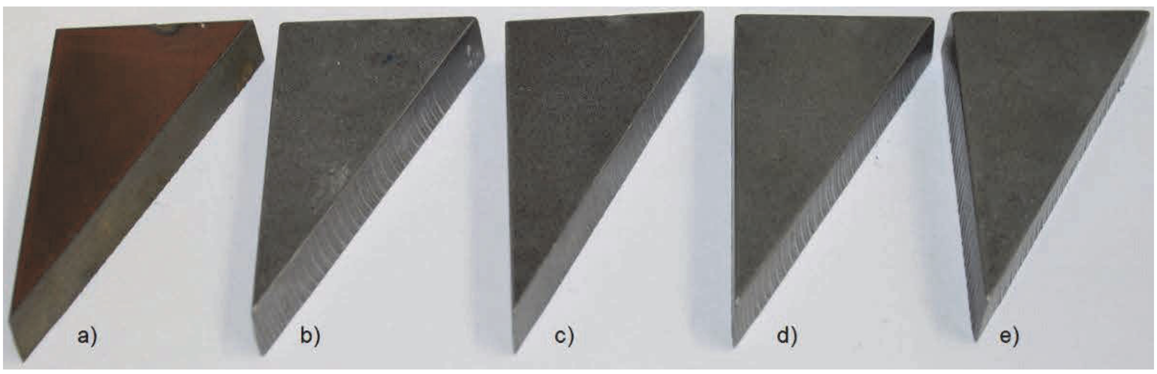

Figure 3 Specimens processed for a) 0, b) 5, c) 10, d) 15 and e) 20 hours

The microscope was also used to measure the radii of rounding at the corners of the triangular specimens made of Hardox 400 steel. The measurement method was illustrated in **Figure 4**. The measurement results obtained for different tumbling times are provided in **Table 3**.

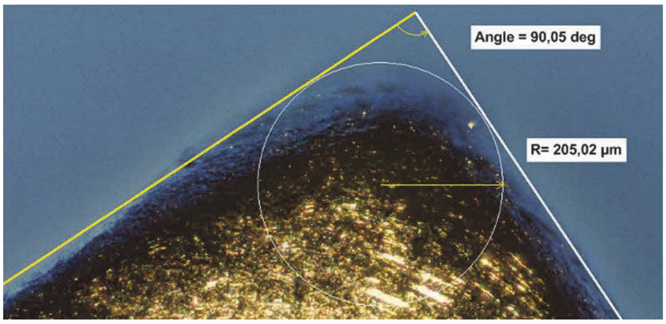

Figure 4 Methodology to measure the radius of rounding

Table 3 Radii of rounding

Tumbling time, hours	R, µm 30° angle edge	R, µm 60° angle edge	R, µm 90° angle edge
0.0	0.00	0.00	0.00
5.0	67.11	107.43	205.02
10.0	97.17	175.05	282.62
15.0	107.28	229.06	308.85
20.0	123.29	249.33	342.04

The measurements were carried out using an optical profiler. The measurement results obtained for different tumbling times are provided in **Table 2**. The 3D surface roughness maps show that an increase in the tumbling time leads to a decrease in surface roughness, i.e. the lowering of the highest peaks - see **Figure 5**.

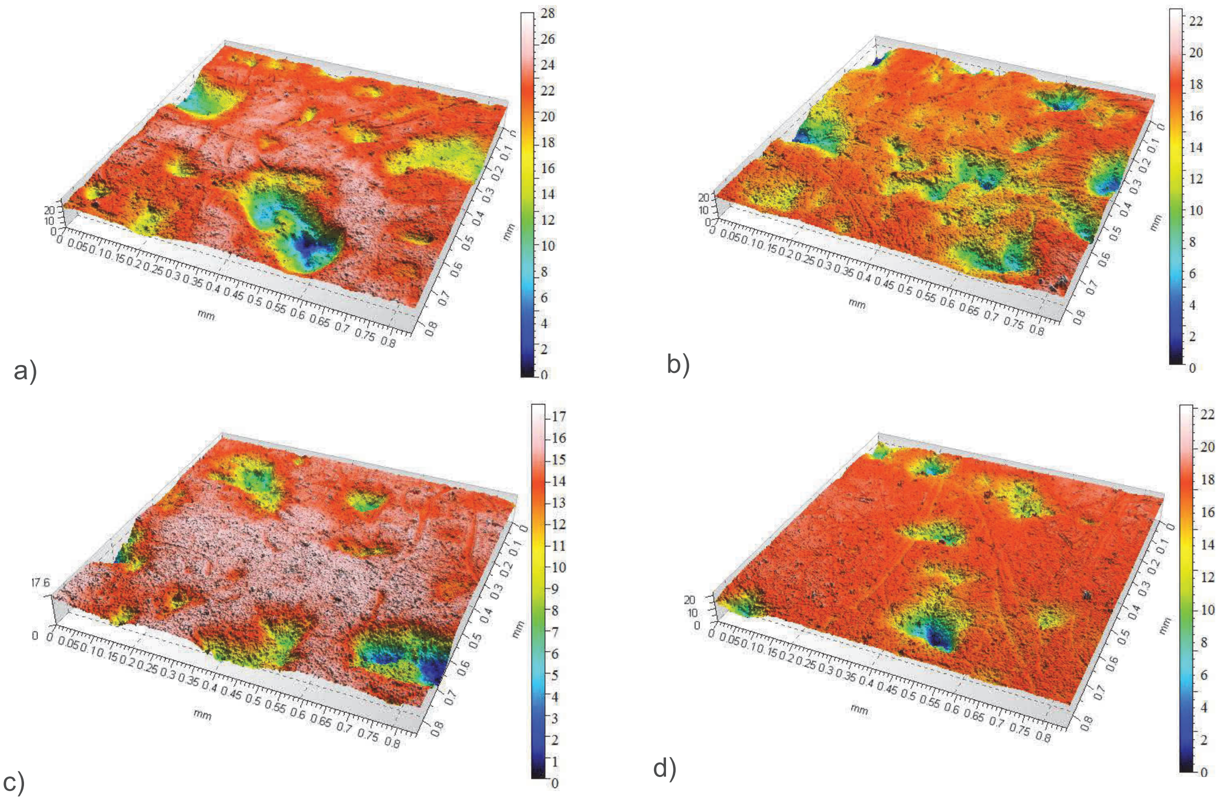

Figure 5 3D Surface texture of Hardox a) after 5 h, b) 10 h, c) 15 h and d) 20 h of vibratory tumbling

The results indicate that there is almost a linear relationship between the tumbling time and the mass loss. However, the steepest portion of the mass loss to tumbling time curve corresponds to the initial period of the finishing process (2 hours). For longer times, the increase in the mass loss rate is linear (**Figure 2**). Similar observations were made when radiusing was performed. Longer times caused the radii of rounding to increase. The largest rounding was reported for 90 degree angle edges, while the smallest for 30 degree angle edges. This is related to the piece geometry. Smaller initial angles (i.e. 30 and 60 degrees) required much larger geometrical losses to obtain the same radii of rounding as that observed in the case of 90 degree angles.

5. CONCLUSION

The vibratory tumbling process using abrasive media can be used to finish hard, wear and abrasion-resistant steels such as HARDOX, but it requires much longer tumbling times than those applied to finish softer materials. The surface is characterized by an anisotropic structure, while the edges are rounded and free of burrs.

The measurements of the basic surface texture parameters revealed that the process performed for several hours is sufficient to reduce the surface roughness. After 20 hours, the arithmetic mean height of the surface, *Sa*, decreased nearly three-fold from 3.41 μm to 1.33 μm.

The largest mass loss was observed during the first two hours. After that time, there was a linear relationship between the mass loss and the tumbling time.

The analysis of the radii of rounding shows that the largest radii were obtained for 90 degree angle edges.

REFERENCES

[1] BAŃKOWSKI, D., SPADLO, S. Influence of the smoothing conditions in vibro-abrasive for technically dry friction the parts made of steel X160CrMoV121. In *METAL 2016: 25th International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2016, pp. 1019-1024.

[2] BAŃKOWSKI, D., SPADŁO, S. The application of vibro - abrasive machining for smoothing of castings. Archives of Foundry Engineering, 2017, vol. 17, no. 1, pp. 169-173.

[3] BAŃKOWSKI, D., SPADŁO, S. Influence of the smoothing conditions in vibro-abrasive finishing and deburring process for geometric structure of the surface machine parts made of aluminum alloys EN AW-2017A. In *METAL 2015: 24th International Conference on Metallurgy and Materials.* Ostrava: TANGER, 2015, pp. 1062-1068.

[4] SPADŁO, S., MŁYNARCZYK, P. Analysis of the mechanical interactions of the filament brush electrode on the formation of the surface roughness. In *METAL 2015: 24th International Conference on Metallurgy and Materials.* Ostrava: TANGER, 2015, pp. 1169-1174.

[5] KONIECZNY, M. Microstructural characterisation and mechanical response of laminated Ni-intermetallic composites synthesised using Ni sheets and Al foils, Materials Characterization, TOM, 2012, vol. 70, pp. 117-124.

[6] MOLA, R., DZIADOŃ, A., JAGIELSKA-WIADEREK,K. Properties of Mg laser alloyed with Al or AlSi20, Surface Engineering, TOM, 2016, vol. 32, no. 12, pp. 908-991.

[7] KRAJCARZ, D., SPADŁO, S. Influence of the Process Conditions on the Diameter of Cylindrical Holes produced by Abrasive Water Jet Cutting. In METAL 2016: 25th *International Conference on Metallurgy and Materials.* Ostrava: TANGER, 2016, pp. 1462-1467.

[8] HARASYMOWICZ, J., WANATUCH, E. *Obróbka Gładkościowa. 1st ed.* Cracow: Wydawnictwa Politechniki Cracowskiej, 1994.

[9] GÓRSKI, E. *Obróbka Gładkościowa.* Warszawa: WNT, 1963.

[10] NOWICKI, B., STEFKO, A., SZULC, S. *Obróbka powierzchniowa.1st ed.* Warszawa: PWN, 1970.

[11] RODZIEWICZ, M. *Wygładzanie luźnym ścierniwem w pojemnikach*. *1st ed.* Warszawa: WNT, 1968.

[12] STAROSTA, R. *Surface treatment*. *1st ed.* Gdynia: Wydawnictwo Akademii Morskiej w Gdyni, 2008.

[13] DAVIDSON, D. A. *Mass Finishing Processes. 2002 Metal Finishing Guidebook and Directory.* New York: Elsevier 2002.

[14] RAO, SUREN, B. Repair of Aircraft Transmission Gears via Isotropic Superfinishing, May 2009, Gear Technology

[15] BRINKSMEIER, E, GIWERZEW, A. Hard gear finishing viewed as a process of abrasive wear. Wear, 2005, vol. 258, pp. 62-69.

[16] FILIPOWSKI, R., MARCINAK, M. Techniki obróbki mechanicznej i erozyjnej, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2000, pp. 304-308

[17] HASHIMURA M, HASSAMONTR J, DORNFELD DA. Effect of in-plane exit angle and rake angles on burr height and thickness in face milling operation transactions of the ASME, Journal of Manufacturing Science and Engineering 121(1): pp. 13-19, Published 1999

[18] KACALAK W., TANDECKA K. Effect of superfinishing methods kinematic features on the machined surface, J. Machine Engineering 4, pp. 35-48, Published 2012

[19] GILLESPIE LK. Deburring and Edge Finishing Handbook, Society of Manufacturing Engineers, Published 1999

[20] http://www.rollwasch.it/en, Vibro Dry Experience PL, Rollwasch Italiana S.p.a (18.04.2017)

[21] AURICH J.C., DORNFELD D. ARRAZOLA P.J., FRANKE V. LEITZ La S. Burrs-Analysis, control and removal, CIRP Annals - Manufacturing Technology 58 Published 2009, pp. 519-542

[22] XIAO L., ROSEN B.-G., NASER AMINI, NILSSON P.H. A study on the effect of surface topography on rough friction in roller contact, Wear 254 pp. 1162-1169, Published 2004

[23] http://hardox400.pl/index.php/hardox-400 (18.04.2017)

[24] ADAMCZAK S.: Pomiary geometryczne powierzchni, Wyd. WNT, Warszawa

[25] MIKOLAJCZYK T., BORBONI A., MACKOWSKI D., MATUSZEWSKI M. Example of Tool with Two Numerical Controlled Axes, Article in Applied Mechanics and Materials 772:224-228, July 2015 DOI: 10.4028/www.scientific.net/AMM.772.224