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STEEL C45 ELEMENTS LAPPING

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Abstract

Lapping is a process by which material is precisely removed from a workpiece to produce a desired dimension, surface finish or shape. It also removes subsurface damage caused by sawing or grinding. According to the classification surface to be generated, type of surface, kinematics of the cutting process, and tool shape (profile), many process variants can be distinguished. Among them face lapping are the most widespread lapping processes. They are used to produce a smooth, flat, unpolished surface.

The process of lapping materials has been applied to a wide range of materials and applications, ranging from metals, glasses, optics, semiconductors and ceramics. Workpiece material properties and structure determine kind of material removal. Material removal by cutting, microfusion processes and material removal by microdeformation or by the induction of microcracks are to be underline.

C45 is a medium carbon steel used when greater strength and hardness is desired than in the "rolled" condition, especially in mechanical engineering and automotive components. To minimize wear in high-speed applications requires extreme size accuracy, straightness and concentricity. To meet those high demands turning, grinding, lapping and polishing processes are used.

This work presents results of steel C45 elements lapping. The experiments were conducted during flat lapping with use of ABRALAP 380 lapping machine. The lapping machine executory system consists of three conditioning rings. The process results were surface roughness R_a and material removal rate.

Keywords: *flat lapping, steel C45 lapping, material removal rate, surface roughness*

1. Introduction

The high demands required today by manufacturing engineers for machine parts and tools necessitate very precise machining. The finishing processes are an important perspective to be considered today to meet the goals like parallelism, tolerances, flatness and smooth surface. These processes are high-precision abrasive processes used to generate surfaces of desired characteristic such as geometry, form, tolerances, surface integrity and roughness characteristics. A leading importance in this perspective has the lapping process. It leads to a surface with low roughness and high precision. The topographical structure resulting from lapping is very advantageous in sliding joints, because of the high ability of lubricant retention, as well as in non-sliding joints because of the high load-carrying ability [4, 6, 7].

Many materials can be lapped including glass, ceramic, plastic, metals and their alloys, sintered materials, satellite, ferrite, copper, cast iron, steel, etc.

Lapping process is used in a wide range of applications and industries. Typical examples of the processed components are pump parts, transmission equipment, cutting tools, hydraulic and pneumatics, aerospace parts, inspections equipment, stamping and forging [6, 11, 12].

The most extensively used type of lapping process is flat lapping. Its goal is to achieve extremely high flatness of the workpiece and/or close parallelism of double-lapped faces. The other applications include removal of damaged surface and sub-surface layers and, enhancement of the surface finish on workpieces [3, 6, 11, 12].

2. Material removal mechanism during flat lapping

Lapping is a machining process that utilises abrasives such as diamond, silicon carbide, boron carbide and aluminium oxide for stock removal and finishing. The abrasive grains in lapping are usually mixed with a liquid to form a slurry. This slurry is placed between a hard rotating wheel, called the lapping plate, and the workpiece. A schematic diagram of the process is shown (Fig. 1).

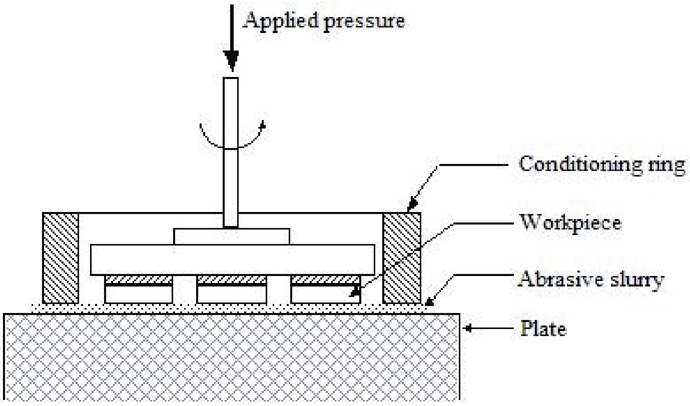

Fig. 1. Schematic diagram of lapping process [3]

The grains are the cutting tools during lapping. There are two models to explain the predominant mechanism for material removal (Fig. 2.). In the first one, the grains roll in the working gap. The workpiece material is elastically and plastically deformed by the indentation of corner points until small particles break off due to material fatigue. In the second mechanism, lapping grains are embedded in the lapping plate and material is removed by chip formation. Which mechanism is dominant depends on workpiece material properties and structure [3, 5, 6, 9].

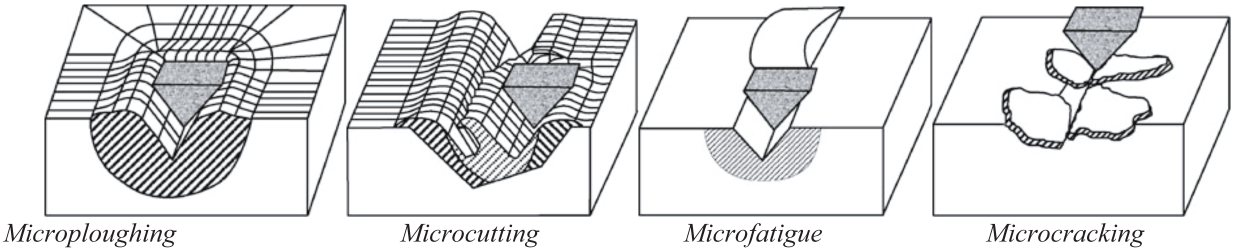
Microploughing *Microcutting* *Microfatigue* *Microcracking*

Fig. 2. Different interactions between abrasive and workpiece surface during lapping [7]

Microploughing shows that the polishing grain after getting in contact with the surface pushes the loosened material along, which finally agglomerates at the sides of the groove. Ideally, no material is removed with the micro ploughing. However, if more and more polishing grains get to the same area, the material is again and again pushed to the sides, until it breaks out. This phenomenon is called microfatigue. During the microcutting, the grain gets deep into the material and due to the maximum forming ability of the material a chip is formed, which matches in the best case to the groove. Microcracking is the result of high tensions, which are put into the material from the abrasive particles. This mechanism exists at brittle materials (e.g. ceramics), while microcutting and microploughing mainly appear at ductile materials (e.g. steel) [5, 6, 9, 10].

Abrasive processes have a large number of parameters that can be varied in order to obtain the desired process output. The lapping process is influenced by load, rotation of the lapping plate, material of the lapping plate, lapping time, type of slurry used, grain size of the abrasive, flow rate, slurry concentration, etc. Tough many years of studies, there is still a lack of a systematic understanding of the process, fine-tuning or developing processes for a new product has always been an empirical process with success dependent upon the skill of the machine operator or engineer. Thus, the operator needs to stop the process continually to measure the results to guarantee that the workpieces will reach the required tolerances.

Fundamentally, benefits and effects of the lapping process must be studied, shedding light on the scientific basis that transforms lapping from art to engineering [1-3, 8, 10].

3. Test procedure

This paper reports the observations of steel C45 elements lapping process results. Workpieces were rollers with diameter 17 mm and height 10 mm placed in the conditioning rings with use of workholdings (Fig. 3). The distance between elements and rings centres was 47 mm.

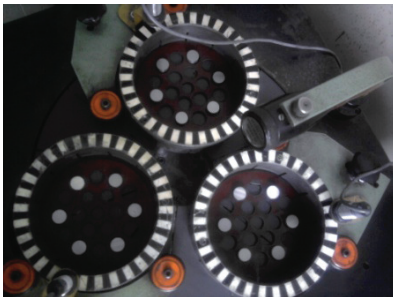

Fig. 3. Samples location in the conditioning ring

Samples were annealed to achieve Vickers's hardness 160 HC and then grounded to surface hardness R_a = 0.67 µm. After grinding, lapping process was conducted. The experiments were carried out on a one-plate lapping machine ABRALAP 380 with a grooved cast-iron lapping plate and three conditioning rings (Fig. 4). The machine kinematics allows for direct adjusting wheel velocity in range up to 65 rev/min. Experiments were carried out with an angular speed of the lapping plate set at 65 RPM, and lapping velocity was v = 49 m/min.

Fig. 4. One-plate lapping machine ABRALAP 380

ABRALAP 380 is also equipped with liquid slurry dispensing system, enabling constant supplying of fresh abrasive grains into the work zone. The supply of the slurry was maintained at $19 \cdot 10^{-8}$ 3^M/s. It was composed of silicon carbide grains mixed with kerosene and machine oil. Abrasive grains size F400/17 was used. Abrasive concentration m which is defined as a ratio of mass of the abrasive to mass of the lapping liquid was m = 0.25. The lapping pressure was provided by dead weights and during experiments executing p = 0.04 MPa. Samples were lapped during 10, 15 and 20 minutes.

The material removal rate (MRR) and specimens surface characteristic are studied in the light of used described lapping parameters, like grains size, lapping pressure, and time. Each workpiece was weighed before and after lapping using a precision weighing scale precise to within 1×10^{-4} g to determine the material removal rate in gram per minute. In addition, the initial thickness of each sample was determined with a digital micrometre precise to within 1×10^{-3} mm. The difference between the initial thickness and final thickness was used to obtain the material removal rate in mm per minute. Equation (1) was used to calculate the MRR [12]:

$$\mathrm{MRR} = \frac{\Delta \mathrm{W}}{\Delta \mathrm{T}} = \frac{W_1 - W_2}{T_2 - T_1}\, or\, \frac{\Delta H}{\Delta T} = \frac{H_1 - H_2}{T_2 - T_1}, \tag{1}$$

where:
W_1 – initial weight of sample,
W_2 – final weight of sample,
T_1 – time at onset of lapping,
T_2 – time at the end of lapping,
H_1 – initial thickness of sample,
H_2 – final thickness of sample.

A Hommeltester T8000-R60 profilometer with a resolution of 0.01 µm was used to determine the surface roughness before and after lapping. The radius of the stylus used was 2 µm. Percentage R_a improvement was determined using [12]:

$$\Delta \mathrm{R}_a = \frac{(\text{Average initial } \mathrm{R}_a - \text{Average final } \mathrm{R}_a)\times 100}{\text{Average initial } \mathrm{R}_a}. \tag{2}$$

4. Test results

Figures 5–7 presents some results obtained during the tests. There are presented dependencies of ΔW, ΔH, MRR, in mg/min and mm/min, and surface roughness parameter R_a and KR_a on lapping time.

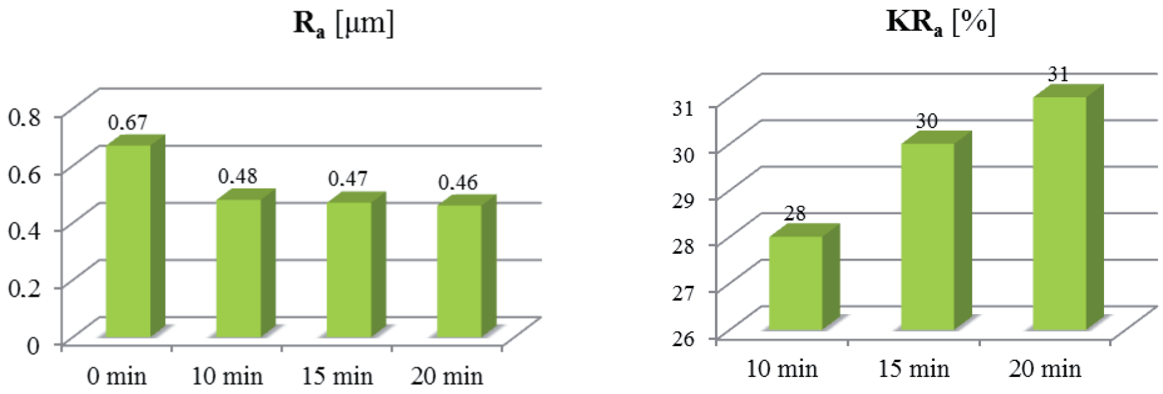

Fig. 5. *Test results of R_a and KR_a depending on lapping time obtained for steel C45elements with hardness 160 HV (SiC-F400/17, $p = 0.04$ MPa, $v = 49$ m/min)*

Figure 5 shows that lapping process reduces the surface roughness R_a by about 30%, and its decrease with lapping time increase can be observed. The biggest surface improvement was achieved during first 10 minutes of lapping. Further lapping time extension does not significantly reduce the R_a parameter.

Obtained R_a values are rather high as for lapping what can be explained in two ways. Firstly, abrasive powder with number F400/17 is generally utilised for rough lapping. Secondly, workpiece material hardness is quite low compared to abrasive and consequently grains get deeper into the work material.

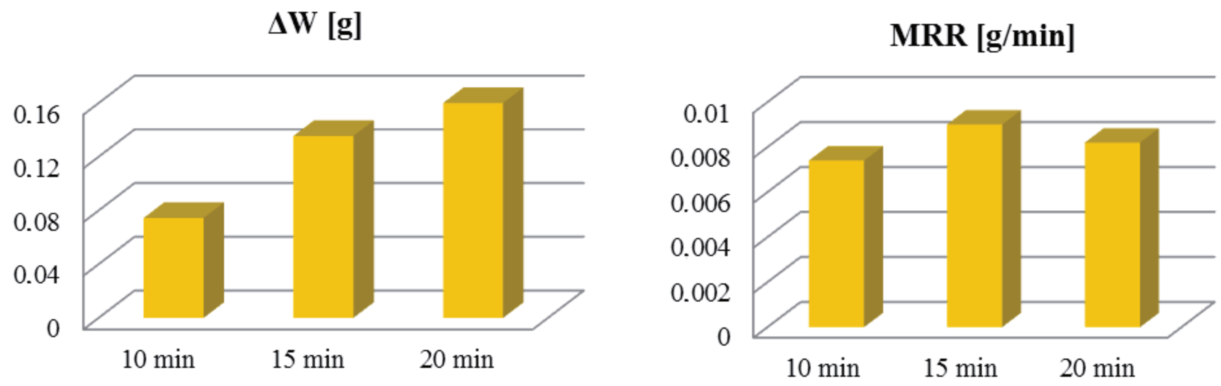

Fig. 6. *Test results of ΔW and MRR depending on lapping time obtained for steel C45elements with hardness 160 HV (SiC-F400/17, p = 0.04 MPa, v = 49 m/min)*

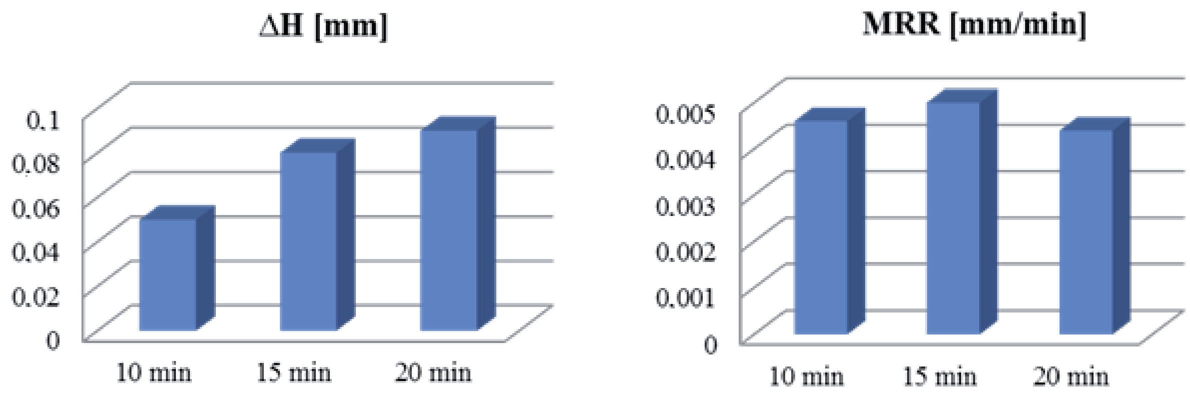

Fig. 7. *Test results of ΔH and MRR depending on lapping time obtained for steel C45elements with hardness 160 HV (SiC-F400/17, p = 0.04 MPa, v = 49 m/min)*

Total amounts of material removed (ΔW, ΔH) obtained during tests are presented on Fig. 6 and Fig. 7. As was expected, in both cases the increase with lapping time was observed. It can be also seen that MRR per minute is in all cases independent on lapping time. It can be result of dividing by machining time, because lapping efficiency gets smaller with time.

5. Conclusions

Lapping process is commonly used for ultra-precision machining of various materials, including steel. This group includes widely used steel C45. Because of its applications requiring extreme size accuracy, straightness and concentricity, lapping process is used. Because of the lack of its complex model, there is a need to empirically finding of optimal parameters. The results are partially presented in this paper. The material removal rate (MRR) and specimens surface characteristic are studied in the light of used lapping parameters. Achieved values of total MRR and MRR per minute are similar to those presented in others authors works what can prove their correctness. Here were presented results for rough lapping conditions. Only lapping time was varied. Others parameters influence will be studied and the results will be presented in future works.

References

[1] Agbaraji, C., Raman, S., *Basic observations in the flat lapping of aluminum and steels using standard abrasives,* International Journal of Advanced Manufacturing Technology, No. 44, pp. 293-305, 2009.

[2] Bhagavat, S., Liberato, J. C., Chung, C., Kao, I., *Effects of mixed abrasive grits in slurries on free abrasive machining (FAM) processes,* International Journal of Machine Tools & Manufacture, No. 50, pp. 843-847, 2010.

[3] Crichigno, Filho, J. M., Teixeira, C. R., Valentina, L. V. O. D., *An investigation of acoustic emission to monitoring flat lapping with non-replenished slurry,* International Journal of Advanced Manufacturing Technology, No. 33, pp. 730-737, 2007.

[4] Horng, J. H., Jeng, Y. R., Chen, C. L., *A model for temperature rise of polishing process considering effects of polishing pad and abrasive*, Transactions of ASME, Vol. 126, pp. 422-429, 2004.

[5] Klocke, F., Dambon, O., Behrens, B., *Analysis of defect mechanisms in polishing of tool steels*, Production Engineering Research Development, No. 5, pp. 475-483, 2011.

[6] Marinescu, I. D., Uhlmann, E., Doi, T. K., *Handbook of lapping and polishing*, CRC Press Taylor & Francis Group, Boca Raton, 2007.

[7] Molenda, J., Barylski, A., *Analiza modelu matematycznego opisującego wzrost temperatury podczas docierania jednostronnego powierzchni płaskich,* Journal of KONES Powertrain and Transport, Vol. 16, No. 4, pp. 343-350, 2009.

[8] Molenda, J., Barylski, A., *Determining the conditions for temperature measurements during flat lapping,* Journal of KONES Powertrain and Transport, Vol. 18, No. 3, pp. 293-297, 2011.

[9] Molenda, J., Charchalis, A., Barylski, A., *The influence of abrasive machine on temperature during one side lapping,* Journal of KONES Powertrain and Transport, Vol. 17, No. 2, pp. 357-362, 2010.

[10] Sreejith, P. S., Ngoi, B. K. A., *Material removal mechanism in precision machining of new materials,* International Journal of Machine Tools & Manufacture, No. 41, pp. 1831-1843, 2001.

[11] www.engis.com.

[12] www.kemet.co.uk.