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The effects of machining strategies of magnetic assisted roller burnishing on the resulted surface structure

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Abstract. The aim of this paper is to investigate the effect of different burnishing strategy on a C45 steel machining. Burnishing is a well-known, cold working surface improving technology, it is usually applied for cylindrical workpiece. In the reported research a novel developed magnetic assisted ball burnishing (MABB) tool was applied which was designed for MABB machining of flat and harmonic surfaces. To increase its efficiency, different types of machining strategies were applied. After the burnishing process the machined surfaces were measured by surface roughness tester to determine the most important Rsk and Rku tribological parameters. According to the results it can be stated that all different burnishing strategies have special application areas where they can be used efficiently (e.g. sliding surface, moulding tool and after- or pre-machining for ultra-precision machining).

1. Introduction

Nowadays, industry is expecting high efficiency and quality of machining surfaces. There are many types of finishing technologies e.g. superfinishing [1], polishing and burnishing [2]. In the reported research high quality surfaces are produced by ball burnishing, to enhance the workpiece characteristics like wearing [3], tribology [4] or corrosion [5]. Generally, the burnishing is an applied technology for machining cylindrical workpiece in order to improve the surface [6]. But in this published research the authors used a novel developed burnishing tool which was designed especially for flat and harmonic surfaces. Different types of machining strategies were applied to increase the tools' efficiency of the burnishing process.

Some of studies report on the advantages of various machining strategies, but most of them was used for milling. These strategies can reduce the machining time, force and surface roughness while increase the tolerance, efficiency and sliding properties [7, 8, 9] not to mention the discerning tool path [9]. Based on these aspects, similarly positive results can be expected for ball burnishing, too. Because the novel MABB tool and operation is similar to a face milling tool, almost the same machining strategies can be applied as were used in milling process. Burnishing has been successfully applied to many materials like titanium alloys [3], stainless steels [11], polyethylene [12], aluminum alloys [13, 14], magnesium alloys [5] and steels [6]. But because the MABB tool works by magnetic force, it requires a workpiece also being magnetizable to ensure the necessary burnishing force between the tool and workpiece.

R. Jerez-Mesa et al. [15], investigated the influence of different strategies of ultrasonic burnishing on the resulted surface. Their tool was a 10 mm diameter ball type in a house and it was attached to a piezoelectric module which can be excited through an external generator with a 40-kHz electrical signal. They burnished a pre-milled specimen with three different strategies (parallel, 45 degrees and perpendicular), the Fig. 1. shows their result [15].

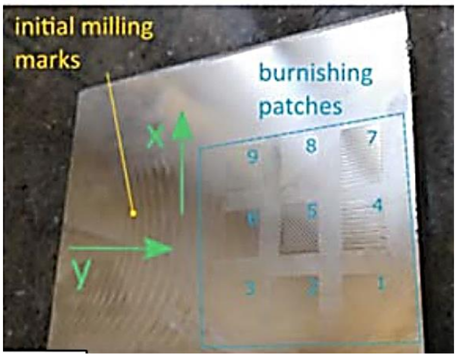


Fig. 1. Burnished workpiece by R. Jerez-Mesa et al. [15]

Based on their results it can be stated that the improvements of surface roughness were equal to the applied feed directions for burnishing, so the parallel feed direction improves the y direction, the perpendicular improves the x direction and the 45 degrees improves both directions [15].

Because the novel magnetic assisted ball burnishing (MABB) tool is able to burnish having a width of 45 mm (thanks to the design), the authors can use all types of strategies which are available in CAM programs. The paper explores the burnished surfaces which were produced by various machining strategies.

2. The MABB technology & tool

The Magnetism Aided Machining or Magnetic Assisted Machining (MAM) technologies are relatively novel industrial machining processes. The newly developed MABB tool works with a NdFeB magnet and it generates the magnetic fluxes which pushes the balls into the machined surface [16]. As represented in Fig. 2., the fluxes are focused in the tool-workpiece contact zone and as a result the magnetic flux density (*B*) is high.

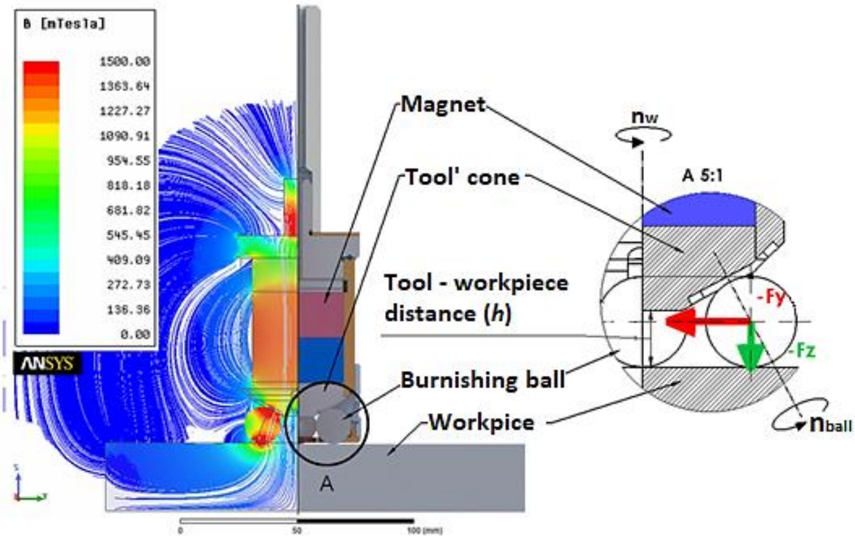


Fig. 2. FEM simulation about the magnetic fluxes around the MABB tool

The Fig. 2. also shows that the tool-workpiece distance has very important role, for ensuring the optimal rolling pressure [17]. The authors determined in their previous research the optimal working gap by calculation and experience, too [18]. This optimum *h* gap is 10 mm where the F_z force is ~350N as shown in Fig. 3.

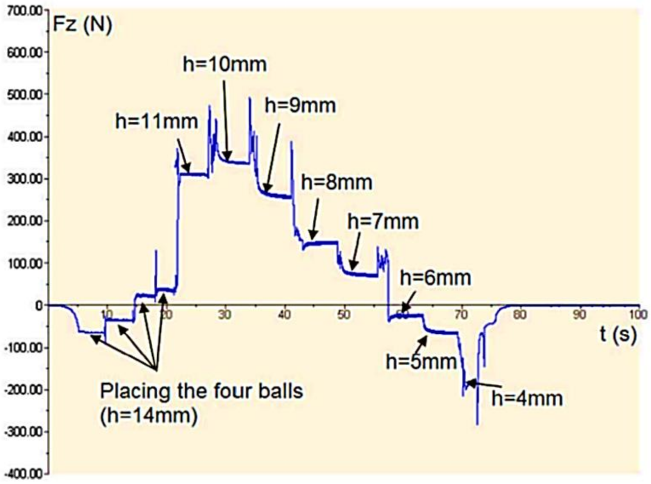
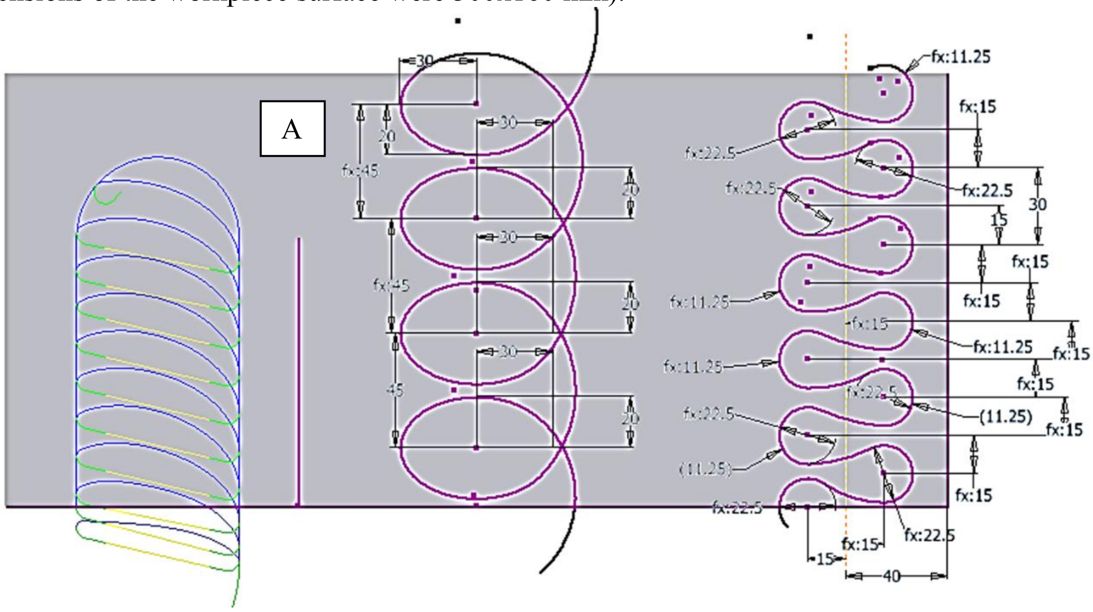


Fig. 3. Magnetic force depending on the tool distance [18]

3. Burnishing experiments

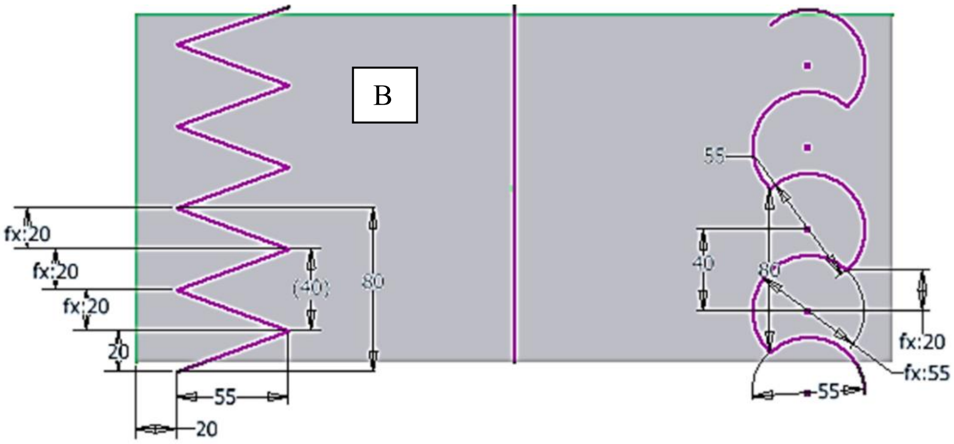
An C45 specimen was fixed on a CNC milling machine. The surface was pre-machined by a 8 teeth face milling cutter, with the cutting velocity of v_c = 120 m/min; feed speed rate of v_f = 200 mm/min, the cutting deep was: a_p = 2 mm, and APMX 160408TR-M14 MP2500 wiper geometrical inserts were used. This previous milling operation allowed homogenizing the surface of workpiece before the burnishing. Fig. 4-5. show some of the used machining strategies which were applied for burnishing. Both sides (A and B) of the workpiece were burnished with three-three strategies, respectively (dimensions of the workpiece surface were 300x160 mm).



1- Adaptive 2- Cycloid 3- All-round

Fig. 4. Burnishing strategies on the A side

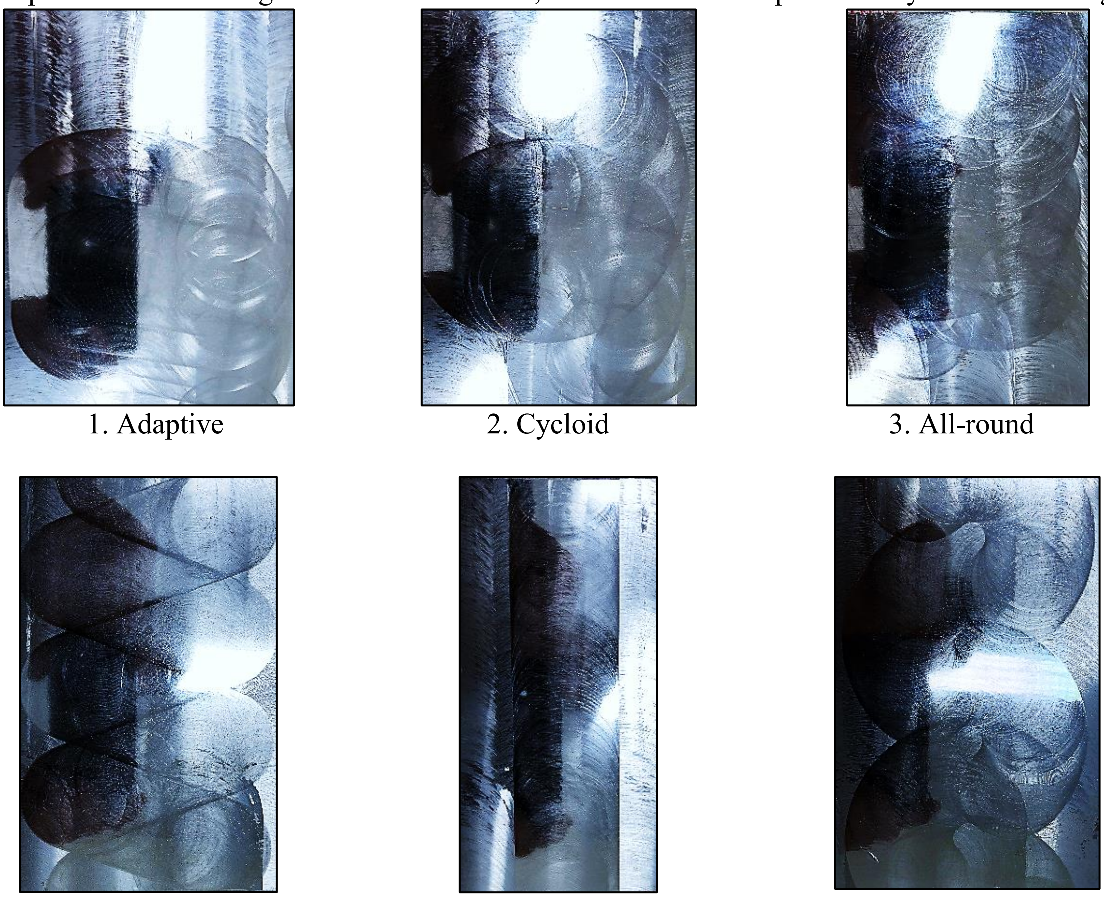
During a burnishing with an strategy, all of the technological parameters were kept constant to ensure homogenized and comparable surfaces (velocity: v_b = 40 m/min, feed speed: f_b = 50 m/min and tool gap: h = 10 mm).



4- Zig-zag 5- Line 6- Stepping-swinging

Fig. 5. Burnishing strategies on the B side

As shown in Fig. 4. there is one adaptive machining strategy which can be found in the Inventor HSM software. The other ones (Fig. 4-5.), were prepared in the same software by the authors, because the adaption of this path is not available for flat surfaces. This software contains many strategies but all of them require some kind of set-up (e.g. slot or pocket). But the Inventor HSM software can make (by post processing) CNC programs by own created strategies, so these four strategies and also a linear path were tested. Fig. 6. shows the resulted, burnished surfaces produced by different strategies.



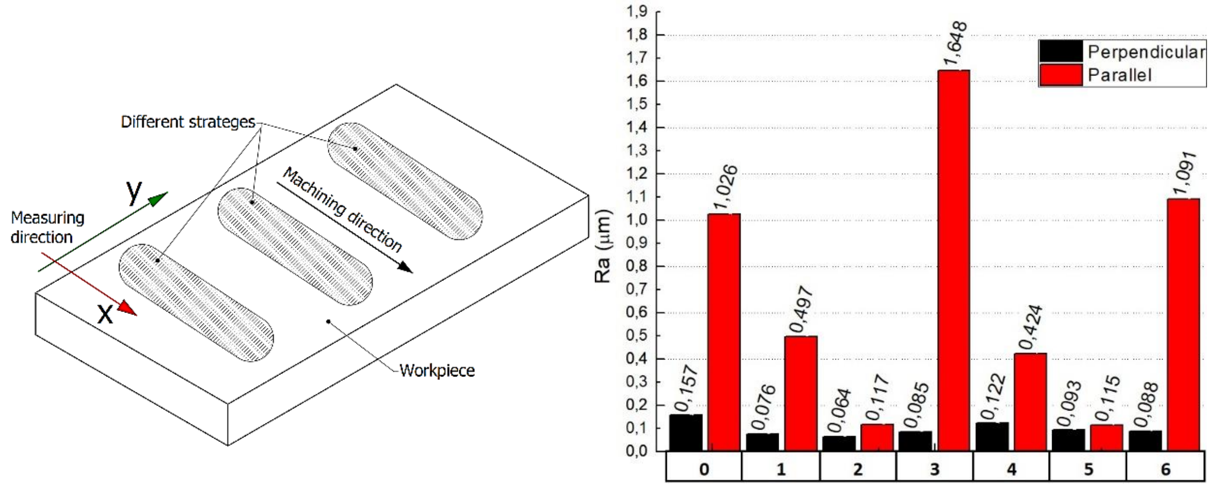
1. Adaptive 2. Cycloid 3. All-round

4. Zig-zag 5. Line 6. Stepping-swinging

Fig. 6. The surfaces of the burnished workpieces produced by six different strategies

4. Results and discussion

All burnished surfaces and the original one were measured along the x (parallel to the machining) and y (perpendicular to the machining) directions by a MITUTOYO Formtracer SV-C3000 surface measurement equipment (Fig. 7.). The pre-milled surface was marked with '0' and it was also measured in both directions.



a) b)

Fig. 7. The a) measuring directions and b) measured R_a roughness parameters Fig. 7. b) respresents that the higher R_a roughness values were measured in parallel directions.

To show the surfaces integrity, too, a summary was prepared about the surface roughness profile (R-profile) which is represented in Fig. 8.

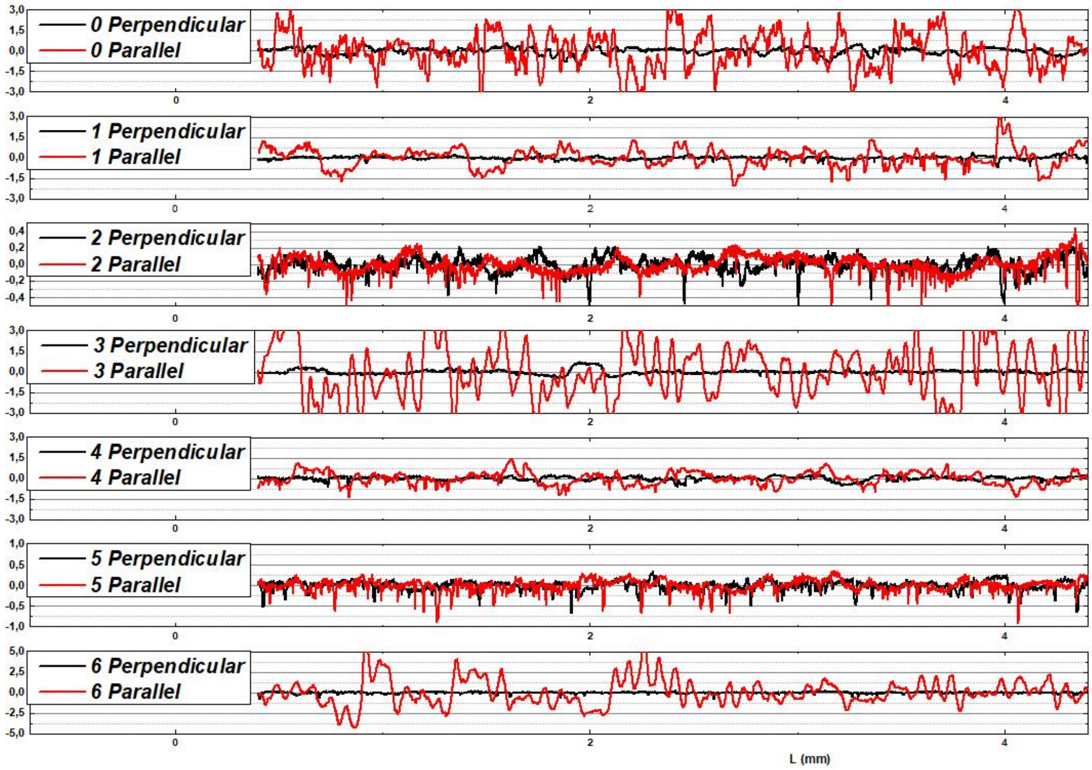


Fig. 8. Comparison of the milled (0) and burnished surface (1-6) roughness profiles (the perpendicular measuring direction is black, the parallel is red while the y-axes have different scaling

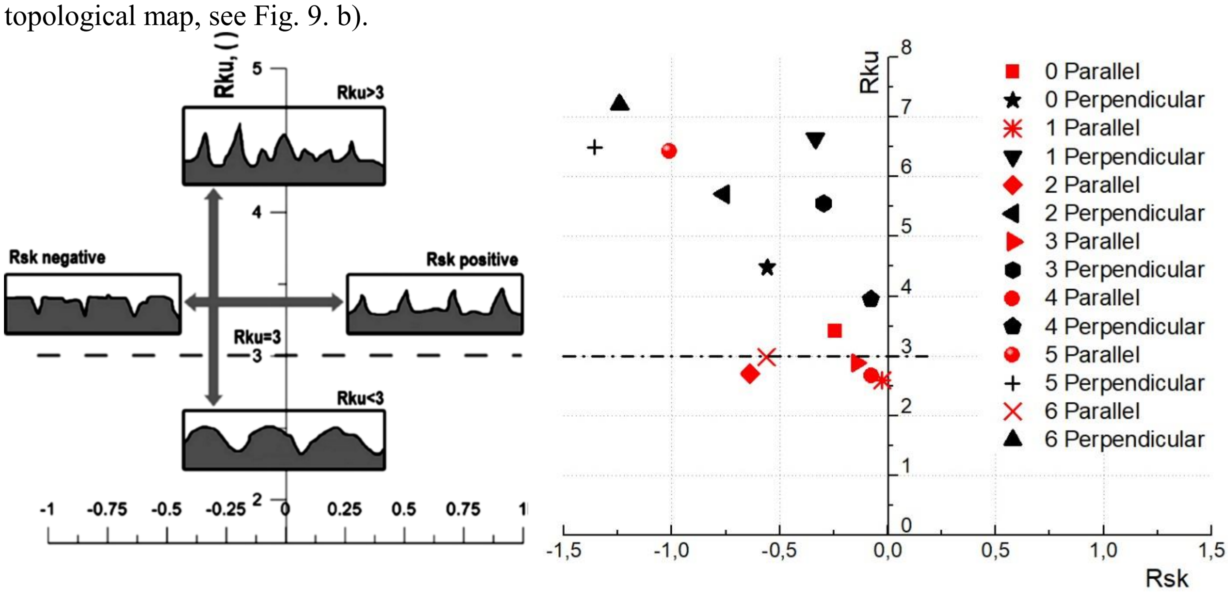
The Fig. 8. well represents that some of this R-profiles mirror advantageous features according to tribological aspects. For example the surface number 2 contains relative harmoniously arranged oil pockets. This can be said about the surface number 5, too. But based only on the R-profile it cannot be determined which surface is the most advantageous according to tribological aspects. So, the authors also measured the classical tribological indicators Rsk and Rku.

The skewness (Rsk) is a measure of the symmetry of the profile according to the mean line, giving information about the asymmetry of profiles having the same Ra values. Negative values of Rsk indicate a predominance of roughness (material), while positive ones are observed for surfaces with peaks [20].

The kurtosis (Rku) is a measure of the sharpness of the profile according to the mean line that provides information about the distribution of spikes above and below the mean line. Thus, spiky surfaces will have a high kurtosis value (Rku > 3) and bumpy surfaces a low value (Rku < 3) [20].

These indicators represented in one tribological diagram can form a so-called topological map. The Fig. 9. represents this topological map and indicates the places of different machining strategies according to tribology aspect.

The measurement of the Rsk and Rku parameters does not require any special instrument because its collection is part of the roughness measurement. So, the resulted surfaces were placed on the topological map, see Fig. 9. b).



a) b)

Fig. 9. a) Graphical representation of Rsk and Rku topological map [20] and the b) topological map of the analysed burnishing according to different strategies

As the Fig. 9. b) shows all of the measured values are negative in Rsk axis and there are five value which are below the value 3 in the Rku axis. These are: 2 Parallel, 6 Parallel, 3 Parallel, 4 Parallel and 1 Parallel.

Overall, surface numbered by 2 (cycloid) has the lowest Ra value (Ra = 0,064) and it is the best in tribological aspect in parallel direction, too. This means that the MABB toll is able producing high quality surfaces with good sliding properties by cycloid strategy in the machining direction.

5. Conclusions

A flat C45 specimen has been burnished by the novel introduced Magnetic Assisted Ball Burnishing tool. Instead of the ordinary linear machining direction five different types of machining strategies has been successfully tested and analysed. Based on this detailed analysis the following statements can be concluded:

- The direction of the measurement has a significant effect on the tribological evaluation, those directions resulted the best tribological criterions which were measured parallel to the machining.
- The cycloid, all-round, zig-zag and stepping-swinging strategies are suitable to produce well working surfaces according to tribological aspects.
- Cycloid strategy can create the lowest Ra roughness values in both measuring directions.
- The cycloid strategy resulted the best surfaces overall, so it will be examined further in the optimisation of the technological parameters.

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