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NEW ADVANCES IN TEXTURING BY GRINDING

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Abstract. *Currently the texturing process on metal parts has been of great importance in the market by enhancing and increasing accuracy in machining parts, providing the production of functional components that generate less wear and loss of energy. Texturing by grinding has been studied since it appears to be a viable alternative to texturing mechanical components. The introduction of the patterns occurs during the conventional machining process itself and does not add an additional manufacturing step, as in the case of the current texturing methods (laser, etching and lithography). The grinding process produces minimal changes the characteristics of the material and allows the generation of relatively complex structures. The aim of this paper is to present recent advances in texturing by grinding in round and flat surfaces.*

Keywords: *grinding, texturing, dressing*

1. INTRODUCTION

The surface represents one of the main targets to obtain enhanced results in the part functionality. Many functional properties can be directly associated with the surface, for instance: friction, optical, lubrication, mechanical adjustment and others (Bruzzone, *et al.*, 2008). Controlling the surface parameters represents one important manufacturing stage of general mechanical parts production. As an example, around 41% of energy loss in internal combustion engines is directly associated with friction (Borghi, 2008). Surface texturing represents one methodology for precise control of surface properties and adds features in order to optimize the surface interaction (Etsion, 2013). Surface texturing is an approach to reduce the amount of energy consumption for fiction.

As presented by Bruzzone (2008), many techniques can be applied for surface texturing. However, material removing and special coatings are the main manufacturing strategies applied. In Silva (2013a), the main processes for texturing with material removing technologies are also presented. For Etsion (2013), the laser surface texturing (LST) process represents the most promising concept, due to the laser's high accuracy and less cycle time compared to other low material removing rates process, such as: etching and lithography. The processes uses laser energy to create dimples or oil pockets with micro-scale depth to enlarge load capacity, wear resistance and improve friction coefficient. The cavities serve as micro-hydrodynamic bearing, micro-reservoirs and micro-trap for particles and chips (Grabon, 2013). Same results could be achieved in Tang (2013) flat tests. Using a micro engraving process, dimples were produced in the surface for friction analysis. For the industry, it is of interest to find a way to produce textured surfaces, so that they easily can be reproduced (Silva, 2013a).

Machining processes are one option to keep industrial requirements for time, cost and efficiency. Denkena (2008 and 2010) carried some tests to evaluate machining options for surface texturing. Particularly, grinding trials could present the best results for efficiency. Similar results can be found in Oliveira (2010) and Silva (2013b). The authors presented an innovative approach for producing textured surfaces applying a plunge grinding cutting process, being a cost efficiency option with enhanced geometrical precision if compared to LST.

In this work, the main typical forms for texturing applied to reduce friction loss are presented. The methodology developed by Oliveira (2010) and Bottene (2012) is then presented and tested for the production of these textures. Another possible manufacturing strategy for textured surfaces in flat parts is also presented including the use of grinding wheels with defined grain pattern.

2. TYPICAL FORMS OF TEXTURED SURFACES PRODUCED BY GRINDING

A structured surface can contain all kinds of forms and shapes, but not every shape has a positive influence on the properties. The following shapes are the most used ones to enhance the surface at the moment.

2.1 Dimples

Dimples are circular shaped holes in the surface of the workpiece. Their convergent flanks are merging at the lowest point of the dimple. They function as lubricant reservoirs, which reduce and prevent wear in terms of friction. Usually they are spread evenly over the surface. In a sliding motion the stored lubricant gets pressed against the flanks and creates a pressure peak which functions like a micro bearing. This effect reduces the friction drastically. The performance of the dimples is independent from the moving orientation. It depends on the quantity and the arrangement. Figure 1 shows an example of the shape of one dimple.

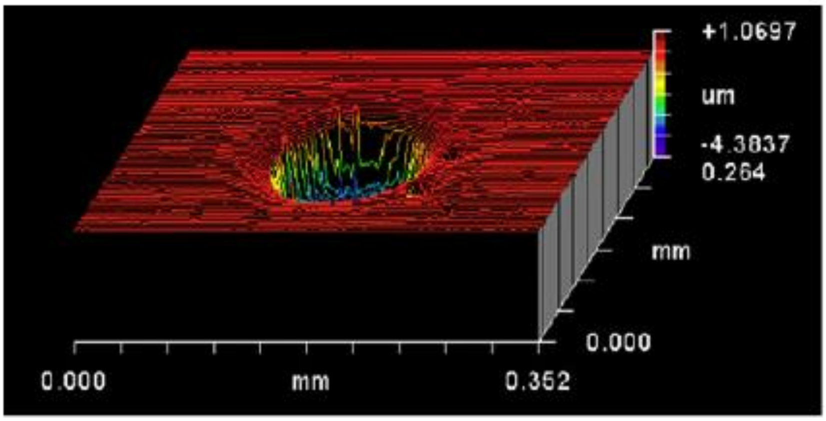

Figure 1. Schematic of a Dimple, adapted from Costa (2009)

2.2 Riblets

Riblets, as shown in Figure 2, are different than dimples. They are spread all over the workpiece and are used to lower the flow resistance of the workpiece. They can be used on wings of planes, on the body of ships or on blades of turbines. The riblets direct the flow of a liquid or gas in the most efficient way across the surface of the workpiece and thereby these structures reduce the friction drastically. The direction of the structure is the key to reach the optimal performance of the riblets. The depth and the quantity or width can alternate their performance. The right design has to be found individually for each workpiece and working conditions.

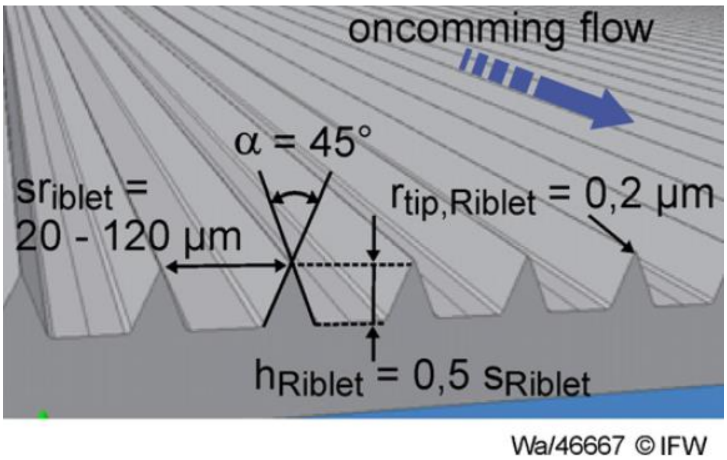

Figure 2.Riblets example, adapted from Denkena (2010)

2.3 Chevron

Another commonly used structure is the so-called Chevron or Fishbone. It has the shape of the tip of an arrow or as two bones connected in the spine, as displayed in Figure 3. The space between the two flanks is used for lubricant storage. In the case of using chevrons as a texture the direction is important. The chevrons can point in or being against the moving direction or being perpendicular to it. These positions influence the performance drastically. For example, if the tips are pointed at the moving direction, there will be a pressure peak that enhances the fluid film and has a positive influence on reducing the friction. If the chevrons are perpendicular to the sliding component the lubricant will be dragged out of the gap and the fluid film collapses.

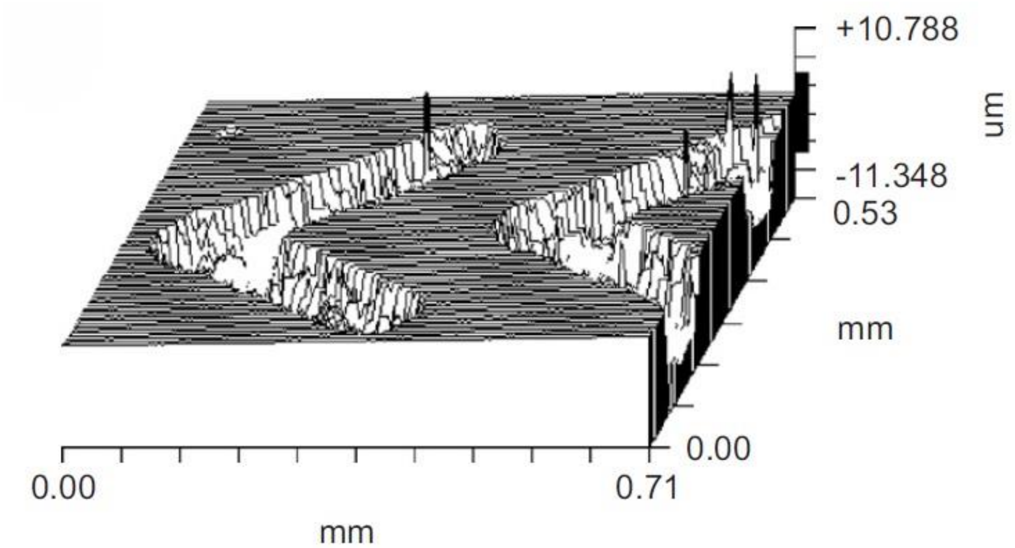

Figure 3. Chevrons example, adapted from Costa (2007)

3. CURRENT TECHNIQUES TO PRODUCE TEXTURING BY GRINDING

At the moment, there are different approaches to produce textured surfaces for round and flat surfaces. The most current production possibilities will be explained. The efficient manufacturing of textured surfaces symbolizes the current challenge for the industry and for the research society.

3.1 Manufacturing of structured surfaces via grinding using textured grinding wheels

One of the methods to manufacture structured surfaces via grinding is to use a textured conditioned grinding wheel. For that, the wheel must be dressed with the desired feature and an integer angular speed ratio between the workpiece and the grinding wheel has to be used in order to transfer the pattern from the wheel to the workpiece. Details on the developed method can be found in Bottene (2012) and Oliveira (2010). Figure 4 presents the instrumented grinding machine at the LAPRAS – EESC-USP, São Carlos, SP - Brazil. For patterning the wheel, the dressing depth (a_d) is dynamically changed according to the desired feature to be produced. A high-speed axis, perpendicular to the wheel surface, is used to perform the modified dressing operation. Patterns were produced using specific software and acoustic emission was used to control the operation. To evaluate the produced pattern on the wheel profile, the acoustic mapping methodology developed by Oliveira (2001) was applied. The methodology uses RMS AE signals to monitor the contact between the grinding wheel and metal surfaces during cycle. The method combines AE signals and the wheel angular position to produce 3D graphs representing the contact intensity along the tool periphery. A 3D mapping graph is created using color scale to visually monitor the wheel surface. Black stands for no contact and yellow to white scale from low to high contact. Further details can be found in Oliveira (2001).

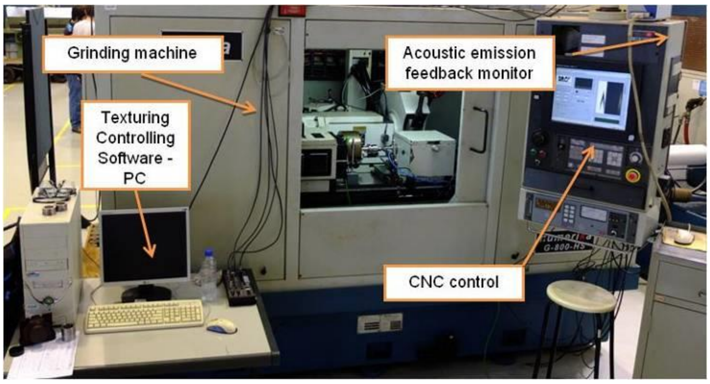

Figure 4. CNC grinding machine with acoustic emission feedback and software for texturing

Figure 5 shows the output result of a dressing pattern operation. The vertical axis represents the circumferential length of the grinding wheel and the horizontal one the wheel width. A pattern type "pockets" was inscribed into the wheel surface. The darker areas represent the lack of contact between the wheel and the dressing tool (pocket valleys). The brighter areas indicate the higher contact intensity regions (pocket peaks). For comparison, Figure 5 (left) also presents an acoustic map of a non-patterned grinding wheel, indicating the contact interaction homogeneity along the wheel surface while dressing.

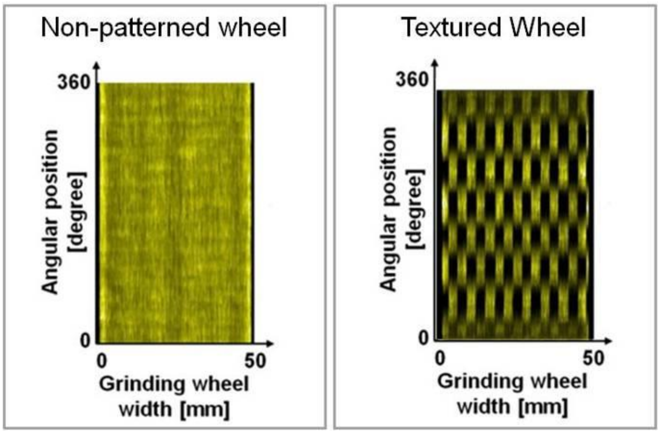

Figure 5. Acoustic mapping for wheel topography control – non-patterned (left) and textured (right) using Oliveira (2010) method

3.2 Manufacture structured surfaces via grinding using grinding wheels with defined grain pattern

The grinding wheels with defined grain pattern used for texturing consist of an electroplated layer where single CBN grains are placed manually in specific desired patterns to generate the texture, i. e. the position of the single grains are defined and hence known. The combination of the kinematic (parameters) and grain pattern enables to achieve different structures on workpieces with flat surfaces. Once the desired structure is known and the influence between kinematics parameters and grain pattern is understood, the process can be fully estimated and controlled. The material removal of every grain is then a priori known and the structures are then a composition of single grain scratches.

Figure 6 presents a picture of the aforementioned wheel, in a setup configuration developed by the Institute for Manufacturing Technology and Production Systems, (FBK), Technical University of Kaiserslautern, Kaiserslautern, Germany.

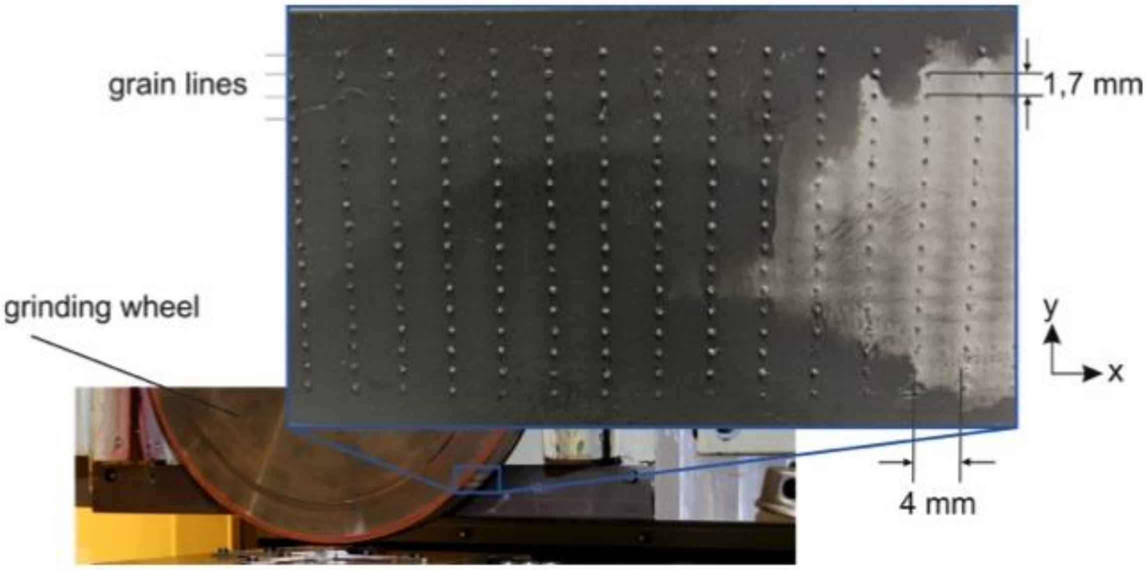

Figure 6. Wheel with defined grain pattern – FBK – TU Kaiserslautern

The chosen grain specification was CBN B251 and according to the guidelines (ISO 6106) grains were sieved but still result into differing grain sizes and ultimately the height distribution of the grains was not uniform. However, for this approach, a uniform height of the grains is mandatory. Otherwise the depth of the single scratches would vary according to the differences in grain height. The targeted structure depths were 2 to 10 µm. As a consequence, the variation of grain height had to be extremely small. To achieve a uniform grain height distribution, the wheel was dressed using a diamond-dressing wheel. After this dressing operation, the grain protrusion heights were measured. A variation in the grain height distribution of 3 µm was achieved, being a suitable value for the targeted application.

A structure simulation tool based on the applied process (surface grinding with two workpiece movements) was developed in MATLAB. Therefore, the process was analytically modeled and the derived equations were implemented in the simulation. This simulation can calculate:

- Required speeds (grinding wheel, workpiece in two directions) and depths of cut with a given grinding wheel pattern and a desired workpiece structure,
- The resulting workpiece structure in dependence of a given wheel pattern and given speeds (grinding wheel and workpiece) as well as depth of cut or
- Required grinding wheel pattern in dependence of desired workpiece structures.

The simulation includes a Graphic User Interface (GUI) to easily navigate through it and to set the input values. To determine required speeds for a specific workpiece structure or a resulting workpiece structure in dependence of given speeds, there are four windows of the GUI. In the first window, the parameters of the grinding wheel pattern and the characteristics of the grains (shape, size and height) can be set. In the second window, deviations of the aforementioned values can be defined to get more realistic results and to adjust the values to the actual manufactured grinding wheel respectively. In the third window, characteristics of the workpiece (Dimension, evenness) can be input. In the fourth window, the kinematics or the structure can be used as input (Figure 7).

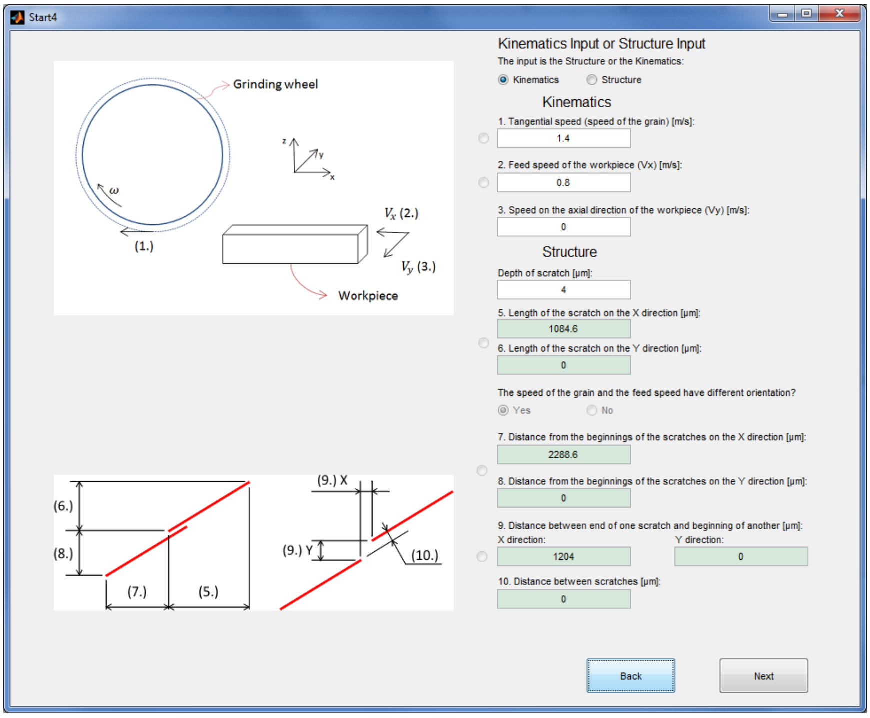

Figure 7. Window 4 of the GUI of the developed simulation – Kinematics input or structure output

4. PRELIMINARY RESULTS

The first step was to develop new software for producing precise textures in the wheel surface. Using the patterning software, the desired texture is mathematically modeled and converted into electrical signals. The model bases on wheel and part diameter ratio, dressing parameters and cutting conditions to generate signals for the actuator. In order to control the texturing, feedback sensor for wheel angular position is used. In addition, piezoelectric acoustic emission sensor is implemented for precisely monitor the contact of the wheel surface with the dynamic dressing tool. The software was developed using National Instruments Labview platform.

For the first tests, the aim was to generate patterns in round parts for friction reduction. The selected geometries were: dimples and chevrons. Data from literature was used as reference for programming the desired textures. Figure 8 presents initial results in terms of AE mapping and Figure 9 the obtained parts by grinding.

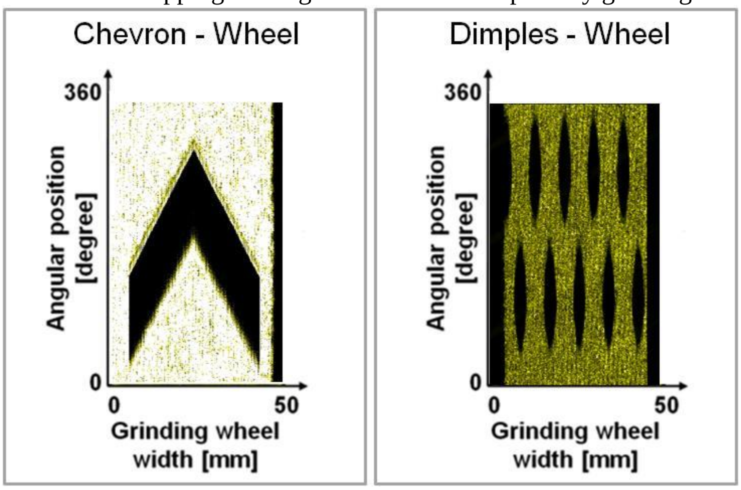

Figure 8. Preliminary results for wheel topography to produce chevron (left) and dimples (right) textures in round parts

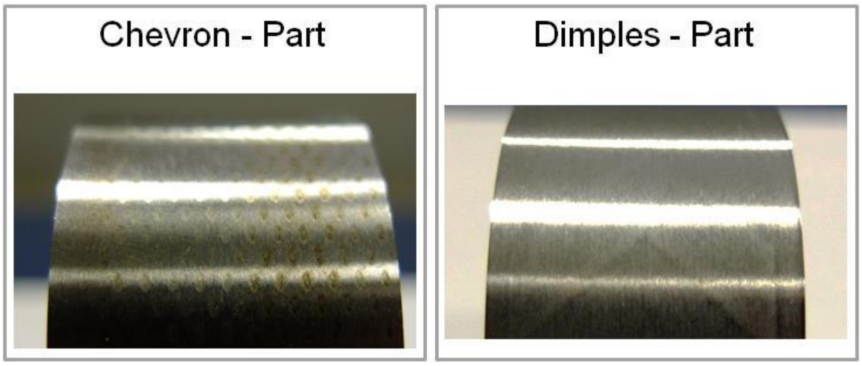

Figure 9. Preliminary results for part surface after grinding: chevron (right) and dimples (left) textures

For the final tests, a new version of the software was evaluated. The main objective was to produce patterns based on black and white images. This feature is important for the possibilities to study complex shapes of texture based on future 3D finite element simulation for lubrication-enhanced surfaces. With this feature, analysis made in the fluid dynamics CAE (computer-aided engineering) can be transferred in sample parts for test field evaluation. Textures with up to 15µm depth could be generated in the final part, precisely based on the pictures selected. Figure 10 represents these results. It illustrates the surface generated from a texturized wheel during the cutting cycle, also the picture used for patterning generation with the new software.

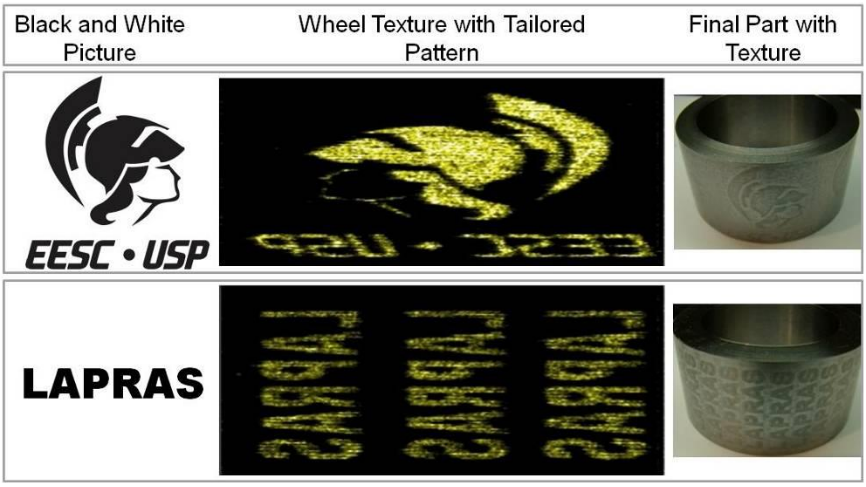

Figure 10. Advanced software results for pattern regeneration based in black and white pictures

Figure 11 presents an obtained texture in a flat part when using the wheel with defined grain pattern. The simulation software developed for texture simulation was tested. For the given grain pattern, different speeds of grinding wheel and workpiece were used and compared to simulation predictions. The results show that the simulation is well suited to predict structures and to choose kinematics. Also, the manufacturing method itself was proven to work. The single scratches of the structure differ in size (length and width). However, this is due to differences in the grain shapes and protrusions and was hence expected.

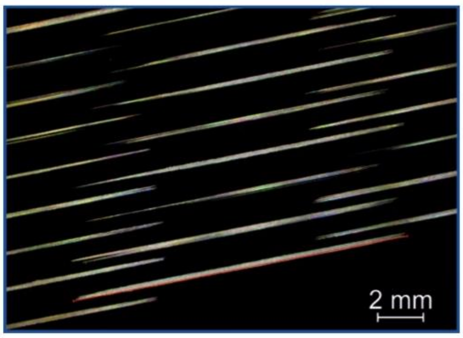

Figure 11. Sample texture manufactured with the grinding wheel with defined pattern

5. CONCLUSIONS

The main conclusions of this research are:

- The proposed methods to produce textured parts (round and flat) were successfully implemented. Textured parts could be obtained as a result of the grinding operation.
- The new software for texturing round parts could be experimental evaluated. The final version proved to be effective, enabling the production of complex parts based on pictures.
- The simulation software developed for producing flat parts enabled the determination of the required speeds for a specific workpiece structure or the resulting workpiece structure in dependence of given speeds. The method was limited to produce only dimples shapes, but could be controlled and simulated.
- Comparable to others available process, (laser texturing, etching and burnishing), the production of patterns by grinding represents a promising option for industrial application.
- Further tests will be carried based on literature review for achieving 3D complex shapes, to be tested for friction loss evaluation of engineered surface parts.

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