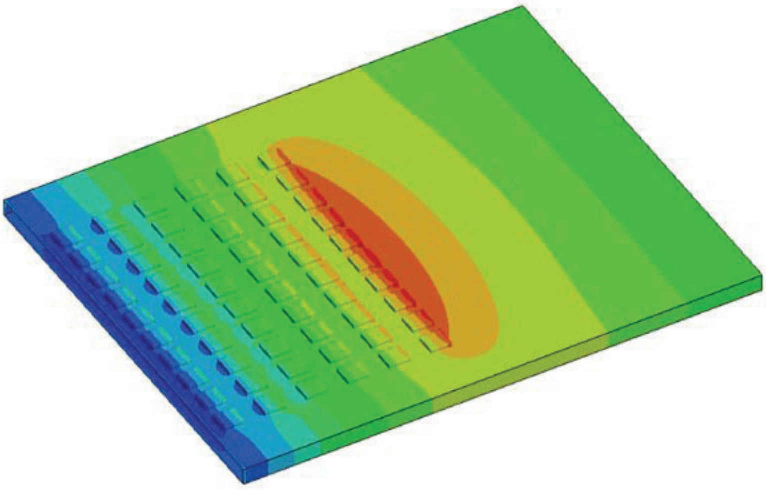
Friction control through surface texturing- FriText

Publik rapport



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1 Sammanfattning

Projektet har stött på många utmaningar men den största påverkan kom från den globala pandemin. Trots det har projektet nått de flesta av de uppsatta målen och kan även presentera en stor framgång.

Utformningen av den enskilda kaviteten har stor påverkan på effekten av den totala strukturen av kaviteter. Om man tar hänsyn till processen att skapa strukturen har cirkelformade kaviteter stor potential att användas i större skala. Den utvärderade strukturen kan minska friktionen på mikro-nivå.

Slipning visar potential att bli en miljövänlig process för att skapa den önskade strukturen till en låg kostnad. Den största utmaningen är att ta skapa processen för dressningen av slipskivan så att önskat resultat från slipningen uppnås. Här har det identifierats att nya arbetsmetoder och digitala verktyg behöver utvecklas.

Projektets stora framgång, med en struktur genererad med laser, visade att den stratifierade strukturen hade stor påverkan på det observerade systemet. Utförda experiment bekräftade resultatet från modeller och numeriska simuleringar, att djupet av kaviteterna i strukturen inte får bli större än 15 microns för att bibehålla den önskade hydromekaniska effekten. Den skapade strukturen minskade även förslitningen, detta är en följd av den hydrodynamiska effekten tillsammans med den förbättrade möjligheten att behålla ett jämnt oljeskick mellan motgående ytor.

Det finns en stor efterfrågan för korrekt och kontrollerbar manipulering av funktionsytor kopplat till elektrifiering, som bidrar till cirkularitet och nollutsläpp.

Projektets huvudmål var att finna en metod för att skapa en ytstruktur som förbättrar friktionskoefficienten och motståndskraften mot förslitning. Detta för att öka de tribologiska egenskaperna hos maskiner. Projektet hade två huvudmål: det första var att utveckla en befintlig abrasiv process för att skapa ytstruktur. Det andra målet var att utveckla en metod för utvärdering av ytstruktur.

Målen har blivit delvis uppfyllda. Det första målet var att utveckla en modell och simulera olika ytstrukturer med olika utformningar av kaviteterna. Detta mål uppfylldes helt. Metoder för slipning och lasertexturering har undersökts. Tyvärr, på grund av många orsaker (de flesta knutna till den globala pandemin) behövs mer undersökning på slipprocessen och dressningen av slipskivorna. Men, försök med slipning har genomförts inom projektets ramar. Lasertexturering blev en stor framgång och industrin ser resultatet som ett lovande steg mot manipulering av funktionsytor på industriellnivå. Utvecklingen av en metod för utvärdering av ytstrukturen är delvis utförd. Arbetet visar att mer arbete bör läggas på ytfunktionsparametrar.

2 Executive summary in English

The project met many obstacles on the way but mostly was affected by the pandemic worldwide situation. Nevertheless, the team was able to achieve most of the goals set for the project and even have one success story. The dimple shape greatly influences the dimple texture effect. Considering the feasibility of the texturing process, dimples with a circle-like shape have great potential to be applied on a large scale. In general, the texture which has been verified could reduce the friction on a micro-scale.

The grinding texturing has the potential to be a green, low-cost way to generate a textured surface. However, the most difficult part is designing the dressing process of the grinding tool to provide desired surface texture, but an additional specific setup and easy-to-program software need to be developed.

The project success story of the laser-textured surface proved that stratified surface texture greatly influences the engineering system behaviour. The experimental test confirmed developed models and numerical simulations, that the depth of the texture dimples cannot exceed 15 microns to keep the hydrodynamical effect. Moreover, the textured surface significantly increased wear resistance, which is an effect of the hydrodynamical effect of the texture and keeping steady film oil thickness between mating surfaces.

Proper and controlled surface functionalization is in high demand, especially for electrification purposes, contributing to circularity and net zero emission.

3 Bakgrund

Friction and wear greatly impact energy consumption, economic expenditure, and CO_2 emissions. Almost 23% of the world's total energy consumption originates from tribological contacts (20% from friction and 3% from wear). Implementing advanced tribological technologies can have a great influence on better control of frictional losses, and wear protection and can significantly reduce worldwide CO_2 emissions. Those problems significantly impact the automotive industry, manufacturing processes, and machinery.

This project can extend the lifetime of the mechanical components, reduce the energy, decrease the fuel consumption, increase the controllability of the friction coefficient, and hence reduce the friction losses, improve wear protection, and have a positive impact on CO_2 emissions reduction. One of the driving motivations in the FFI Sustainable Production sub-program is to reduce the automotive industry's CO_2 emissions from a life cycle perspective, and this project is the next step to achieve this goal.

4 Syfte, forskningsfrågor och metod

The project's main objective was to determine the surface texturing method to control the coefficient of friction and surface protection against wear, to improve the tribological properties of machinery components. The project included two main goals: the first goal was the development modification of existing abrasive processes to texturing the surface, whereas the second goal was to develop a method for evaluating surfaces after texturing.

Objectives of the project were partly accomplished. The first goal was to model and simulate different surface textures with different dimples shapes. This part is accomplished successfully. Further, the grinding and laser texturing were under investigation. Unfortunately, due to many obstacles (mostly pandemic situation) grinding texturing requires more development, with a focus on special dressing technology for grinding tools. Nevertheless, grinding texturing attempts were made. Laser texturing end-up as a success story of the project and is considered by the industry as a promising development towards industrial surface functionalization. The surface evaluation methodology was partly done, indicating that a closer look should be put at surface functional parameters.

5 Mål

The project's main objective was to determine the surface texturing method to control the coefficient of friction and surface protection against wear, to improve the tribological properties of machinery components. The project includes two main goals: the first goal is the development modification of existing abrasive processes to texturing the surface, whereas the second goal is to develop a method for evaluating surfaces after texturing.

Objectives of the project will be accomplished by developing a special abrasive process (based on existing production procedures) with micro-texturing of abrasive tools, as well as developing an evaluation methodology for the textured surface. The tribological effects of surface texturing can be summarized as follows: the micro-texture on sliding surfaces could induce extra hydrodynamic pressure and increase the film stiffness of lubricant oil; meanwhile, the dimples (micro pits or grooves) could act as reservoirs for lubricants and could trap debris to reduce 3rd body abrasive wear.

6 Resultat och måluppfyllelse

6.1 Wear type identification

The study of wear identification serves to compare a newly produced crankshaft with a worn crankshaft, to see if there´s a wear pattern emerging during the lifetime of the engine.

- Understand topography, tribology, and the application of textured surfaces to achieve specific utilities in mechanical systems.
- Assessment is of the lubrication regime predominant during testing.
- Analysing quantitatively and qualitatively the changes in surface parameters before and after testing.
- Elaborating a hypothesis on new improved textures based on the conclusions from the analysis.

The measurements are performed by the BE63730 department in Skövde and provided as text and pdf files with data for a large number of roundness traces. In addition to the roundness trace data, the measured diameters and radial deviation of the origin for each trace are provided. For each journal, a set of 4 straightness traces are also provided to be able to link the roundness traces to each other. The provided data is processed with scripts created in Python that adjusts the diameters and origin locations using least square error fittings in several steps. The processed data is used to create images of the surfaces shown as deviations from a cylindrical shape, see the example in Figure 1.

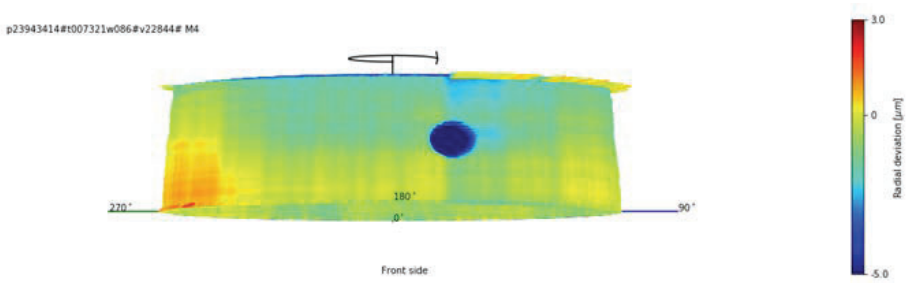

Figure 1. Example of the image created from Python script.

The measurements were done using a CCMM (Cylindrical Coordinate Measurement Machine) from Adcole, see Figure 2, which is used for roundness measurements. The standard measurements were done at three axial coordinates for each bearing journal where roundness, diameter, runout etc. is evaluated.

The idea with the measurements performed for the work in this report is to measure at tightly spaced axial coordinates, here with 1mm spacing, and to afterwards use scripts to patch the individual traces to a continuous surface map that can be used for illustration and simulations.

Figure 2. Adcole CCMM. Left: Image of the actual machine at dept. BE63730. Right: Image from Adcole homepage.

The data points of the roundness traces correspond to radial deviations from a fitted circle and do not contain information regarding diameter or origin offsets. Hence, more information is needed in order to construct a consistent surface map. The measured diameters and origin offsets compared to the axis of rotation are reported in a separate pdf file, but the resolution of the data is somewhat too coarse to give a smooth surface, though the stated precision is ±0.5µm in radial coordinates. Therefore, also four straightness traces, with 90° spacing, are measured on each journal covering the length between the front and rear measured roundness traces. These axial traces allow for a better and more fine-grained fitting of the roundness traces, though the straightness traces do neither contain diameter information in themselves.

As shown to the right in Figure 2, the measurement gauge is shaped like a blade, which in itself gives a certain degree of mechanical filtering. A Gaussian filter with 500 undulations, or oscillations, per revolution is used, which is the highest one available in the measurement software.

Unfortunately, all measured data cannot be stored in the machine memory for each crank, so a manual file readout is necessary between every journal before the memory is flushed, which makes this type of measurement quite work-intensive. In total, one crankshaft may take up to one shift of work and can therefore only be performed for special cases.

In the CCMM, the crankshaft is placed with the flywheel end pointing upwards and during measurements, it rotates in the same direction as during engine operation. The zero-degree reference point is pointing towards the angular location of crankpin 1.

Each of the measured traces has 3600 data points, both for the roundness and the straightness traces, and are provided as individual text files with 3600 rows each. In addition to these text files, a pdf file is attached for each journal, which contains the measured diameter and origin position for each roundness trace, which can be used for assessing tapering, runout, tilt etc.

The local surface shapes are essentially based on the roundness and straightness traces. Since the measurement software fits each trace to an ideal circle from which radial coordinates are given, the main part of the work is to align the individual traces to a common reference cylinder. In short, the following steps are performed for each journal:

1. Straightness traces are derived from the roundness traces at the same angles as where the supplied reference traces are measured.
2. Least square error fitting is then performed of the in-plane origin coordinates and diameters of the roundness traces so that the deviation of the derived straightness profiles relative the measured ones is minimized. When aligned, this gives a set of points that can be plotted as a continuous surface.

The diameters obtained in the previous step are relative diameters based on fitting relative a cylinder. Based on the measured diameters, another round of least square fitting is performed so that any tapering in the measured data is captured. This is done by adding a linear variation of the diameters along the journal so that the least square errors between the measured diameter variation and fitted diameters are minimized. In this step, the two rear and front traces are omitted since the data towards the radii becomes irrelevant.

Since no diameters are available for the used crankshaft when it was new, that wear type is unknown.

- Main 3 showed very little wear overall.
- Main 5 showed more wear towards the front side of the bearing. The bearing tends to be oval in geometry at that side, up to 8µm in diameter. This is for sure a wear pattern.
- Pin 3 showed wear at 230°-320°, up to 5µ radially at this position. This indicates a wear pattern. However, there’s uncertainty regarding the general condition of the bearing as it has started to seize.
- Pin 5 showed clear wear at 90°- 150°, up to 5µ radially at this position.

It´s clear that the pins are more affected by wear than the mains. The positions of the wear on the pins also correspond well to the 120° split between Pin 3 and Pin 5. The possibility to create surface maps of the journal shapes provides a good possibility to illustrate the shapes and get a deeper understanding of what the product looks like. The method is also useful as a tool to examine shafts from the field to see, for example, the wear patterns over time. However much more measurements are for sure needed to get a complete picture of this.

6.2 Surface texture and its effect on friction

The consequences of energy inefficiency in the automotive industry are not only the overuse of unrenewable resources but the pollution created by CO_2 emissions. These emissions are caused by the usage of fuel and energy necessary to compensate for friction and part remanufacture and transport. For heavy-duty vehicles as of 2014, only 34% of the total fuel usage is translated into vehicle motion, and the rest was lost on overcoming friction and parasitic frictional losses. Researching solutions to decrease friction in the automotive industry proves to be a core factor in moving towards a more sustainable industry on all layers of transport: public, private, and logistics.

The environmental, economic, and social future depends on changes performed now for the better. In this sense, tribology holds vital importance to reduce the energy losses produced by unwanted friction. Surface texturing becomes, as a result, one of the main subjects of study to implement solutions in the manufacturing industry in this regard. If applying different texture patterns on surfaces affects the coefficient of friction, the question then becomes: How do these textures affect friction? How can these findings be used to control friction in the desired way?

Widening the possibilities for research on surface texture is one of the main motivations of this work. Acquiring an understanding of how different textures affect the coefficient of friction and theorizing about the reasons this happens opens the door to more concrete research. Optimizing operating conditions, choosing adequate texturing methods, or observing the response of specific textures against different lubrication regimes are some of the studies that can derive from a grounded project like this one.

Through testing, measuring, and analysing three different surface textures, the thesis aims to identify the texture properties that translate into a response in friction. Moreover, tribological performance is a more general object of study that not only includes friction but also surface wear and lubricant film behaviour. These three key components contribute to tackling the energy inefficiency problem.

In addition, even though there is extensive research on the benefits of precise micro-texturing design, certain users do not have the resources to use the equipment that these texturing methods require, due to being costly. Texturing achieved through abrasive methods is the more affordable alternative and thus assessing its relationship with friction is a global necessity.

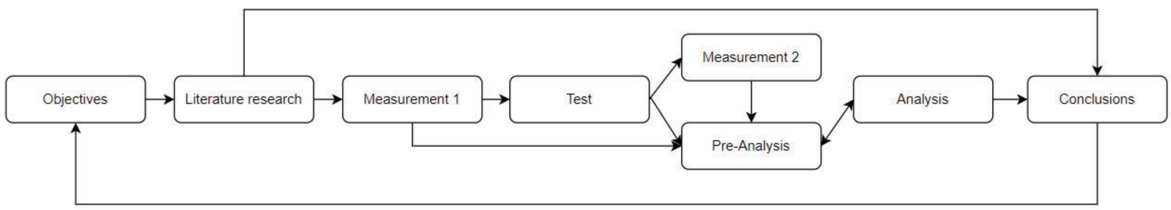

Figure 3. The flow diagram for the tests.

The bases followed in this thesis as a methodology are separated into the measurement process, the tribotest, and the analysis process. The methods will adapt to the needs and resources available with a focus on maintaining a clear and structured workflow, allowing a certain degree of iteration within the processes. At the end of the project, it should be possible to reflect on the initial goals and compare them with the conclusions using the same standards set in the beginning. This means that a flexible or adaptative methodology does not entail the constant change of criteria to achieve the initial expectations.

Scope of the tests

Several delimitations are defined for this purpose:

- Three surface textures are analysed. Two of them have a circumferential pattern with coarse and fine textures, after grinding and polishing. The third surface has a crosspatch pattern achieved by transversal grinding.
- All tribotests run keep the same experiment conditions, only varying the disks and changing the pin when all three textures of the same type have been tested.
- The analysis of the lubricant oil is limited to studying film thickness, the film parameter, and their relationship with the surface and friction. Thorough observations on the lift, pressure generation, or detailed fluid dynamics are not included.

Experiments

The three textured surfaces are machined on disks displayed in Figure 4. The textures are applied to the outer ring after hardening. The hardening treatment consists of 16MnCr5 carburized gear steel, a case depth of 1mm with a surface hardness of 60 ± 2 HRC. The outer diameter is 46 mm. The first texture corresponds to a crosspatch pattern achieved by employing a transversal grinding method. The other two textures correspond to the same type of pattern, a circumferential texture with rings concentric to the disk, but achieved by a grinding method and a polishing method.

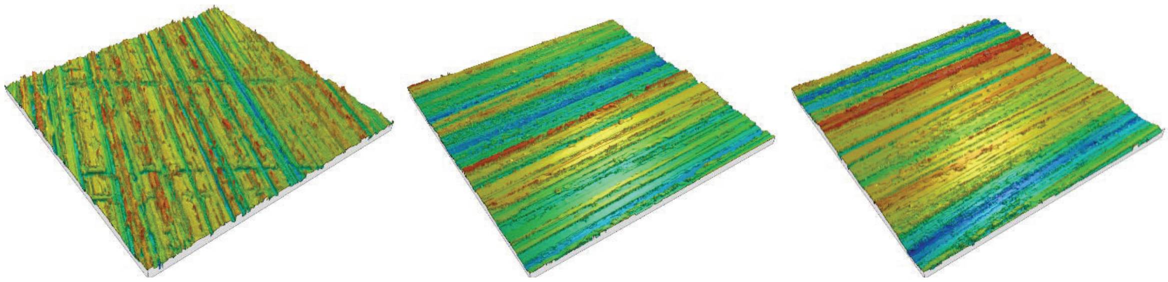

Figure 4. The crosshatched, circumferential polished, circumferential ground surfaces use for tests.

A total of three pins were used on the tests and analyzed further. The pins have a partial sphere geometry of radius 50 mm and hardness 63 HRC. Nine disks were tested on three types of surfaces. Three types of disk surfaces were measured, tested, and analyzed. In addition, the pins used for the pin-on-disk tribotest were also measured after testing.

Tools and measurement setup

The tool used to perform the topographic measurements was an optical profiler, with model Zygo NewView 7300 (Figure 5), that uses white light interferometry to capture data from the sample's surface. Magnifications used x10 and x50.

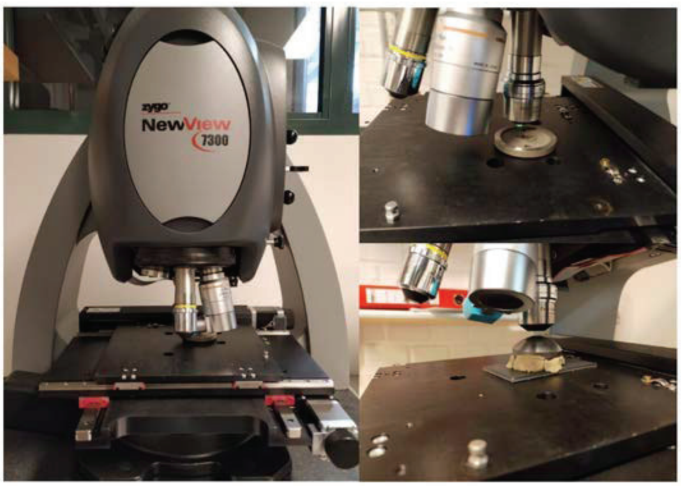

Figure 5. The optical profiler tool used to scan all surfaces (left), the disc positioned for measuring(top right), the pin fixture to facilitate orientation (bottom right).

In every surface type involved in the process, twelve measurements were performed. Because only one disc per surface was measured for untested disks, the twelve measurements are divided into four areas where three measurements are conducted on different spots as shown in Figure 6 (left). Because the tested discs consist of three discs per type of surface, only four measurements were performed on each of them. This time, five images were stitched transversally across the surface in four different areas using an x10 magnification.

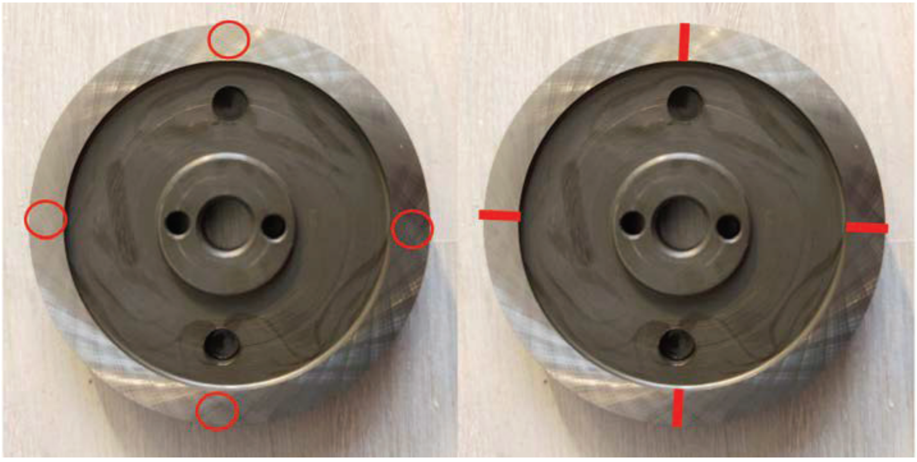

Figure 6. Marks where three measurements were performed (left), and four areas were generated by stitching five images (right).

The groove on the surface caused by wear during the test is in the centre of the surface and concentric to the disk. First, it was necessary to find the centre of the groove to extract samples from it. The waviness profile of the stitched image allows for finding the exact location of the wear scar.

Unavoidably, slight deviations from total horizontality when orienting the disk before measuring affect the scanned image and the effect multiplies when stitching five images with the same deviation. Figure 7 displays how subtracting a plane generated by the least squares method levels the surface area to correct this defect, as well as how a Gaussian filter was applied with a cut-off length of 0,08 mm so that the S-F component could be extracted, making the groove observable.

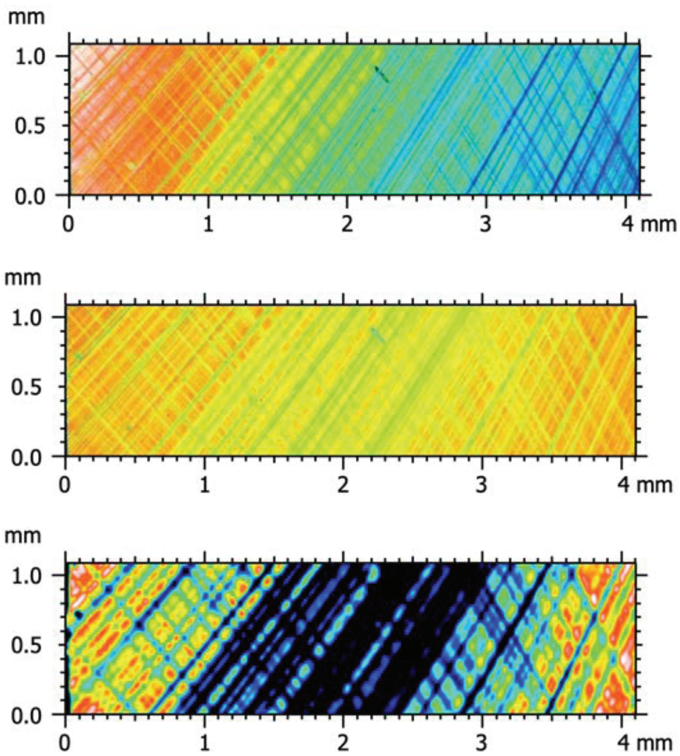

Figure 7. Original image (top), levelled image (middle) and waviness component (bottom) used to find the groove.

The experiment consisted of a pin-on-disk tribotest that aims to remain unchanged in all controllable variables and only modified the disk used on each run. The testing equipment sampled the tangential force between the disc's surface and the pin and calculated the coefficient of friction by computing the load included in the setup. The discs and pins used are shown in Figure 8. The lubricant used was a 20w50 mineral oil with a kinematic viscosity of 124 cSt at 40ºC and a density of 886 kg/m^3 at 20ºC.

Figure 8. From left to right, circumferential rough, circumferential smooth, crosshatched surface and the pins used during the tribotest.

The pin-on-disk test performed contained several elements in its setup. The disk was placed inside a rotatory plate and in an initial 50 ml oil bath. The pins were fixed in a holder as shown in Figure 9 and placed directly on the disc.

Figure 9. The pin-on-disc tribotesting machine setup.

6.3 Modelling and simulation of stratified surface textures

Investigation of surface texture's effects under lubricated conditions is one of the main objectives of this study. According to published works, under the lubricated condition, the surface texture could bring additional hydrodynamic pressure to enhance the carrying ability of the lubricant film. The texture's section shape, depth, and other geometric features significantly influence the additional hydrodynamic pressure generation. Having a better understanding of the pressure generation mechanism is necessary.

CFD simulation regarding single texture pattern pit

CFD simulation using a single texture pattern pit is conducted to investigate the pressure generation mechanism. The 3D models were built with different texture section shapes, as shown in Figure 11. A 3D model without texture is built as the reference, see Figure 10. The relative motion of two surfaces is mimicked with the flow of the lubricant, as shown in Figure 11. Thermal transfer is not considered. The distance between two friction pair surfaces (film thickness) is 10 µm as well as the depth of the texture pit. The inlet and outlet lubricant flow are constant at 0.0001 kg/s.

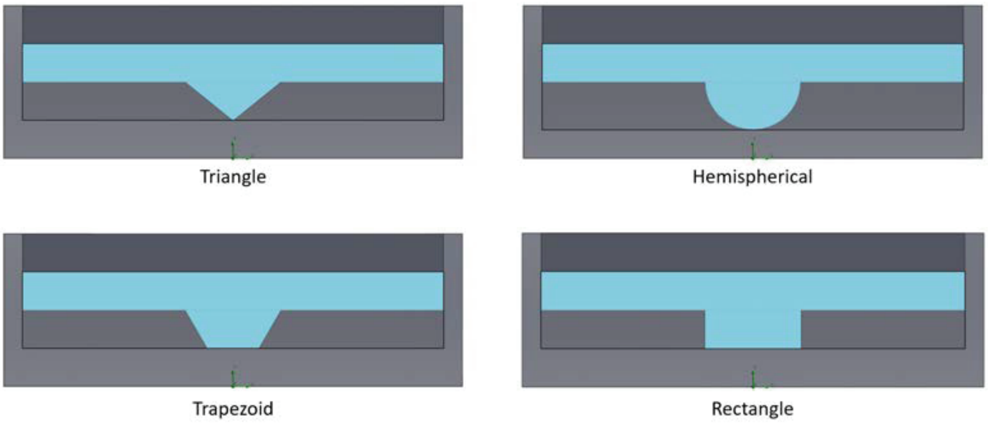

Figure 10. Sections of different single texture pattern pit.

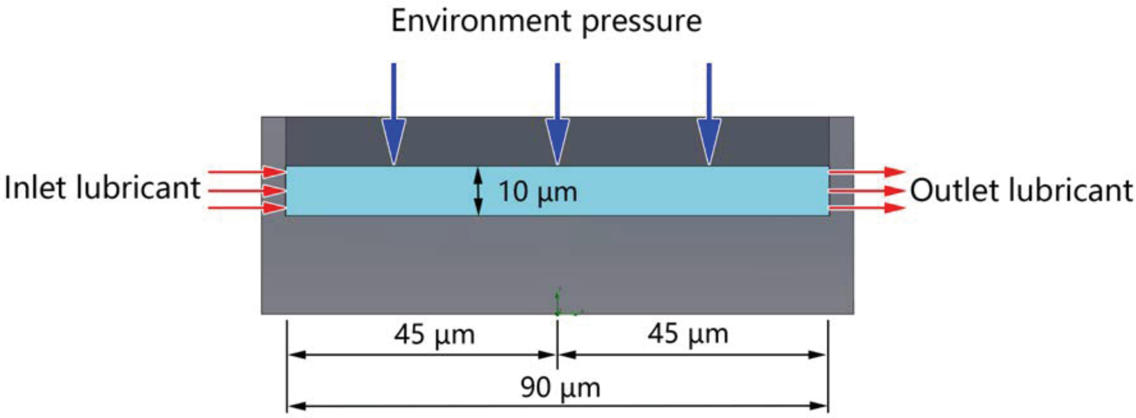

Figure 11. Reference model and boundary conditions.

The simulation results regarding the pressure distribution are shown in Figure 12. Each line indicates the pressure difference between the texture pit and the non-textured surface. The pit in a semi-circular shape shows higher and more stable additional pressure generation. The triangle shape shows a good result as well. The significant drop in the pressure for the Trapezoid and Rectangle shapes may be due to the cavitation, more investigation is needed. As a preliminary study, the CFD simulation regarding a single texture pattern pit provides a reference for texture design and choosing a proper texturing method.

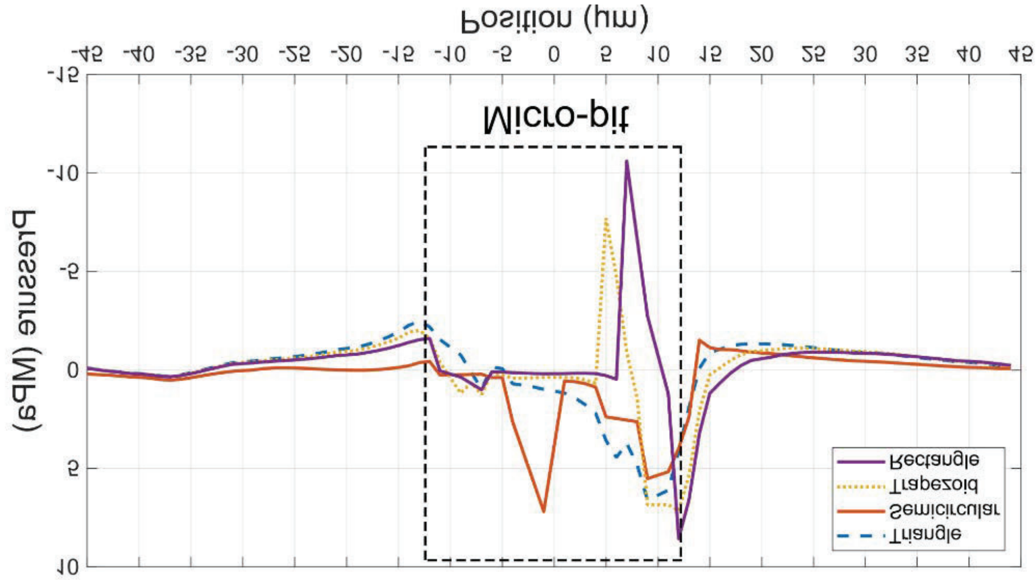

Figure 12. Comparison of pressure difference.

As an improvement of the simulation, the edges of the texture pit are modified with fillet which is closer to reality. The simulations using a modified model are progressing.

CFD simulation regarding texture generated by grinding processes

Textured grinding wheels could be used to generate texture on object surfaces in grinding operations. The groove array is the most common texture which could be generated in a grinding operation. In this study, CFD simulation using groove-textured surfaces is conducted to investigate the effect of the angle between staggered grooves in additional pressure generation. To have a reasonable calculation time, the simulation was simplified by picking a small area of the tribology test disk, as shown in Figure 13.

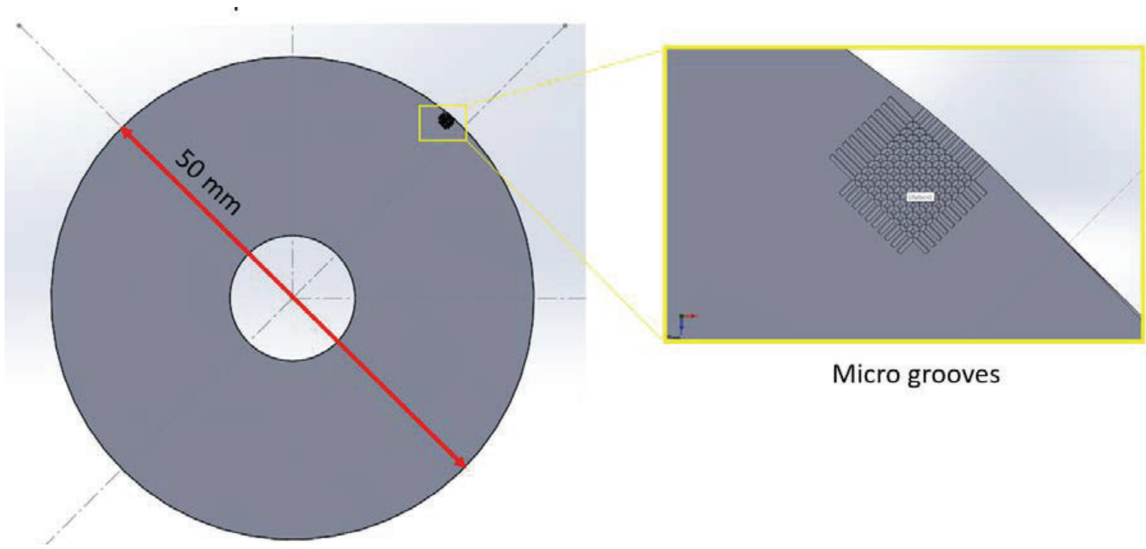

Figure 13. Disc for tribology test.

The 3D models are built with staggered grooves by different angles on the surface, as shown in Figure 14. The groove's width and depth are 20 μm and 10 μm respectively. The angle between staggered grooves is designed as 30º, 60º, 90º, 120º and 150º. Thermal transfer is not considered as well. The distance between two friction pair surfaces is 10 μm. The inlet and outlet lubricant flow is set constantly.

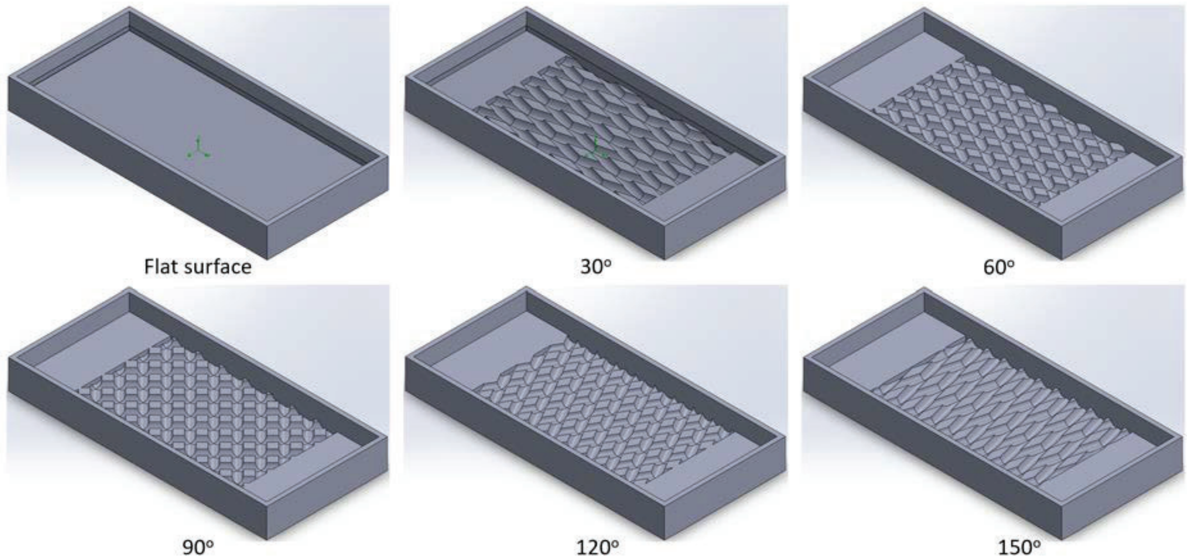

Figure 14. The 3D models with various angles between staggered grooves.

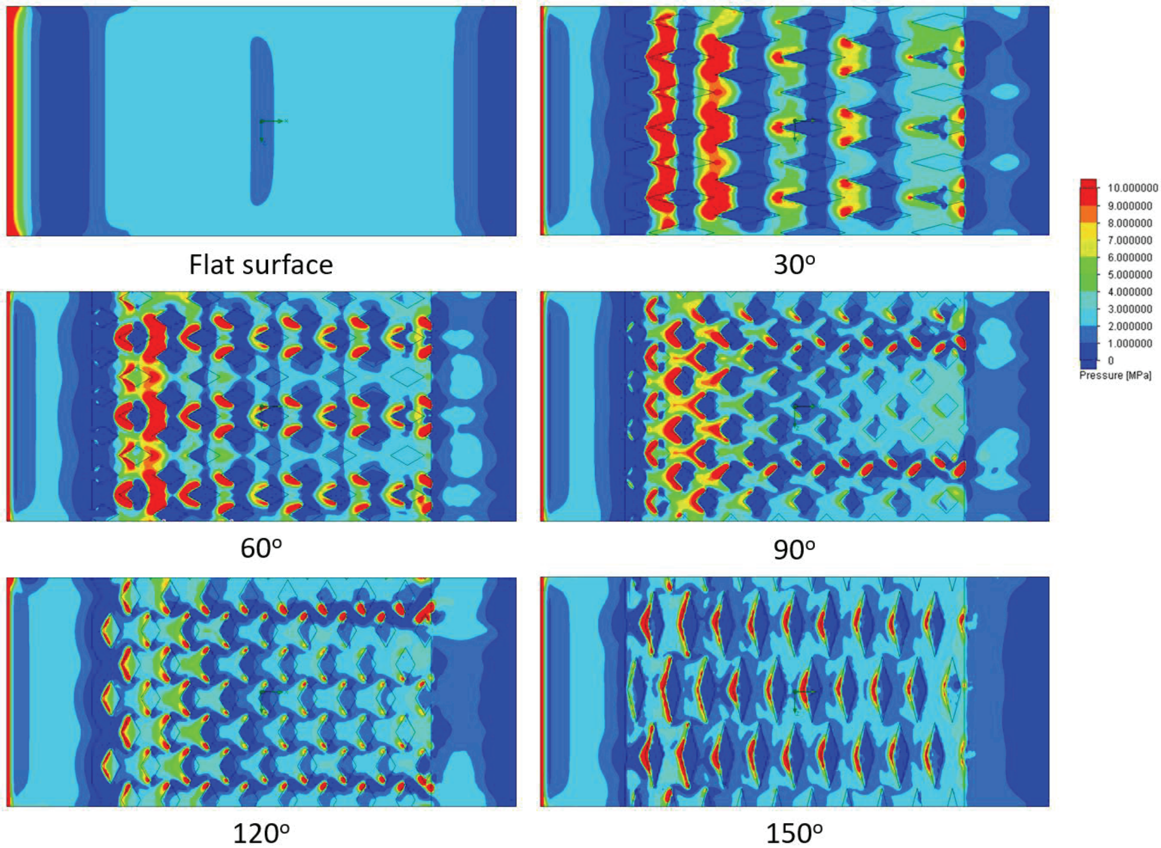

Figure 15. Pressure distribution varies the angle between staggered grooves.

Figure 15 shows the pressure distribution with different grooves' angles. By changing the angle, the pressure generation and distribution are changed obviously. With further investigation, the result could be a reference for texture design regarding grooves angle. The angle 60° could be a good candidate for further simulation with different grooves width (15~30 μm).

In addition, the mesh sensitive simulation is going to perform soon. Compared to the single texture pit simulation, a larger calculation domain, and more mesh cells need to be considered in the current simulation. To have a reliable and less time-consuming model is important, and it depends on the proper mesh strategy. In that case, the mesh-sensitive simulation could be a reference for choosing the proper mesh strategy and a suitable number of cells.

Different type of texture dimples was modelled and tested over the simulation. Five basic dimple shapes are designed and modelled, including a circle, square, ellipse, trapezoid and triangle.

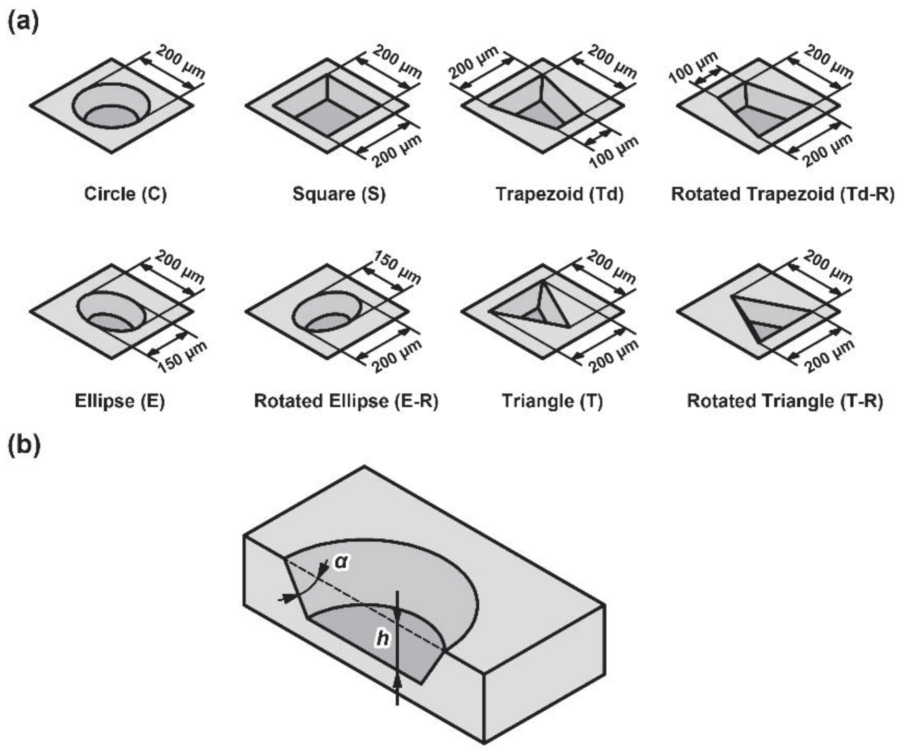

Figure 16. a) Designs of the dimples with different shapes and (b) the definition of dimple surface angle α and dimple depth *h*.

The simulations were performed with different dimple shapes, dimple depths, minimum film thickness, dimple densities, and dimple surface angles.

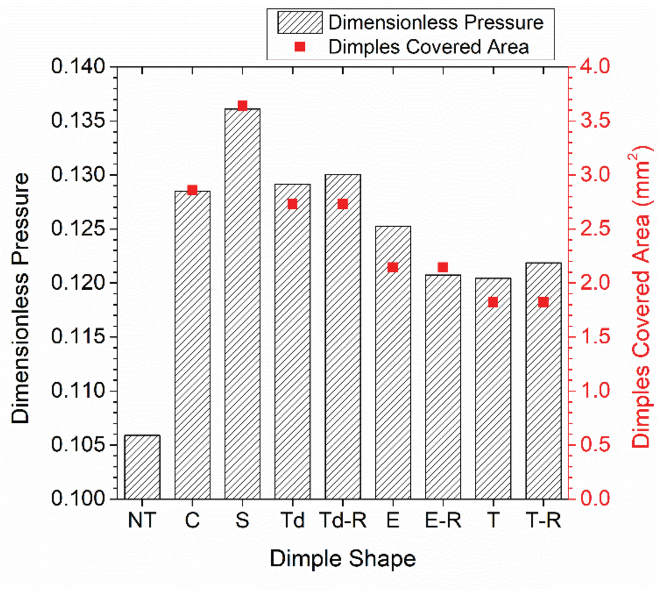

Figure 17. Comparison of average pressure on the top surface of the model for the different dimple shapes: non-textured (NT), circle (C), square (S), ellipse (E), rotated ellipse (E-R), trapezoid (Td), rotated trapezoid (Td-R), triangle (T), rotated triangle (T-R).

By considering pressure generation, the square dimples should be the optimal solution for the surface texture with dimples. Several published numerical surfaces texturing studies use square dimples. However, if we aim to utilize surface texturing in large-scale, industrial applications, texturing efficiency and cost should be considered as well. If efficiency and cost are considered, the circle dimple is the most suitable candidate for further study because, compared to the other dimple shapes, circle dimples can be fabricated using many texturing processes, including micromachining, and on large-scale surfaces easily and quickly. It is foreseeable that circle dimples have more potential to be applied in the industry compared to other shapes.

Dimple depth is a vital factor for surface texture design because different dimple depths change the texturing processes, cost, and wear of the surface. Shallow dimples may wear out quickly, but deep dimples may negatively influence the strength of the part itself. Choosing a proper dimple depth is important in applications of dimple texture.

Figure 18 shows the average pressure on the top surface of the model for each dimple depth and minimum film thickness H_{min}. When H_{min} is 10 µm, the pressure increases with an increase of dimple depth until 10 µm; then, the pressure decreases as the dimple depth becomes deeper. In addition, with a larger H_{min}, pressure increases due to the dimpled texture being gradually minimized. When H_{min} is 30 µm, the maximum pressure difference for the non-textured and textured cases is less than 3%. As shown in Figure 18, for all four lines, the highest pressure is shown when the dimple depth is 10 µm. Only for H_{min} = 10 µm (black line) is the optimized dimple depth close to the minimum film thickness. However, when H_{min} = 20 µm (blue line) or 15 µm (red line), a slight change of the pressure varying dimple depth from 5 to 20 µm is observed.

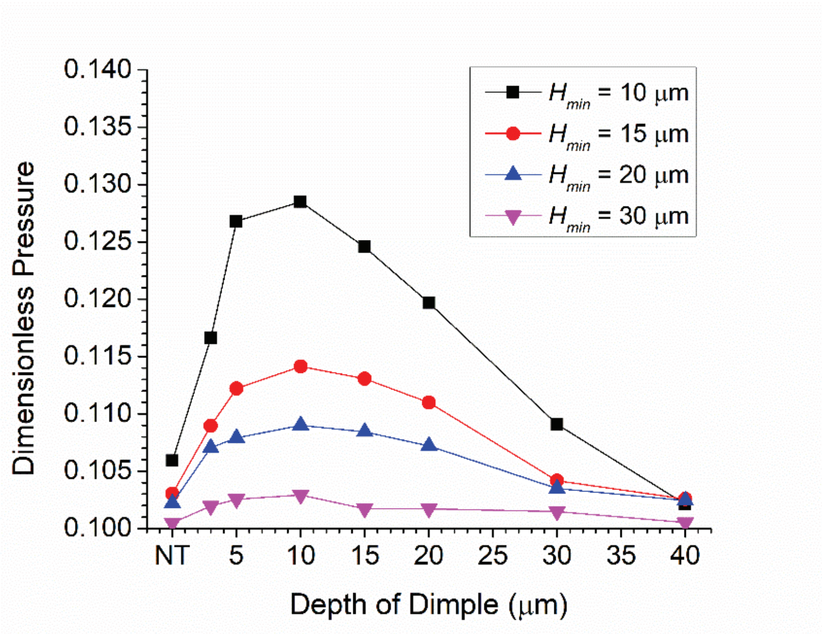

Figure 18. An average pressure of the model top surface regarding different dimple depths and film thickness.

Table 1. Comparison of different dimple depths

Case	**Range of depth**	**Average depth**	**Dimensionless pressure**
a	10 µm	10 µm	0.128
b	9~11 µm	10 µm	0.128

c	7~13 μm	10 μm	0.128
d	5~15 μm	10 μm	0.127

Dimple surface angle α is introduced to represent more accurately the geometric features of dimples using a simplified three-dimensional model in this study. The surface angle mimics a real dimple bottom surface profile with an acceptable simplification, which is easily utilized in numerical studies to investigate the dimple surface texture effect. It is important to understand how this factor influences additional hydrodynamic pressure generation.

To investigate the influence of dimple surface angles, 9 sets of dimple surface angles varying from 90° to 7.5° are applied in the simulations. Figure 19 shows the pressure distributions on the bottom surface of the model for varying dimple surface angles. Pressure does not significantly change as the dimple surface angle decreases from 90° to 30°, at which point, the pressure drops rapidly as the dimple surface angle gets smaller.

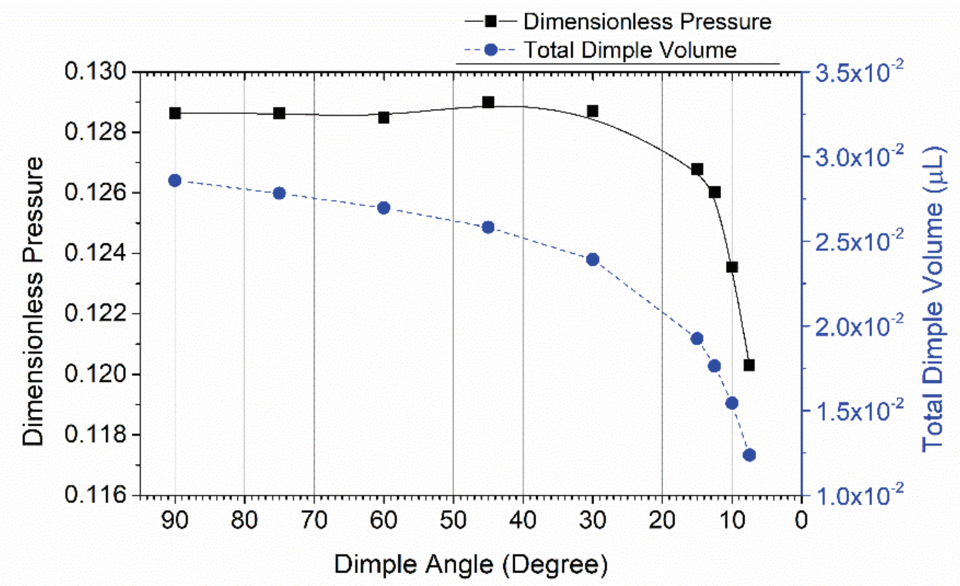

Figure 19. Pressure distribution of model top surface regarding different lubricant film thickness and dimple angle.

However, it is noted that the dimple surface angle can be changed from 90° to 30° without a significant reduction in hydrodynamic pressure generation. This result is important for texturing dimples using lasers and micromachining tools because there is no need to restrict the dimple bottom profile. In the laser texturing process, the dimple bottom profile may relate to the laser beam profile types, output power, workpiece material, etc.

Conclusions

- The dimple texture effect increases linearly as density increases.
- An optimal dimple depth is identified with a certain minimum film thickness. In this study, 10 μm is an optimal value when the minimum film thickness is 10, 15, 20, and 30 μm.
- As the minimum film thickness increases from 10 to 30 μm, the effect of dimple texture is minimized.
- The introduced dimple surface angle influences the dimple texture effect. The most significant changes occur when the dimple surface angle is smaller than 30°.

6.4 Surface texturing via grinding

In the study, a costumed CNC grinding machine with a dressing tool is used to create patterned grinding wheels, the patterned wheel could be used to transfer the texture to the object surface.

In general, the texture which has been verified could reduce the friction on a micro-scale. However, according to the published papers and simulations, the largest size of the pattern is around 100 microns. In addition, there is no evidence provided by the presenter for friction reduction even in the test results. They may still be working on the tests. We have reason to believe they met challenges in the verification of their texture friction reduction. In conclusion, grinding texturing has the potential to be a green, low-cost way to generate a textured surface.

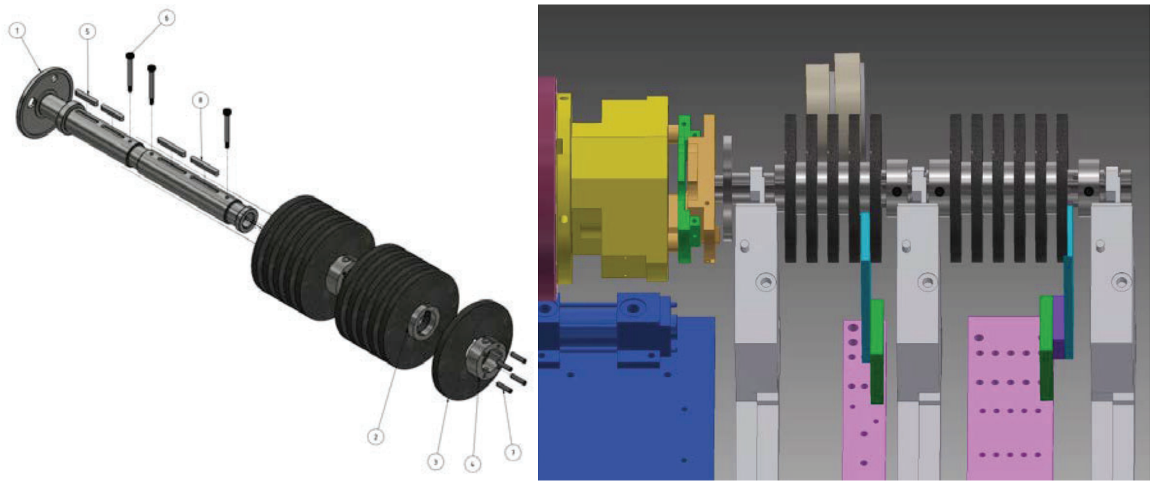

Figure 20. LEFT: Special fixture design for rotary samples, RIGHT: Fixture model in the grinding machine.

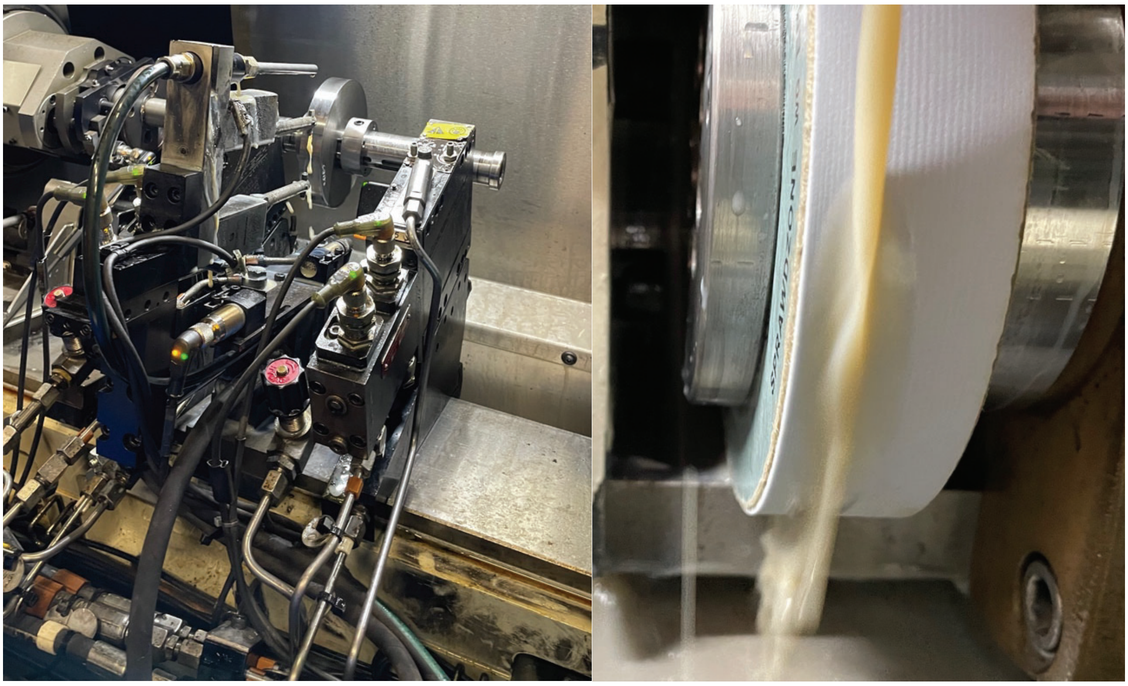

Figure 21. LEFT: Fixture for rotary samples in the grinding machine, RIGHT: Grinding wheel after texturing attempt.

However, the dressing process and texturing process need an additional specific device, a high-precision motion stage, and a grinding machine. Moreover, the grinding process has a vital drawback which cannot be ignored, the texture size cannot fully meet the demands of texturing for reducing friction (micro texturing). The kinematics for the texturing purpose is very complex and not easy to implement (program) on the CNC grinding machine.

Most of the content and pictures come from the published paper. A fully developed specific grinding dressing mothed, evaluation and producing technique is introduced. Different patterns could be generated with patterned grinding wheels, including grooves, dimples, and other uniform patterns.

1. Most of the textures which developed by other researchers currently are in micro-scale, all the texture patterns in your works are in mm. Is it possible to generate micro-texture with the patterned grinding wheel?

It is quite hard to generate a micro-texture, the texture only could produce in mm. Due to the grinding wheel's RPM and the grinding wheel material, the RPM cannot be too high. The feature size is recommended by the industry partner, so there is no pattern size-choosing process. I suggest you start with dimples texture and CFD simulation for your project.

2. Have you done any tribology tests or friction tests with the texture?
   We have done a hydrodynamic tribology test, the results are good, and our goal is to reduce 30% of friction for the engine shaft friction pair.

6.5 Success story

Modelling and simulations allowed deduct that stratified surface texture can prevent significant surface wear in engine components. It was important to verify the dimples depth effect on the hydrodynamical lift. One of the partners tested different textures and successfully implemented a textured surface in one of the highly loaded components. Due to competitiveness policy, the final surface texture cannot be presented in this report. However, some indications and simplifications for presentation purposes.

The problem was defined as follows:

- A dynamic bushing seal is made today in a Cu alloy.
- One of the flat surfaces in the bushing is in contact with a shaft while it rotates.
- The latest iteration of the system containing the bushing is experiencing excessive wear.
- The cause of failure is a mixture of changed system conditions and longer life-timespan requirements (Figure 55).
- Texturing of the bushing was studied as a possible improvement/solution.

Figure 22. Left: Wear NOK (O-ring removed), Right: Wear OK.

General description of the conditions

The bushing causes a pressure drop on the sealing surface. There is a net force pushing the bushing towards the shaft due to the difference in pressure. The shaft is fixed axially. The bushing can freely glide in the axial direction (with some resistance from the O-ring friction). A test was developed to simulate the worst conditions for the bushing, each test lasts 24 h + mounting/dismounting. The test represents 50% of ONLY the worst cycles the bushing should see during a regular endurance test (3 months).

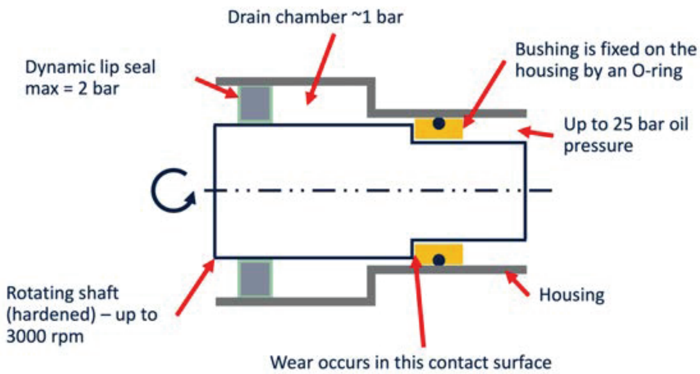

Figure 23. Tested sub-system with bushing.

- Different textures were applied on the bushing to investigate their effects on the wear rate.
- Mass loss of the bronze bushing before and after testing was used as a means to evaluate the wear resistance.
- Many variants were tried. 3 of the more successful are shared.
- Simulations of these textures were not possible.
- Manual grinding and laser engraving.
- P80: coarse grinding + polishing step to flatten tops (manual).
- S80: Coarse grinding.
- Laser: fine grinding + laser engraving.

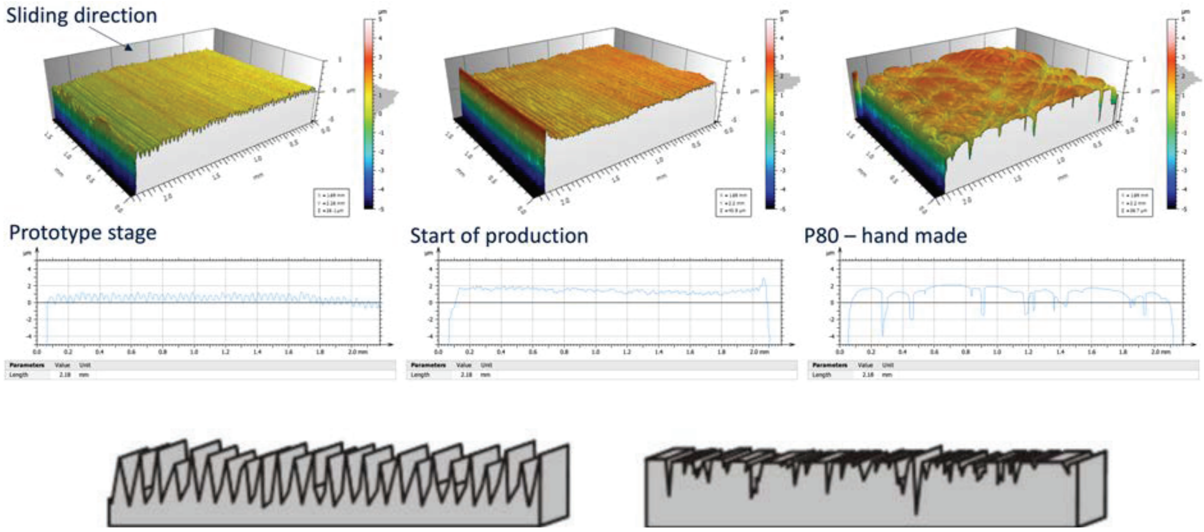

Figure 24. Different surface textures for wear test measurements.

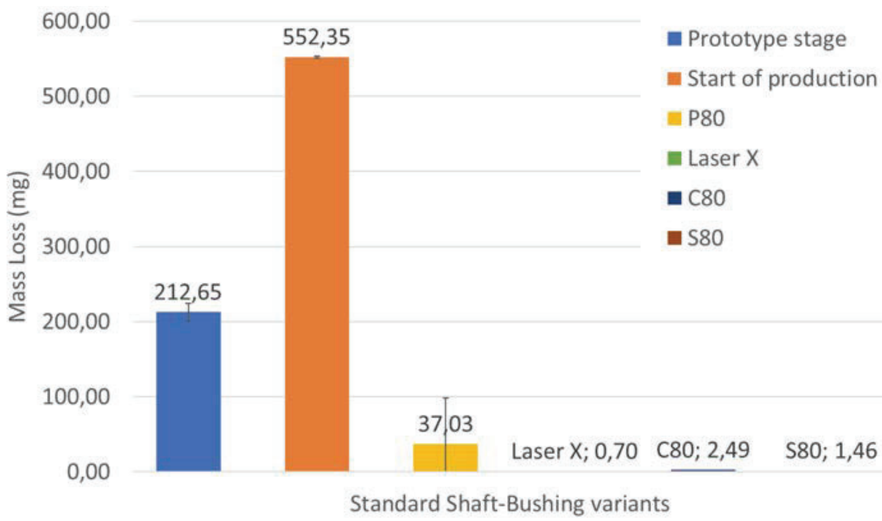

Figure 25. Mass loss distribution in relation to surface texture type.

Laser X after Wear

- Sliding in the tops.
- Oil can reach the whole surface and contribute to cooling and lubrication.
- The sealing function is not affected.

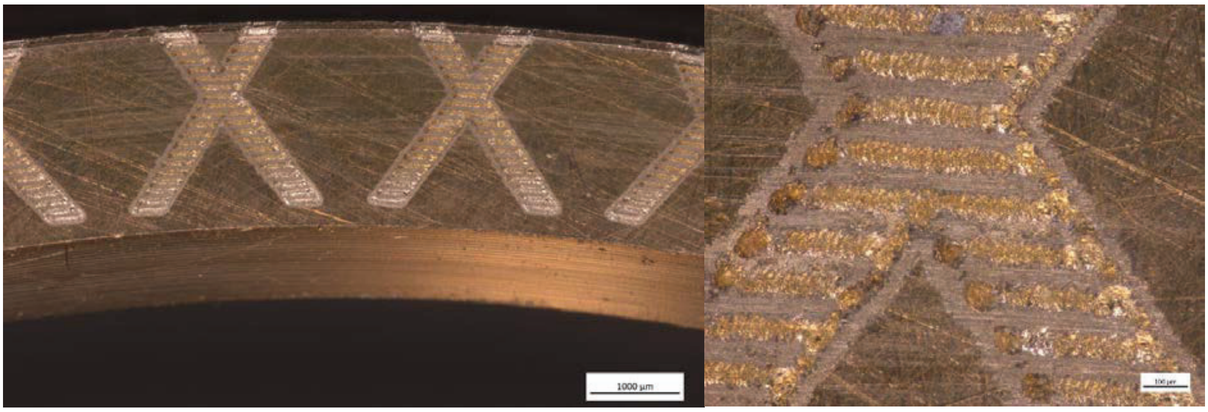

Figure 26. Laser textured bushing surface with an X-like pattern.

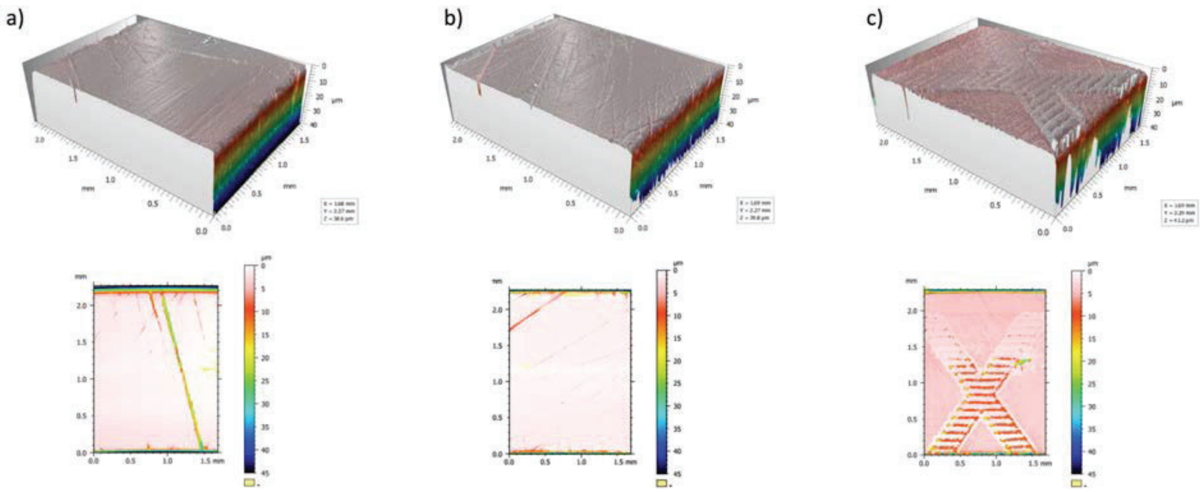

Figure 27. a) P80-3, b) S80, c) Laser texture

Conclusion

- Scuffing damage was present to different extents in all bushings.
- Not all textures are beneficial. Turning finish is detrimental, while crosshatch grinding showed great improvement in the wear rate.
- There seem to be very good results by having a texture that can retain oil on the surface but that is not oriented in the direction of rotation.
- The improvement from the laser texturing seems to come from allowing more oil in the sliding surface.
- CFD simulations for examining the effect of different textures are needed in future work.

6.6 Summary

The project met many obstacles on the way but mostly was affected by the pandemic worldwide situation. Nevertheless, the team was able to achieve most of the goals set for the project and even have one success story. The outcomes of the project are summarized below.

The dimple shape greatly influences the dimple texture effect. Squared dimples generate the highest additional pressure build-up. However, considering the feasibility of the texturing process, dimples with a circle shape have greater potential to be applied on a large scale.

- The dimple texture effect increases linearly as density increases.
- An optimal dimple depth is identified with a certain minimum film thickness. In this study, 10 µm is an optimal value when the minimum film thickness is 10, 15, 20, and 30 µm.
- As the minimum film thickness increases from 10 to 30 µm, the effect of dimple texture is minimized.
- The introduced dimple surface angle influences the dimple texture effect. The most significant changes occur when the dimple surface angle is smaller than 30°.

In general, the texture which has been verified could reduce the friction on a micro-scale. However, according to the published papers and simulations, the largest size of the pattern is around 100 microns. In addition, there is no evidence provided by the presenter for friction reduction even in the test results. They may still be working on the tests. We have reason to believe they met challenges in the verification of their texture friction reduction.

In conclusion, grinding texturing has the potential to be a green, low-cost way to generate a textured surface. However, several obstacles are on a way. The most difficult part is designing the dressing process of the grinding tool to provide desired surface texture. Therefore, the texturing process needs an additional specific device, a high-precision motion stage, and a grinding machine. Moreover, the grinding process has a vital drawback which cannot be ignored, the texture size cannot fully meet the demands of texturing for reducing friction (micro texturing). this is due to the grinding wheel's complex structure and the kinematic grinding process.

For the test conditions of this project, the crosshatched texture yields the lowest coefficient of friction, followed by the circumferential smooth texture, and the circumferential rough texture is the one with the highest friction. However, the lowest and highest values of wear and the lubricant film parameter, respectively, are achieved by the circumferential smooth texture. None of the considered surface parameters shows a strong correlation with the obtained friction values. The developed interfacial area ratio *Sdr* is linearly correlated with the film parameter, as well as the ratio *Svk/Spk*. Additionally, the interaction between *Sk* and *Sdr* has a second-degree correlation with the friction coefficient. The phenomena behind these correlations cannot be explained or confirmed by the pin-on-disk tests performed. Even though the crosshatched texture yields higher wear than the circumferential smooth one, the volume of wear presented in the pins is higher for the circumferential smooth.

The project success story of laser texture surface proved that stratified surface texture greatly influences the engineering system behaviour. The experimental test confirmed developed models and numerical simulations, that the depth of the texture dimples cannot exceed 15 micrometres to keep the hydrodynamical effect. Moreover, the textured surface significantly increased wear resistance, which is an effect of the hydrodynamical effect of the texture and keeping steady film oil thickness between mating surfaces.

Achieved outcomes of the project are aligned with FFI Hållbar Produktion program and can positively impact the sustainability goals by improving the longevity of components. The work on surface functionalization will be continued with some of the partners from the FriText consortium. Proper and controlled surface functionalization is in high demand, especially for electrification purposes, contributing to circularity and net zero emission.

7 Spridning och publicering

7.1 Kunskaps- och resultatspridning

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	X	
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	
Föras vidare till produktutvecklingsprojekt	X	
Introduceras på marknaden		
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut		

7.2 Publikationer

1. Wei, Y.; Tomkowski, R.; Archenti, A. Numerical Study of the Influence of Geometric Features of Dimple Texture on Hydrodynamic Pressure Generation. *Metals* **2020**, *10*, 361. https://doi.org/10.3390/met10030361
2. Bergseth E., Zhu Y., Söderberg A., Study of surface roughness on friction in rolling/sliding contacts: ball-on-disc versus twin-disc, Tribology Letters 68, 69 (**2020**)
3. Wei, Y.; Resendiz, J.; Tomkowski, R.; Liu, X. An Experimental Study of Micro-Dimpled Texture in Friction Control under Dry and Lubricated Conditions. *Micromachines* **2022**, *13*, 70. https://doi.org/10.3390/mi13010070
4. Krumins A., Bergseth E., Olofsson U., Towards gearbox fault diagnosis based on data fusion of multi-physical measurements, presented at NordTrib **2022** conference 14-17th June, Ålesund, Norway.
5. Ellen Bergseth et al, Test with different surfaces and low viscosity oils in an FZG test rig with efficiency setup", presented at Tribology Days, 22-23 November **2022**, Göteborg, Sweden.
6. Krajnik, Peter, Fukuo Hashimoto, Bernhard Karpuschewski, Eraldo Jannone da Silva, and Dragos Axinte. 2021. 'Grinding and Fine Finishing of Future Automotive Powertrain Components'. *CIRP Annals* 70 (2): 589–610. https://doi.org/10.1016/j.cirp.2021.05.002.
7. Miguel Ángel Valdivieso Muñoz, Effect of the Textured Surface on Friction Coefficient, KTH, *Master Thesis*, **2022**, TRITA-ITM-EX ; 2022:37, diva2:1642830

8 Slutsatser och fortsatt forskning

The project met many obstacles on the way but mostly was affected by the pandemic worldwide situation. Nevertheless, the team was able to achieve most of the goals set for the project and even have one success story. The outcomes of the project are summarized below.

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The project success story of the laser textured surface proved that stratified surface texture greatly influences the engineering system behaviour. The experimental test confirmed developed models and numerical simulations, that the depth of the texture dimples cannot exceed 15 micrometres to keep the hydrodynamical effect. Moreover, the textured surface significantly increased wear resistance, which is an effect of the hydrodynamical effect of the texture and keeping steady film oil thickness between mating surfaces.

The work on surface functionalization will be continued with some of the partners from the FriText consortium. Proper and controlled surface functionalization is in high demand, especially for electrification purposes, contributing to circularity and net zero emission.

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