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STUDY OF THE EFFECT OF THE ISOTROPIC SUPERFINISHING ON THE SURFACE INTEGRITY OF GEARS

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Abstract: *In recent years, the term "electric mobility" has been the focus of several discussions and studies. The electrification of mobility is seen as a way to minimize greenhouse gas emissions since transportation based on internal combustion engine is responsible for about 15% of the global carbon dioxide emission. Electric mobility is accompanied by tighter surface quality requirements of the transmission gears. Therefore, improvements in surface finishing processes are necessary. Due to the micrometric scale surface correction and the homogeneous distribution of surface loads, the Isotropic Superfinishing process, in which its functionality is linked to chemical embrittlement and later an abrasion process, has been taken as a possible application in electromobility gears. This study's main objective is to evaluate Isotropic Superfinishing's impact on the surface integrity of gears. It is presented a method to assess different conditions of Isotropic Superfinishing in carburized & hardened DIN 20MnCr5 gears, including processing time and abrasive material. For characterization, experiments of geometric evaluations, topography, residual stress, and durability tests were developed. Results showed a significant decrease in surface roughness in two abrasives investigated. On the other hand, one of them showed a higher profile bulging tendency. For the durability tests, simplified samples processed via Isotropic Superfinishing were tested in a rolling contact fatigue (RCF) test rig. They showed a fatigue lifetime of approximately five times higher than the ground samples. Thus, due to the roughness reduction, the Isotropic Superfinishing process applied to gears can offer a higher fatigue life compared to conventional finishing processes. However, the process and its procedural variables must be fully understood not to impair the expected gear profile and thus increase load capacity, fatigue life, and gear efficiency.*

keywords*: Isotropic Superfinishing; Surface integrity; gears.*

1. INTRODUCTION

In recent years, the term "electric mobility" has been the focus of several discussions and studies. The theme is seen as one of the ways to minimize the greenhouse effect since the means of transportation that use combustion engine emits about 15% of the global carbon dioxide emission. Thus, automobiles are expected to increase from 730 million to approximately 1.3 billion between 2006 and 2030 (SCHULHAUSER, 1996).

Given the environmental and market demands mentioned above, there is a need for the automotive sector to adapt. The operating systems must change to meet the requirements of electric mobility, knowing that the introduction of the electric motor raises the maximum speed of approximately 8,000 rpm to at least 12,000 rpm in a short-term scenario, in which it is considered to reach magnitudes of 30,000 or even 50,000 rpm (RENIUS, 2005).

It is clear then that the systems must be evaluated and optimized to attends the needs requested. The transmission system will have a significant influence on the optimization process of automotive engines. Since they are responsible for reducing the route's engine speed, this activity meets the final speed of the vehicle (SCOTT; GÖSSLING, 2021).

The transmission system of a vehicle is responsible for managing the force and power of the engine, serving as a connective of the engine to the wheels. This connection has as its main element the gears responsible for the process of defining the transmission ratio of the system aiming at a better use of the power and thus associated with the speed (HOLZKNECHT, 2008).

The gears are toothed bodies responsible for transmitting movements that can vary according to size, shape, and material. These variables must be parameterized according to the evaluation of motion propagation, highlighting the parameters power, torque, and speed. The type of material to be used must also be considered, as it can optimize the gears' life.

Faced with the need to change the gearing system, the Isotropic Superfinishing process has been taken as a possible application in gears given its surface correction in micrometer scale and, consequently, more homogeneous distribution of surface loads (BRAUER, 2017). Classified as an IGS (Improved Gear Surface) process, Isotropic Superfinishing is a surface correction process whose functionality is associated with a joint action between chemical and mechanical factors, where an oxidizing agent causes a surface oxidation of the material to be removed and then the media, small abrasive particles with defined geometry, effect a mechanical drag that is responsible for drawing the previously oxidized layer. Figure 1 illustrates the processing steps for surface correction via Isotropic Superfinishing (BRAUER, 2017; AGMA2021).

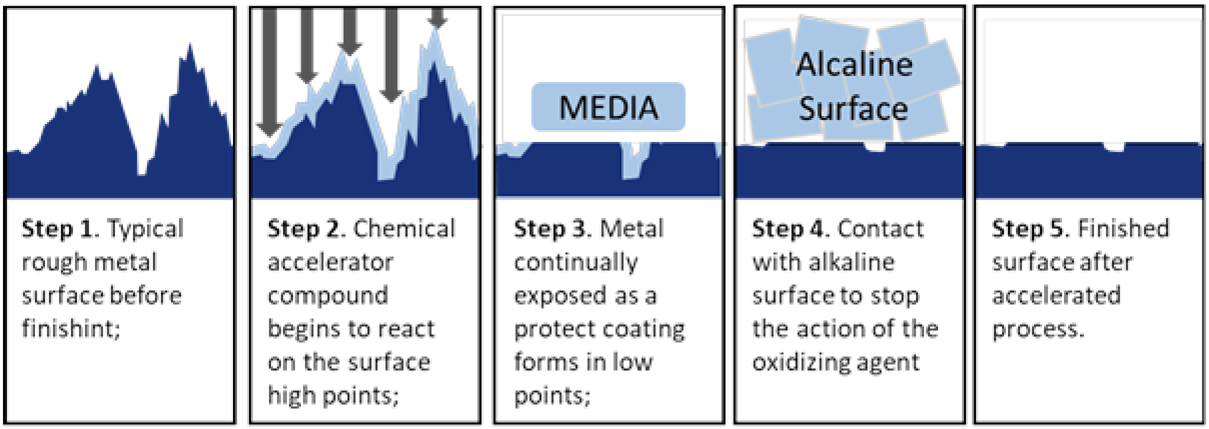


Figure 1 – Isotropic Superfinishing processing.

Applying Isotropic Superfinishing for gears can result in a higher load capacity and transmission efficiency through reduced friction in gear. Despite this, the process still requires further exploration, as it is a relatively new process, not being wholly mastered yet. Thus, the present work aims at understanding the application of Isotropic Superfinishing as gear post-processing. For this, studies of surface integrity characterization and, in some conditions, rolling contact fatigue tests on a Ball-Rod bench were developed.

2. MATERIALS AND METHODS

2.1. Surface integrity analyses

The present study was developed using two geometries to be tested. The first was gears, where main interest was evaluating the feasibility of processing gears in the Isotropic superfinishing process. In other words, to investigate the effect of processing variables and the main impact on surface integrity, studies were developed related to the geometry of the abrasive material used and the exposure time of the process. Figure 2 shows the processing conditions used in the study and the surface integrity tests used. The mode of action between the abrasive material and the gear teeth differs.

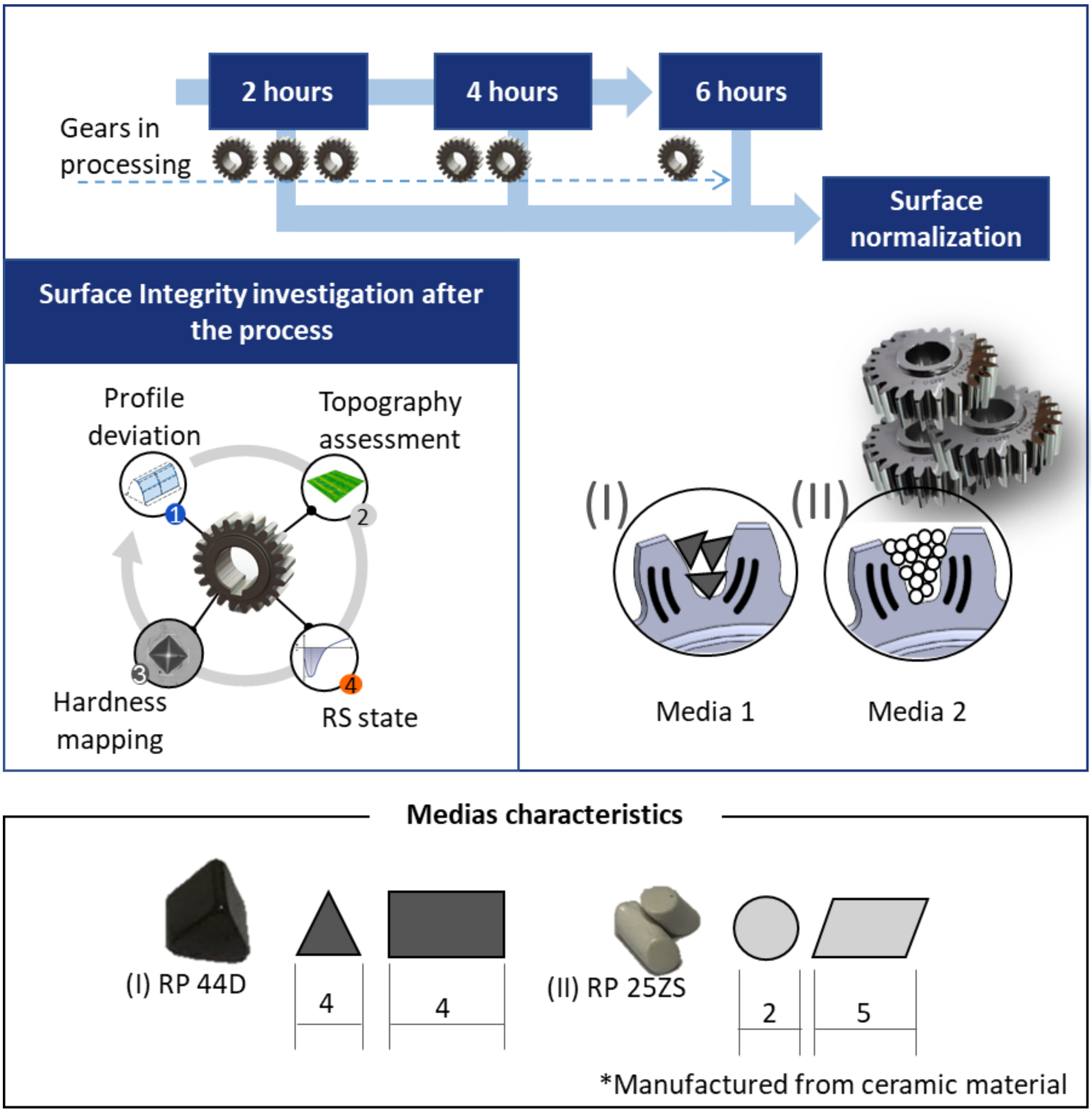


Figure 2: Processing conditions and surface integrity characterization

Roughness and profile deviation were evaluated to understand the effect of Isotropic Superfinishing processing on the gears. These evaluations measured the effectiveness of the roughness reduction processing and what effect it had on the microgeometry of the gears, as extracted parameters for roughness were evaluated:

- Rz: Maximum height of the roughness profile, the sum of the size of the largest valley and the largest peak along the measurement length;

Complementarily to the evaluation of the Rz, it was verified which was the effect of the processing in the specific regions that compose the roughness, peaks, and valleys. This way, the Abbott-Firestone curve was built, and the functional factors were extracted (DIN, 1978). Unlike the roughness factors, it could be linked to the gear usage conditions and evaluated in which regions the process managed to be more effective, peak or valley reduction. In this way, the data investigated were (DIN, 1978):

- Rk: Core height (central region of the topography), the distance between the highest and lowest levels of the surface core;
- Rpk: Reduced height of the peaks, or twice the average height of the peaks located above the core;
- Rvk: Reduced height of the valleys, or twice the average height of the valleys located below the core;
- Mr1: Material ratio (material fraction), Percentage of the material area at the intersection line separating the core peaks from the surface;

- Mr2: Material ratio (material fraction), Percentage of the material area on the intersection line separating the core valleys from the surface.

2.2. Durability tests

Fatigue tests were performed in a test rig of the "Ball-Rod" concept, which reproduces rolling contact loading (GLOVER, 1982). To generate the stresses in the test rig, three balls are in contact with a rod sample in a constant rotation of 3600 rpm.

The "Ball-Rod" test rig is composed of: (1) Five main components acting as fixed supports; (2) Load applicators responsible for transposing the force to the system being tested; (3) Compression springs that create the contact between the rod and spheres and; (5) Spheres that are in contact with the rod perform the test. Figure 3 illustrates a complete view of components and their arrangement on the rig.

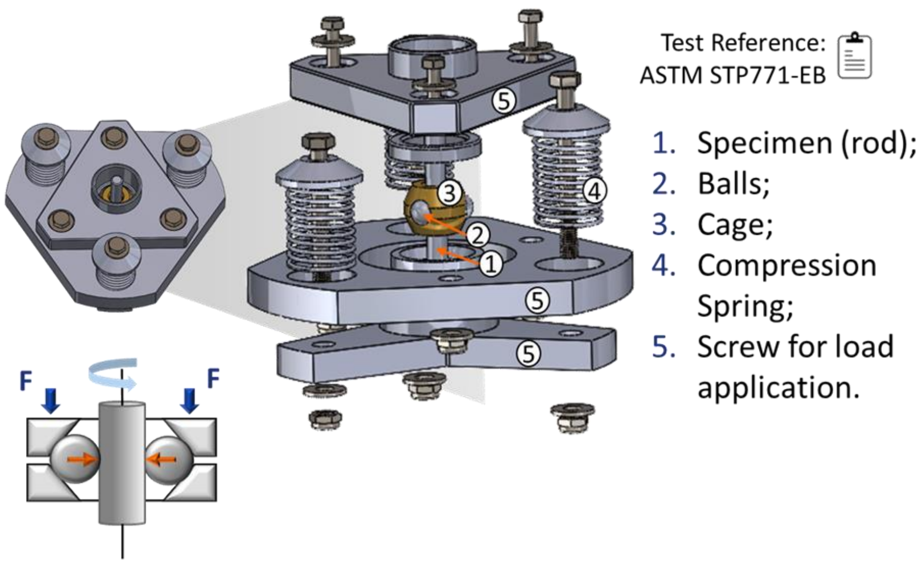


Figure 3: Rolling contact fatigue tests, Ball-Rod.

The Ball-Rod test rig is classified as a laboratory test bench, i.e., a simplified accelerated test equipment with known system stresses in analogy to the actual application of the research. For gears, the stress composition involved during the application is a summation derived from rolling and sliding mechanisms. The rolling stresses are predominant in the pitch region, an area more susceptible to contact fatigue failure modes such as spalling (SADEGHI et al., 2009). The tests were conducted with a single loading of 3.8 GPa generating three tests per surface condition.

2. RESULTS AND DISCUSSION

After performing the topography and profile deviation tests, Figure 4 will show the results of the different processing conditions and their effect on the roughness. The main observation will be concerning the two experimentally explored abrasive materials.

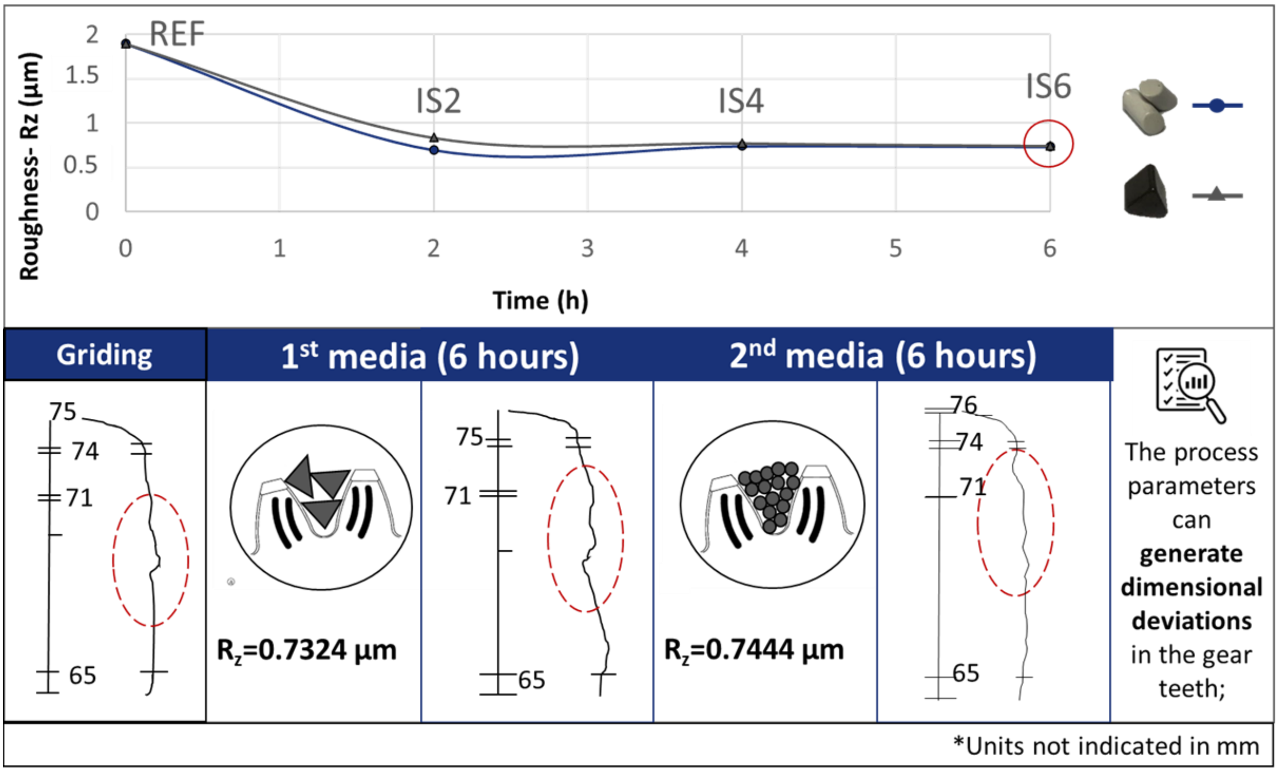
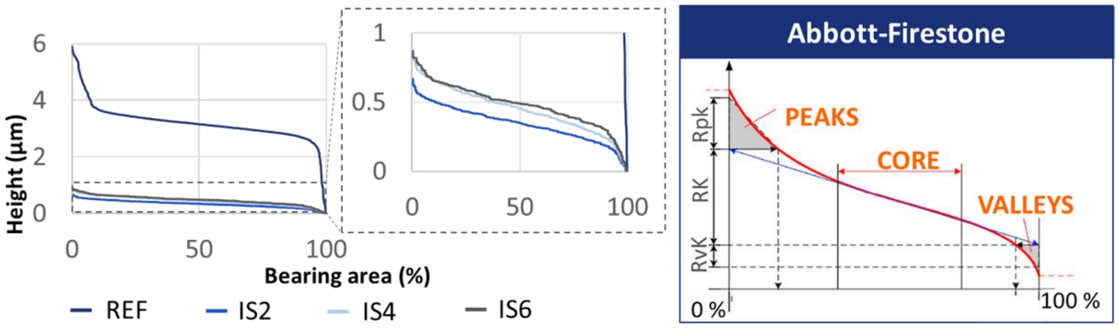


Figure 4 – Roughness obtained by isotropic processing and analysis of distortions generated.

It is possible to verify in Figure 4 that the Isotropic Superfinishing process causes a roughness reduction starting from an Rz of 2 µm, reaching results lower than 1 µm. This factor is observed in the two investigated averages. It is also possible to observe that after 2 hours of processing, the results remain constant about the Rz. Thus, the evaluation of the Abbott-Firestone curves must be done.

On the other hand, a profile bulging due to the processing interface is also evidenced. This factor is observed in different ways between the two medias studies. The first media investigated, by its geometric interface with the flank, is possible to verify a profile bulging, being the flank in the exposure of the processing time of 6 hours. When the second flank, generated by the second media, is evaluated, the process does not lead to changes in the microgeometry of the gear.

Thus, the second media geometry, 23D, showed less geometric variation and achieved a roughness reduction of approximately 60%, demonstrating a process feasibility for the gear. As a result of the isotropic processing, it is expected that the process cannot remove material significantly, having as its main function the reduction of roughness.
Given this, the geometric variations generated with the second media can be complemented by evaluating the Abbott-Firestone Curve. Figure 5 presents the previously mentioned curves.



#	Grinding	IS 6	Reduction rate
Rk	0.94 µm	0.38 µm	60% Rk
Rpk	1.66 µm	0.12 µm	93% Rpk
Rvk	1.21 µm	0.22 µm	82% Rvk

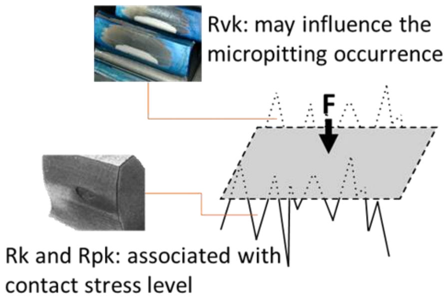


Figure 5 – Evaluation of the Abbott-Firestone curve results of the isotropic superfinishing process for the second media.

Figure 5 allows us to observe a difference between the height of the ground curve and the curves generated during the Isotropic Superfinishing. This deformation strengthens the ability to reduce the roughness of the process, which is also evidenced in Figure 4. However, the generated curves showed similar behavior among them.

At the end of the process, it can also be observed that the process reduces Rk by 60%, which is related to the surface that will be in contact, while for Rvk, a reduction of 82% of the initial value is observed while Rpk was reduced by 93%. When linked to gears, this reduction will be related to a more homogeneous load distribution, leading to a higher fatigue resistance and a delayed appearance of micropittings.

Subsequently, durability tests were performed on a ball-rod bench, and simplified bodies, called rods, were tested in the ground and superfinished condition. These were processed via Isotropic Superfinishing by 23D media in 6 hours. At the end of the grinding process, a surface was generated whose Rz was 1.4 µm, while after superfinishing, an Rz of 0.3 µm was developed. Thus, the samples were submitted to the same test conditions in a single loading of 3.8 GPa. Therefore, Figure 6 presents the durability results obtained.

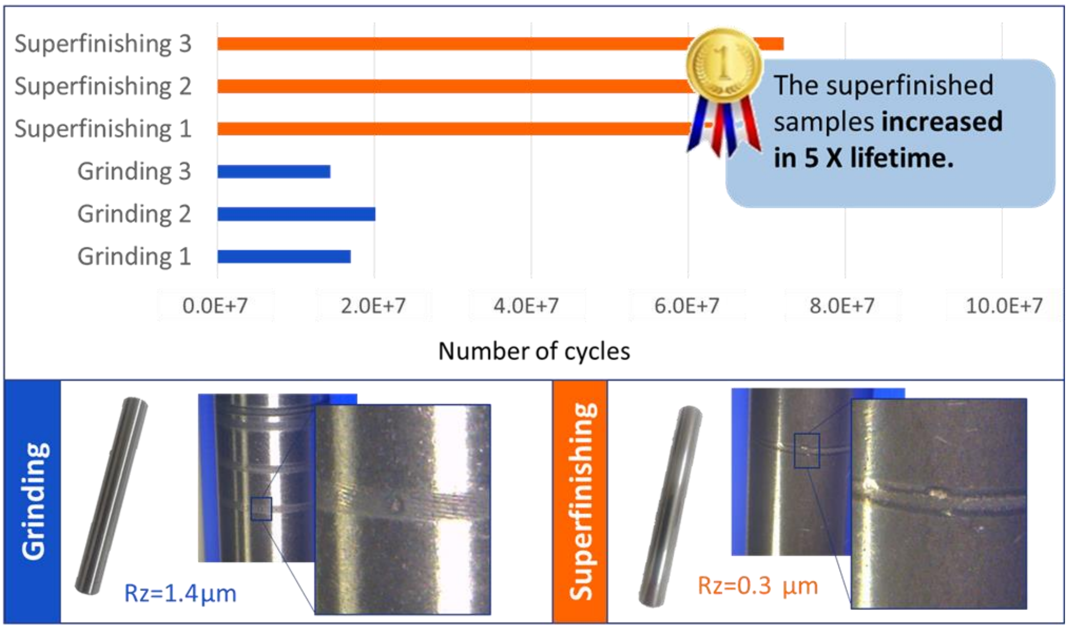


Figure 6 – Rolling contact fatigue testing.

The ground specimens presented 20 million cycles run until failure, while the superfinished specimens presented results in 70 to 80 million cycles. This result presents an effectively increase in fatigue life by approximately 5 times, showing that the roughness reduction can lead to a significant improvement in the fatigue life of machine elements with contact as their primary actuation.

For gears, rolling contact fatigue is the most representative actuating mechanism for contact fatigue, a failure generated in the Ball-Rod bench. This way, it is also possible to verify through the macro failure analysis the presence of spallings.

3. CONCLUSION

It can be concluded that the superfinishing process makes the surface more homogeneous, consequently reducing the linear and functional roughness parameters. As a result, the surface will have more accessible contact with other surfaces. In this way, the surface presents a more homogeneous surface loading and thus increase its fatigue life and loading capacity.

It was also noted that the variation of parameters during Isotropic Superfinishing can alter the capacity and the way of material removal from the gear toothed, where for the first media, there was a bulging of the profile, unlike the second media that reduced the roughness without changing the geometry pre-established in the previous manufacturing processes.

In this same sense, the flank also suffers superficial alterations when submitted to the process, distorting the expected microgeometry to the one obtained at the end of the chain, in parallel to the layer to be considered in the carburizing, the stock to be considered will also favor the control of the generated distortions and the obtaining of the microgeometry described in the project.

As subsequent studies to the present document, it is possible to use the knowledge for other machine elements, emphasizing elements subjected to cyclic loading cycles, such as bearings, different gears, pulleys, and sliding bearings. A study related to the lubrication of the superfinishing samples is also valid, where the lower the rugosity, the lower the amount of fluid needed to reach the elastohydrodynamic regime. Thus, the fluid could be varied in quantity and viscosity.

As far as performance testing is concerned, the study covers surface integrity and durability tests on simplified benches. To better extrapolate the final application, component or even system tests can be developed to evaluate the effects and phenomena related to the dynamics of the operation of parts with extremely low roughness.

As a result of this study, it is possible to verify that the Isotropic Superfinishing process can reduce the surface roughness of components, which can bring benefits in fatigue life, loading capacity, and friction reduction. These factors can be returned to optimized process conditions, including downsizing or even increasing life of transmission systems.

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