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GEAR SURFACES AND OPERATIONAL PERFORMANCE

While the surface of a gear comprises only a fraction of the component's overall mass, its physical properties impact the performance of that component in operation.

IN THE SEARCH FOR INCREASED performance and durability, gear and bearing design has sought to make use of improved steel grades combined with enhanced heat treatment techniques. The aim of these improvements is to prevent irregularity or impurity failures of the bulk metal substrate. This advancement in material preparation has enabled design limits to be pushed further for the benefit of the end application.

By enabling components to perform for longer periods of time and/or at higher loads, the surfaces of these components are being tested to a greater degree. As a result, surface fatigue is now a routine issue that must be factored in during the design stage. This article focuses on what engineers at REM mean by the term "surface," how different machining techniques alter the physical properties of a component's surface in undesirable ways, and how isotropic superfinishing can remedy these deleterious effects.

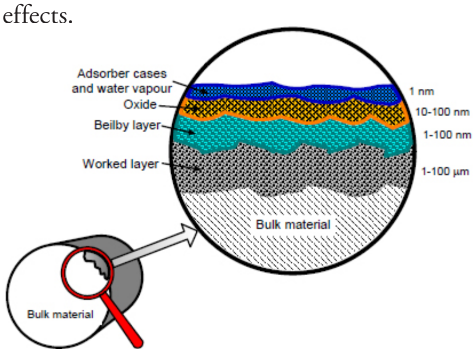

Figure 1: Example of the physical layers of a machined surface [1]

WHAT IS A SURFACE?

The term "surface" often evokes the idea of a single homogenous entity. However, when used in reference to a machined component, the surface is instead made up of multiple layers with varying thicknesses and physical properties. (See Figure 1.)

The two outermost layers — the adsorber cases and oxide layer — are essentially regions that have been contaminated by environmental factors and are only nanometers thick. These layers have little influence on the performance of the component in loaded operation. However, below these regions are more influential layers that are generated as a result of the machining process(es) that have been applied to the component: the Beilby layer and the worked layer. These layers, while still extremely small (typically less than 100 µm in combined thickness), play an important role in the performance of a component and are its true "surface."

MACHINED SURFACES

The term machining can be applied to a multitude of techniques, each with unique properties and characteristics. However, all such techniques require a tool that is strong and/or sharp enough to cut into the surface in a predefined manner. To achieve a cutting action, the technique employed must overcome the physical strength of the metal, which results in the generation of a large amount of heat. This force and heat affects the stress-strain relationship and causes the fracture and flow of metal, leading to the creation of the Beilby layer [2]. Plastic deformation of the metal during machining results in cold working of the surface and the creation of the worked layer. These physical alterations to the surface have the effect of increasing the hardness and tensile stresses while decreasing ductility and reducing performance values. Because the stress and strain exerted on the component is high, discontinuous micro-cracks form [3]. In addition to these physical property changes, all machining operations produce "peak asperities" that reduce the effective contact areas of the component.

ISOTROPIC SUPERFINISHED SURFACES

As described in the October "Materials Matter" column, an isotropically superfinished surface will possess a surface roughness of <0.25 µm and a non-directional surface texture. Through the use of isotropic superfinishing in the form of chemically accelerated vibratory finishing, the distressed material layer (the Beilby layer and the uppermost portions of the worked layer) can be completely removed, leaving behind a layer of homogenous material, free from the defects inherent to a machined surface. These surface improvements are possible due to the nature of the chemically accelerated vibratory finishing process — namely, that it is carried out at ambient temperatures and requires exceptionally little force. These factors dictate that no detrimental physical property alterations will occur during the material removal process.

OPERATING PROPERTIES OF MACHINED VS. ISOTROPIC SUPERFINISHED SURFACES

The surface of a gear is the point of contact between two mating surfaces, and the contacting properties will be derived directly from the interaction of these two mating surfaces. (See Figure 2.)

With machined surfaces, the unfavorable properties of the surface material itself and the peak asperities serve as initiating factors for surface fatigue during operation via the progression of micropitting or abrasive wear.

Figure 2: Example of the interaction of two machined surfaces

An isotropically superfinished surface, no longer having any micro-cracks or surface distress (tensile stress) and possessing a planarized texture, will not suffer from either of these failure modes. In fact, the surface's contact properties now resemble that of Hertzian contact theory, as the two contacting bodies are, in essence, flat. This characteristic allows the

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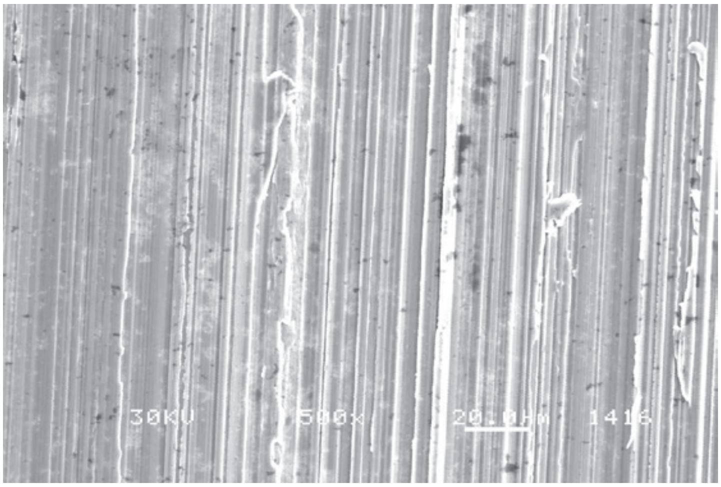

Figure 3: SEM example of a machined surface

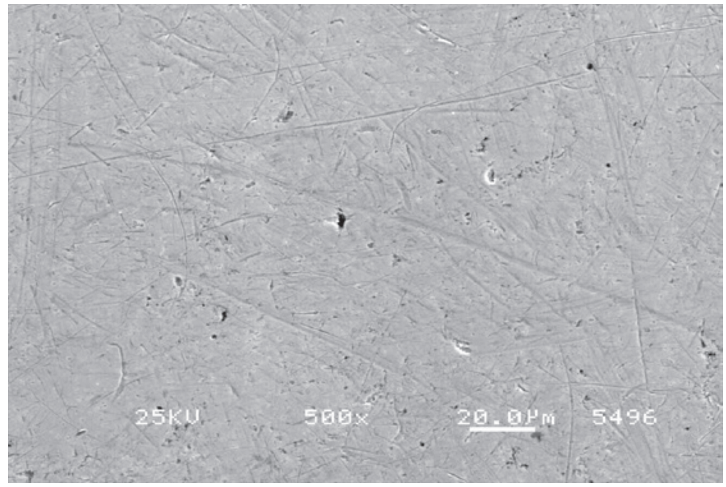

Figure 4: SEM example of an isotropic superfinish (Ra = ~0.034 µm)

surfaces to distribute the load over the whole theoretical contact area, diminishing the contact pressure across the active flank and significantly improving the component's resistance to contact fatigue.

THE IMPORTANCE OF TEXTURE

It is important to note that the texture of an isotropic superfinish is critical, as a surface that is free of all texture is, in fact, too smooth. A non-textured or "too smooth" surface struggles to retain adequate lubrication during operation and is therefore at a greater risk for scuffing or galling damage. The machined surface shown in Figure 3 will fail well before the surfaces shown in Figures 4 and 5 in any contact fatigue testing for these reasons. However, despite both surfaces having no peak asperities of distressed metal flaws, the surface shown in Figure 4 has been shown to outperform the surface shown in Figure 5 by a considerable degree in scuffing tests due to its more favorable lubricant retention properties despite the surface in Figure 5 having a lower coefficient of friction.

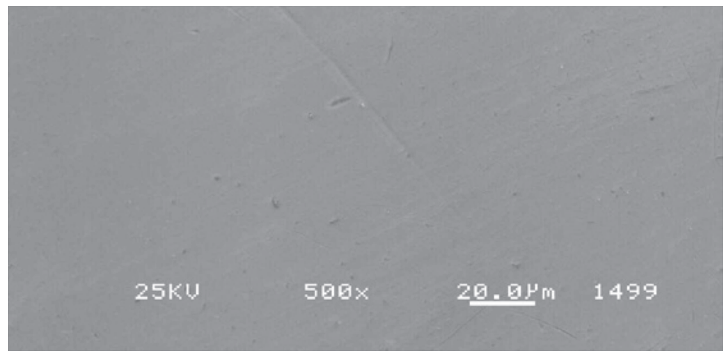

Figure 5: SEM example of a non-textured/too smooth superfinish (Ra = ~0.017 µm)

GETTING THE OPTIMAL SURFACE

In conclusion, it is clear that the surface of a gear is a key factor in its operational performance. To achieve maximum performance, it is beneficial to remove the distressed material that is generated during the machining process(es). It is also critical to planarize the surface while making sure that you retain an adequate level of texture for optimal lubricant retention during loaded operation (this is how REM's ISF® Process functions). The importance of the surface to a gear's operational performance and the ability to accurately evaluate or verify these desired surface characteristics in production is clear. To this end, the next part of this series will discuss the methods of measuring and evaluating surfaces and surface roughness in order to avoid misconceptions or errant classifications.

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