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## **AGMA Technical Paper**

# **The Effect of the Surface Roughness Profile on Micropitting**

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# The Effect of the Surface Roughness Profile on Micropitting

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

## Abstract

A wide choice of surface roughness parameters is available to characterize components, such as gears or bearings, with the goal of predicting the performance of such metal-to-metal contacting parts. Commonly in industry the Roughness Average ( $R_a$ ) or the Mean Peak-to-Valley Height ( $R_z$  (DIN)) is chosen to calculate the Specific Film Thickness Ratio for both superfinished and honed surfaces. However, these two surface roughness parameters fail to adequately predict the performance properties of surfaces that are superfinished or surfaces that are honed. In this paper, a superfinished surface is defined as a planarized surface having a  $\leq 0.25 \mu\text{m } R_a$ . A honed surface is not considered to be planarized, even with a finish of  $\leq 0.25 \mu\text{m } R_a$ . Thus, one is falsely led to predict that a planarized surface or a honed surface, having an equivalent  $R_a$  or  $R_z$ , will perform similarly. Experimentally, an isotropic planarized surface delivers superior performance. The following discussion utilizes another roughness parameter,  $3\sigma_{50}$ , to further explain this phenomenon.

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## Introduction

The roughness profile of metal-to-metal contacting parts is one of the most important characteristics in making mechanical systems more durable and energy efficient. Unquestionably, it is the interaction of the peak asperities from ground or honed surfaces that contributes to the degree of friction, high operating temperatures, deteriorated lubrication and system failure [1]. Lubricant films attempt to keep such interactions to a minimum, but under high loads and low speeds peak asperity contact still occurs. The surface roughness profile may be defined as any parameter that is used to characterize the topographical features of a given surface. However, several parameters are used commonly. Table 1 represents a few of the most prominent surface roughness parameters in use by industry and academia today in addition to all parameters cited throughout this discussion.

Two parameters most commonly chosen to characterize the surface texture are the roughness average,  $R_a$ , and the mean peak-to-valley height  $R_z$  (DIN). Yet, it is evident that surfaces having an identical  $R_a$  can have completely different characteristics as illustrated in Figure 1<sup>1)</sup> [2].

**Table 1. Definition of parameters**

| Symbol         | Definitions                                                                        | Notes                                                                                             |
|----------------|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| $R_a$          | Composite arithmetic mean roughness                                                | Commonly used as a standard roughness parameter in industry                                       |
| $R_q$          | Root mean squared roughness (RMS)                                                  | The standard deviation in the "Histogram of Heights" in Figure 5 through Figure 7, based on $R_q$ |
| $R_z$ (DIN)    | Mean peak-to-valley height                                                         | Commonly used as a standard roughness parameter in industry                                       |
| $S$            | Composite surface roughness of mating surfaces                                     | Several different equations exist depending on industry/historical preferences                    |
| $R_1, R_2$     | General $R$ profile used in calculation of $S$                                     | May be $R_a, R_q$ , etc.                                                                          |
| $R_{SK}$       | Skewness                                                                           |                                                                                                   |
| $R_{pm}$       | Average maximum profile peak height                                                |                                                                                                   |
| ISF®           | Isotropic superfinish or planarized surface profile having a $\leq 0.25 \mu m R_a$ |                                                                                                   |
| $\sigma$       | Standard deviation                                                                 |                                                                                                   |
| $3\sigma_{50}$ | Roughness based on population of peaks within 30s of the mean roughness            |                                                                                                   |
| $\lambda$      | Minimum film thickness divided by the composite surface roughness                  |                                                                                                   |
| $H, h_{min}$   | Minimum film thickness                                                             |                                                                                                   |
| $t_p$          | Bearing ratio                                                                      |                                                                                                   |
| $e_s, e_b$     | Heights of the asperities on the contacting surfaces "s" and "b"                   |                                                                                                   |

1) Surface finish measurement procedures, general terminology, definitions of most parameters and filtering information can be found in ASME B46.1 (2009), ISO 4287:2009 and ISO 4288:1998. Units are in micrometers ( $\mu m$ ).

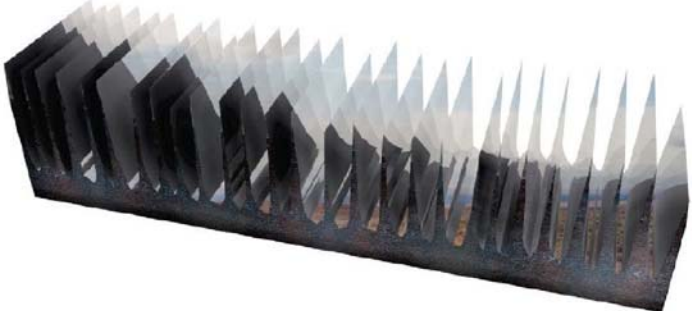
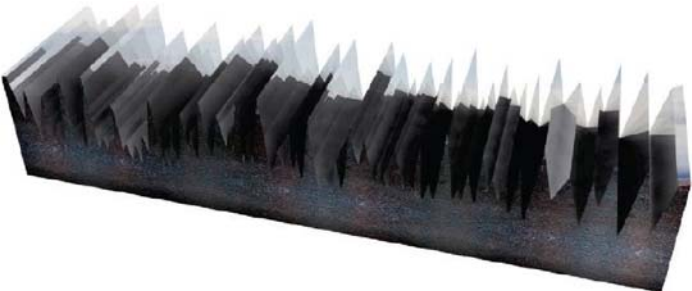
| Characteristic surface                                                              | $R_a$             |
|-------------------------------------------------------------------------------------|-------------------|
|   | 2.4 $\mu\text{m}$ |
|   | 2.4 $\mu\text{m}$ |
|  | 2.4 $\mu\text{m}$ |

**Figure 1. Illustration of component surfaces having approximately equivalent  $R_a$  values but radically different surface textures and performance characteristics in operation**  
(Courtesy of Hommelwerke, GmbH)

For well over a decade many companies, universities and research organizations carried out concerted investigations of gear and bearing micropitting. Recently these investigations have taken on even more urgency with the growth of wind turbine size and exponential growth in the number of megawatt wind turbines in service. Due to the extremely high load and low speed operation of the input stage of wind turbines, micropitting has become an epidemic problem and is now recognized as a failure indicator that can lead to premature gear and bearing failure. Prior to this epidemic problem in the wind turbine industry, micropitting was often assumed to be self-arresting and not a failure mechanism in gearboxes.

Researchers seem to be in universal agreement that micropitting is initiated by peak asperity interactions of the metal to metal contacting surfaces whereby high subsurface stresses arise[3] [4]. However, they pay little or no attention to the method used to generate the surface or the specific topographical features of the final surface. For example, ISO/TR 15144:2010 uses the effective composite arithmetic mean roughness to calculate the local specific lubricant film thickness[5]:

$$R_a = 0.5 (R_{a1} + R_{a2}) \quad (1)$$

where

- $R_a$  is effective composite arithmetic mean roughness value;
- $R_{a1}$  is arithmetic mean roughness value of pinion;
- $R_{a2}$  is arithmetic mean roughness value of wheel.

Although the technical report states explicitly, “At present  $R_a$  is used, but other aspects such as  $R_z$  or skewness have been observed to have significant effects which could be reflected in the finishing process applied”, in practice the roughness profile of the surface is ignored.

The parameter  $R_a$  is used repeatedly with little consideration of the actual topographical features or surface texture of the polished surface in the 2004 patent *Polished Gear Surfaces* [6]. In this pivotal patent, gears having different surface roughnesses were generated by radically different techniques (hobbed and shaved, ground, honed, fine grit honed, physicochemically polished and electrochemically polished). Although the patent acknowledges that each surface has a different roughness profile, only the  $R_a$  is used to predict contact fatigue life, wear resistance and performance. While the authors correctly conclude the macroscopic correlation of reduced surface roughness and stress reduction the specification ignores the microscopic intricacies of the nature of the surface roughness and the resulting variations in the magnitude of stress reduction by the surface roughness generation technique.

## The planarized surface

The planarized surface is that generated by chemically accelerated vibratory finishing (henceforward referred to as superfinishing). Figure 2 summarizes the process of superfinishing on an “as-ground” or “as-honed” surface. Depicted in scanning electron microscope images and profilometer traces, the superfinishing process removes the peaks resulting in a planarized surface. The planarized surface has no sharp peak asperities and hence, even if two planarized surfaces come in contact the subsurface stresses are significantly less than those generated by surfaces having sharp peak asperity interaction. Eventually even the valleys disappear as the superfinishing process continues leaving a planarized, micro-textured surface. In general, on different surfaces with an equivalent  $R_a$  and  $R_z$ , the planarized surface will give superior performance to that of a ground surface or honed surface since the latter has peak asperities (Figure 3). The optimum surface is that surface where the valleys also have been completely removed.

Figure 4 illustrates ground or honed surfaces brought into contact (top) versus two planarized surfaces brought into contact. The film thickness required to separate the planarized surfaces is much less than that required to separate the ground or honed random surfaces. Recently, the performance of honed gears with an average  $0.25\text{ }\mu\text{m}$   $R_a$  were compared to superfinished gears with an average  $0.04\text{ }\mu\text{m}$   $R_a$  [7]. The superfinished gears lasted 2,000 hours with no indication of micropitting while the honed gears showed micropitting after only 150 hours. One can argue that a gear with a smoother (honed) surface should outperform a gear with a rougher surface. However, a  $0.25\text{ }\mu\text{m}$   $R_a$  planarized surface devoid of stress raisers (peak asperities) should outperform a honed  $0.25\text{ }\mu\text{m}$   $R_a$  surface.

## A better parameter to characterize the planarized surface

The specific film thickness ratio,  $\lambda$ , is a dimensionless parameter commonly used to predict or define the degree of separation between two contacting and lubricated surfaces. The degree of separation may range from full contact or boundary lubrication to full separation or hydrodynamic (full fluid) lubrication. Specifically,  $\lambda$  refers to the minimum lubricant film thickness divided by the composite surface roughness of the mating surfaces (equation 2).

$$\lambda = \frac{\text{Minimum film thickness, } H}{\text{Composite surface roughness, } S} \quad (2)$$

Historically, there were several derived methods of determining the composite surface roughness. Examples are shown in equations 3 through 5.

$$S = \left( R_{a1}^2 + R_{a2}^2 \right)^{0.5} \quad [8] \quad (3)$$

$$S = 0.5 \left( R_{a1} + R_{a2} \right) \quad [1] \quad (4)$$

$$S = \left( R_{q1}^2 + R_{q2}^2 \right)^{0.5} \quad [9] \quad (5)$$