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Characteristics and Performance of Surfaces Created by Various Finishing Methods (Invited Paper)

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Abstract

The functional performance of mechanical components depends on their surface characteristics, surface integrity and geometric accuracy. It is critical to understand the influence of these surface properties on product performance, so the manufacturing processes can be designed to deliver the required performance. This paper presents the influence of surface characteristics on functional performance including surface topography, surface 2D/3D parameters, tribological parameters and residual stresses. It then discusses the surface properties created by various finishing methods such as hard turning, grinding, superfinishing, mass finishing, etc. Finally, it provides guidelines for the design and selection of finishing processes in order to yield the critical product performance characteristics.

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Keywords: Surfaces, Finishing, Surface integrity, Product performance

1. Introduction

In a product made up of mechanical parts, certain critical components are required to achieve the product's desired functional performance. There are three key factors – material, product and manufacturing process – in designing a critical component that yields the required functional performance as shown in Fig.1. Which factor is more critical depends on the demands placed on product performance. A component might need to satisfy multiple demands on product performance at the same time e.g., long fatigue life, high wear resistance and low friction. Another component might be required to meet only one, such as low vibration/sound performance. A product's superiority comes from a rigorous design of these three factors: 1) material, 2) product and 3) manufacturing process.

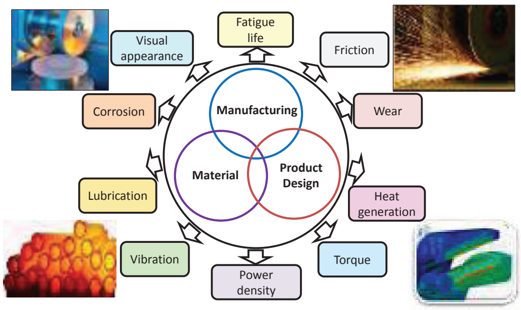

Fig.1. Functional performance and three key factors of product design.

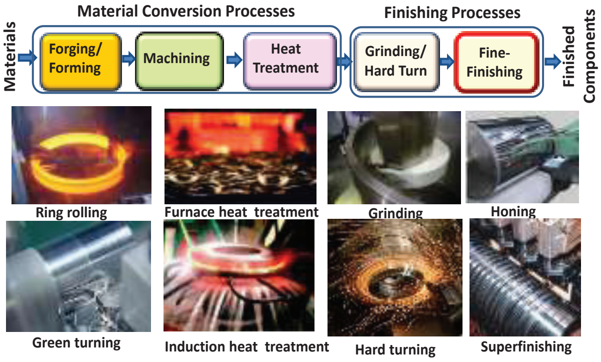

Fig.2. Typical manufacturing process sequence from material to product.

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The proper design of manufacturing processes ensures not only product quality, but also the product-performance capability and efficiency in manufacturing costs [1, 2]. Fig.2 illustrates the typical manufacturing process sequence used to transform raw material to a finished component such as a bearing ring. The processes from raw material to heat treatment are termed “material conversion processes” and are used to generate the basic shape of the product followed by material removal processes such as milling, turning, drilling, etc. The hardness and microstructure of the machined component is then refined in the heat treatment process to obtain a hardened component. In the finishing process, material removal with grinding or hard turning is used to produce components with specified dimensions and tolerances. In addition, the finishing process imparts the required geometrical accuracy (e.g., roundness, profile and roughness) to the component.

After the finishing process, the components can be used in assembled products. Some products are subjected to an additional finishing process after grinding or hard turning in order to enhance functional performance. This post-finishing process is called “fine-finishing” and is used to obtain the required surface topography [3], surface integrity (e.g., subsurface mechanical and metallurgical properties) and geometrical accuracy. Abrasive fine-finishing methods include superfinishing, honing, mass finishing, lapping and polishing. Sometimes, a surface structuring process is used to generate an engineered surface texture on the component surface [4].

The material conversion processes influence product performance, especially wear performance, through control of the material hardness. However, the finishing process, which often constitutes the final manufacturing process step, has a more significant impact on product performance. It is therefore of considerable importance to better understand the fundamental aspects of finishing methods and to design proper finishing processes by selecting the appropriate finishing method.

The objective of this paper is to describe the basic characteristics of surfaces created by various finishing methods and the influence of those surfaces on product performance. This knowledge is used to develop guidelines for the selection of appropriate finishing methods and their design.

2. Finishing methods

Fig.3 shows the classifications of finishing technology. Finishing process technology can be classified into two categories based on the machining principle: 1) motion-copying processes and 2) pressure-copying processes. Motion-copying processes remove material at a given depth of cut. Grinding and hard turning are two finishing methods that utilize the motion-copying principle. While grinding removes material via a grinding wheel with multiple non-deterministic cutting edges, hard turning is a method that removes material through a single-point cutting tool. Both methods are capable of high material removal rates and precision control of form accuracy and dimensions within given tolerances. In contrast, pressure-copying processes have no given depth of cut, but create a finished surface by applying tool pressure against the workpiece surface. This process is called “fine-finishing” and is suitable for obtaining desired the surface topography and surface integrity. While fine-finishing has the ability to improve form accuracy, it cannot control dimensional accuracy.

In abrasive fine-finishing processes, there are two types of abrasive grains: 1) bonded abrasives, and 2) un-bonded abrasives. Examples of abrasive fine-finishing methods using a bonded abrasive tool are: superfinishing, honing, film/tape finishing, brushing and mass finishing. Examples of fine-finishing methods using un-bonded abrasive tools are: blasting, jet finishing, lapping, polishing, buffing, abrasive flow finishing and magnetic abrasive finishing.

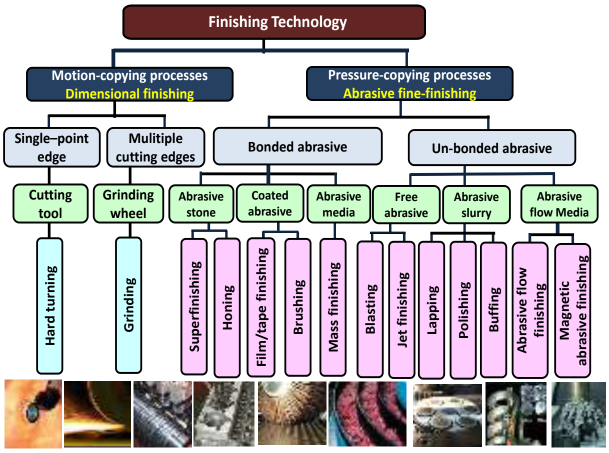

Fig.3. Classifications of finishing technology.

3. Characterization of surfaces created by various finishing methods

Four kinds of surfaces finished by 1) grinding (GD), 2) superfinishing (SF), 3) hard turning (HT) and 4) isotropic finishing (IF) (mass finishing) [5] are investigated. Representative 2D and 3D images of the four surfaces produced in AISI 52100 (HRC 60-64) are shown in Fig.4. Also, the corresponding 2D and 3D surface parameters are summarized in Table 1.

The GD part surface shows a typical ground surface consisting of one-directional grinding grooves while the SF surface has the typical crosshatch pattern characteristic of superfinished surfaces. The HT surface consists of periodic tool feed marks [6]. The IF surface shows an isotropic surface without any directional machining marks.

Examination of the 2D surface parameters reveals that the IF surface has the lowest average surface roughness R_a, while the GD surface has the highest roughness. The trend of the peak-to-valley roughness R_t is similar to R_a. The positive skewness ($R_{sk}>0$) indicates a surface with predominant peaks, while the negative skewness ($R_{sk}<0$) indicates a surface with predominant valleys. Only the HT surface exhibits positive skewness, which is not suitable in a rolling element bearing surface. The SF and IF surfaces have high negative R_{sk} values, which indicates that the surfaces have a flat-topped or plateau surface with valleys or pits. In general, the plateau surface improves the functional