

Development and Application of Grinding process with Superior Surface Integrity

Shuai Wang^{1,2,a}, Shu sen Zhao^{3,4,b}, Bin Li^{1,2,c}, Hua Bao^{1,2} and Zhan shu He^{3,4,d}

¹State Key Laboratory of Superabrasives, Zhengzhou 450001, China

²Zhengzhou Research Institute for Abrasive & Grinding Co., Ltd., Zhengzhou 450001, China

³School of Mechanical Engineering, Zhengzhou University, Zhengzhou 450001, China

⁴Henan Province Engineering Laboratory for Anti-fatigue Manufacturing Technology, Zhengzhou 450001, China

^awangshuai@zzsm.com, ^bzssc1994@163.com, ^czhifeng920920@126.com and ^dhezhanhu@qq.com

Abstract. As an important finish machining process, the grinding process plays an important role in the equipment manufacturing industry. This paper gives a quick overview of the development of surface integrity theory, illustrates the important influence of surface integrity on the fatigue life of component, introduces the development and research status of grinding process, and states the theory and application of grinding process with superior surface integrity after the case hardening or surface modification of key component.

1. Introduction

American society of metal-machining studied the surface quality after different processes, and provided the empirical data of surface integrity. However, the fundamental relationship between turning mechanism and surface integrity was not clarified, and the research on surface integrity is mostly focused on mild steel [1]. No much research on hardened steel with a high hardness of greater than 65 HRC has been done, and the results of these researches are inconsistent.

The surface denatured layer of some key components possess a high strength and toughness formed by case hardening or surface modification, which has a surface hardness of 65~70HRC resulting in some problems of grinding such as high grinding forces and temperature, severe work hardening and grinding wheel wear, etc [2]. Hence, to improve the fatigue life of component, it is urgent to eliminate these defects and improve the surface integrity of component.

2. Surface Integrity

The concept of surface integrity was first proposed by Field et al in 1964, and the evaluation method of surface integrity was subsequently proposed in 1972 [3]. At present, as shown in figure.1, the research of surface integrity mainly focuses on surface topography, surface residual stress, microstructure and hardness, etc [1][2][4]. Among these, the surface compressive residual stress is beneficial to the fatigue life of component, which is of great significance for anti-fatigue, because that the distribution of surface compressive residual stress is the key factor of contact anti-fatigue [5].



Mantle et al [6] found that the magnitude of surface roughness is inversely proportional to that of fatigue life after removing the influence of compressive residual stress factor. Suhr et al [7] conducted fatigue tests on CrNiMo steel specimens with different surface conditions, and results show that surface roughness has a significant influence on the fatigue life, i.e., the fatigue limit of specimens with a larger roughness is relatively small. This is because that material or component experiences two stages before fracturing: crack initiation and crack propagation. The crack initiation stage of high-strength alloy steel accounts for a large percentage ($\geq 90\%$) of the total fatigue life. Crack always initiates from the surface. Besides, it is sensitive to the surface roughness during the stage of crack initiation [8]. For the machining of key components, a high surface integrity is required, i.e., the machining precision is greater than 4 and the surface roughness $R_a \leq 0.1 \mu\text{m}$.

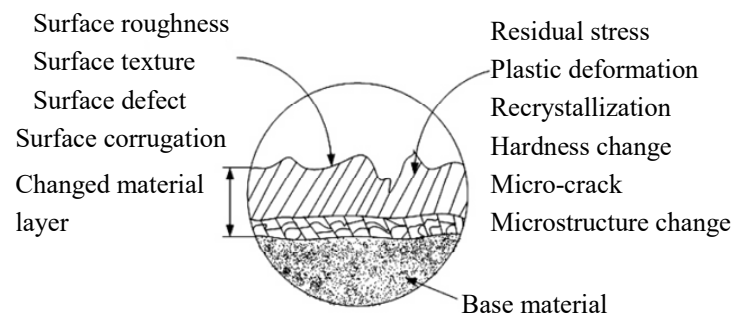


Figure.1 Schematic of surface integrity [4]

3. Development and Research Status

The development of grinding can be summarized into three stages, (a) the basic research stage of improving grinding efficiency — the removal rate of material has been greatly increased, the grinding speed has been increased to over 50m/s, and the processing efficiency and the duration of grinding wheel have been increased by 25-30%; (b) the developing stage of high speed grinding concept and grinding machine — the grinding speed reached 120m/s and the CBN grinding wheel was created; (c) the typical application, the pursuit of efficient, and ultra-high speed grinding stage — the laboratory grinding speed reached 1000 m/s, the limit application speed can reach 200m/s, and the material removal rate can reach $800 \text{ mm}^3/(\text{mm}\cdot\text{s})$; (d) the developing stage of high speed and high quality grinding machine as well as compound grinding machine — a comprehensive benefit of grinding process, the precision, reliability and stability of high-speed grinding system, a higher grinding accuracy (i.e., level 4) and surface integrity are concerned by researchers.

A lot of investigations have been conducted to study the grinding process. Figure 2 shows a typical high-speed surface grinding machine. Figure 3 shows a specimen after the grinding machining. Kovach et al [9] found that increasing the grinding wheel speed can decrease the grinding force and the surface roughness of component. Ichida et al [10] studied the formation mechanism of bearing steel JIS SUJ2 (62 HRC) surface under a grinding wheel speed of greater than 200m/s, and found that the surface roughness is improved with an increase in the grinding wheel speed. Hedi Hamdi et al [11] proposed a calculation model of predicting compressive residual stress induced by surface grinding under a high-speed grinding condition (i.e., a grinding wheel speed of greater than 120 m/s). Jin [12] investigated the surface quality of component under a CBN grinding wheel speed of 30~100m/s, proposed the change trend of surface quality under different grinding speeds, pointed out the major influence factor of surface quality, and finally proposed the control measures of surface quality. Luo et al [13] used a plane grinding test-bed with an ultra-high-speed of 150m/s to study the influence of different grinding parameters on the surface roughness of 45 steel. Zhao et al [14] found that high-speed and ultra-high-speed grinding all can improve the grinding efficiency, decrease the surface roughness of specimen, and induce compressive residual stress into the specimen surface, thus increasing the fatigue strength of specimen.

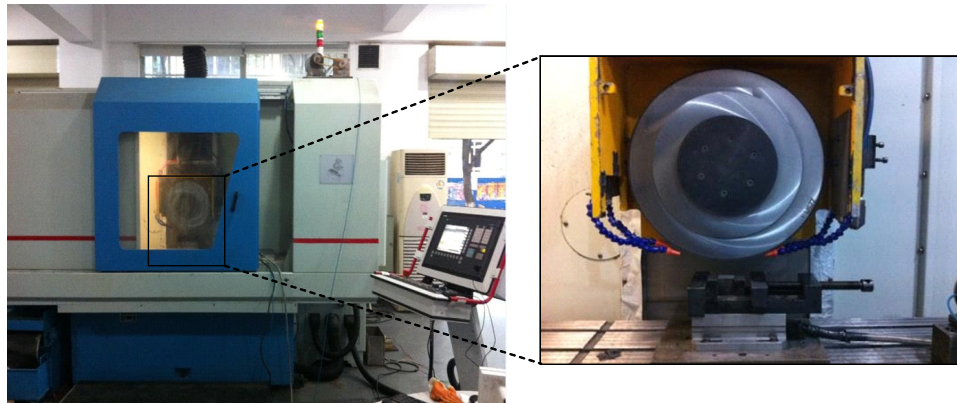


Figure.2. Image of high-speed surface grinding machine (MKL7132X8/17)



Figure.3. Specimen after grinding machining [4]

4. Application

However, some surface modification techniques such as shot peening and water jet peening can induce compressive residual stress into the component, but increase the surface roughness thus affecting the surface integrity [15]. To satisfy the specific requirement of surface integrity, a finishing process is needed to be conducted for the manufacture of precision mechanical components. At present, the conventional finishing processes mainly include hard turning, high-speed milling and grinding, etc. The hard turning can induce a deeper compressive residual stress layer into the hardened steel GCr15 than that induced by the grinding, but the multiple crack sources on the circumferential surface increase, and thus the fatigue life of GCr15 decreases [1]. Therefore, the finishing process of key component is still mainly grinding.

Besides, the key component requires a high surface integrity, i.e., machining accuracy level of greater than 4, surface roughness of $Ra \leq 0.1 \mu\text{m}$, the distribution of residual stress field is reasonable, and no surface burn or micro-cracks, etc. The conventional grinding process requires a machining accuracy level of 5~7 and a surface roughness of $Ra 0.2 \sim 0.8 \mu\text{m}$. Even though the magnitude of surface roughness is decreased by a polishing process, the fatigue life of component is decreased resulting from the decrease of depth of compressive residual stress layer. During the conventional grinding process, due to the high grinding temperature, surface burns and other problems may occur, and tensile residual stress is induced in the component surface resulting in the decreasing of fatigue life.

For solving these problems and improving the grinding accuracy and surface quality, the high-speed grinding (i.e., grinding speed of larger than 45 m/s) is becoming a hot research field [16-18]. The theoretical basis of high-speed grinding comes from the hypothesis proposed by Salomon (a German physicist): under the high speed machining condition, the high-temperature valley during the turning process can be passed over and the heat generated by the turning process is decreased. The grinding wheel speed of less than 140 m/s is recognized and successfully applied in industry, while surface burns, and internal micro-crack still occur on component under a grinding wheel speed of $45 \sim 50 \text{ m/s}$ in most enterprise production process, resulting from the lacking of understanding chip formation,

grinding wheel state and machining mechanism under high speed grinding condition. Therefore, many important scientific problems in engineering application need to be solved.

5. Summary

The existing research mainly focuses on high speed and high efficiency grinding, the depth of single grinding is usually 20~50 μm , and the depth of grinding defect layer is relatively deep (>10 μm). The depth of compressive residual stress layer induced by surface modification process is relatively small, so that the grinding allowance should be decreased as much as possible, i.e., the depth of single grinding must be strictly controlled within 5 μm , which is different from high-speed and high-efficiency grinding in the mechanism. Therefore, the grinding process with superior surface integrity is proposed and studied.

Acknowledgments

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