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Development of Novel CBN Grade for Electroplated Finish Grinding of Hardened Steel Gears

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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

The unique requirements of an electroplatable superabrasive CBN grit used in profile grinding of hardened steel gears as well as the attributes and grinding behavior of a new CBN developed specifically for this application are discussed. Profile gear grinding parameters were simulated in through-hardened AISI 4140 steel (56 HRC) and the grinding performance of the new CBN was compared against a competitive CBN grade widely used in the application. Consistent with field criteria, grinding performance was characterized based on occurrence of 'burn' or 'form' failure. The 'burn' or metallurgical phase transformation failure was detected by Barkhausen Noise Analysis (BNA) and corroborated by microstructural and microhardness evaluations. The 'form' failure was simulated by tracking average radial wheel wear to a threshold value where form loss was expected to occur. Grinding tests indicate that the new CBN grit can grind 35% more parts compared to the competitive CBN grade before burn failure. In addition, the new CBN displayed a lower wear rate. The new CBN grade also exhibited a unique ability to grind with lower grinding power, resulting in a near constant BNA response on the ground surface throughout the test. This implied minimal microstructural change on the ground part from start to end of the test compared to the progressive softening of ground surface noticed with the competitive CBN.

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INTRODUCTION

Gears are the most common power transmission devices used in a wide range of applications like automobiles, power generation and machine tools. Depending on their usage, gears can be qualitatively classified as commodity gears and precision gears. Commodity gears usually are small gears with minimal load cycles and geometrical tolerances requirements. Precision gears which are used in high-end aerospace and automotive applications have ever increasing requirements imposed on them. These include increased service life, lower NVH levels, minimized backlashes and ability to accurately predict service life for preventive maintenance [1].

Such stringent requirements have naturally had an influence on manufacturing and process control of precision gears. The past two decades has seen a steady rise in demand for gears to be hard finished by machining or grinding to achieve the above mentioned performance metrics. Gear manufacture begins with forming processes like forging or blank machining processes like hobbing. This is followed by heat treating processes such as case carburizing, through hardening, and nitriding. The heat treating process induces distortions in the gear which necessitate hard finishing as the last step to ensure maximum load capacity and reduced transmission noise [2].

Hard finishing is either done by machining process with defined cutting edges like skive hobbing, hard turning, etc or by abrasive finishing processes like grinding or gear honing [2]. The classification of abrasive finishing processes is as shown in Figure 1 [2].

The grinding processes used in finish grinding of hardened gears can be classified as generating grinding and profile grinding depending on how the profiles of gear tooth are finished. The grinding process can be continuous where the gear profile is achieved progressively by grinding with a splined wheel or discontinuous profile grinding where a specific profile is ground one gear tooth at a time.

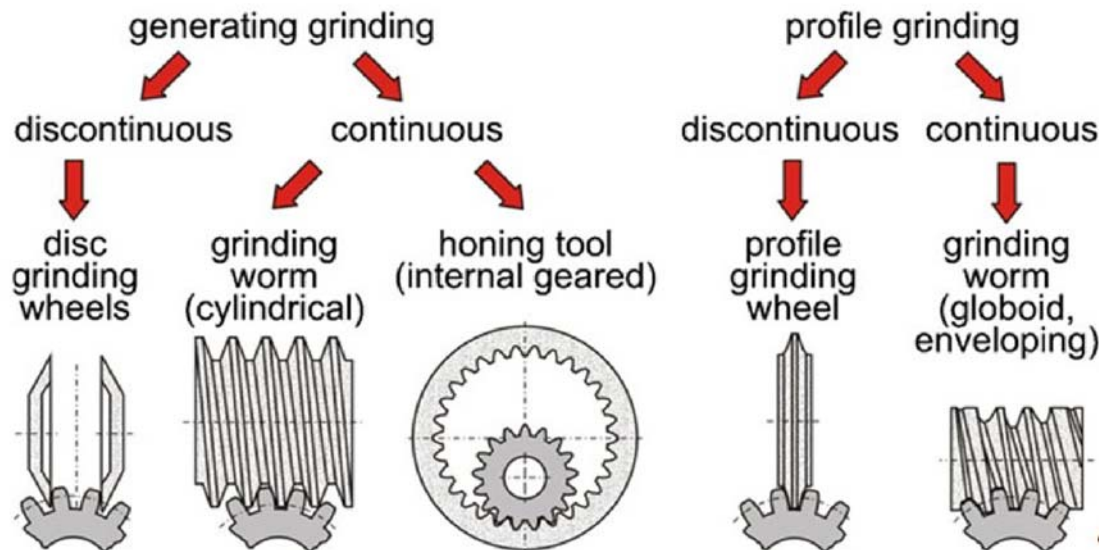


Figure 1. Breakdown of abrasive hard finishing processes [2]

Continuous generating grinding is typically adopted when grinding small batches with varying gear profiles and hence use dressable conventional aluminum oxide wheels into which profiles can be easily dressed using a diamond dressing tool. In certain special cases where maintaining gear surface integrity is important vitrified bonded CBN wheels may be preferred over conventional vitrified wheels [3].

Discontinuous profile grinding is generally used in a high volume repetitive process and typically uses an electroplated superabrasive CBN wheel. Electroplated CBN wheels contain a single layer of abrasive embedded in a nickel matrix and have the negative profile of the gear tooth ground with abrasive protrusion tolerance typically less than 5 μm . This is essential to achieve accurate profile on each gear tooth due to the single pass nature of the process.

This paper focuses on the unique requirements, physical attributes and grinding performance of a developmental grade of CBN designed specifically for electroplated profile grinding process.

Profile Grinding CBN I

Due to the nature of the grinding process itself and also the type of bond system used in the wheels, the requirements of a CBN grit used in an electroplated profile grinding wheel differs from a CBN grit type used in a vitrified bonded CBN wheel for other applications..

Vitrified bonded wheels are characterized by high natural porosity a multiple grit layers held together by the glass frit in the bond. Hence physical properties of a CBN such as shape and toughness only partially influence the performance metrics of the wheel such as ability to maintain form, grind with low power to reduce risk of part burn and greater intervals between wheel reconditioning. In contrast electroplated wheels exhibit high abrasive protrusion with 40–50% of the abrasive embedded in a non-porous nickel matrix. This is one of the primary reasons why electroplated wheels work best in a profile grinding set up as the high level of grit protrusion enables high material removal rates enabling fewer grinding strokes per tooth while achieving the required gear form. Because of this, the physical properties of CBN grit have a greater influence on the wheel performance in an electroplated wheel than a bonded wheel.

CBN grits used in an electroplated wheel are typically highly blocky in shape with average aspect ratios of the particles lower than 1.50 to promote uniform wheel wear. They are also much tougher than the CBN grits used in a bonded wheel to ensure long wheel life. The range of material removal rates used in profile gear grinding application results in the CBN crystal wear being more attritious than in other applications. Thus the CBN grits tend to become progressively dull with wheel usage resulting in an increase in grinding power and the associated risk of thermal damage.

In gear grinding, where thermal damage adversely affects the life and performance of the gear, it is imperative to use a CBN which exhibits a tendency to fracture in small fractions and thus keeping the wheel sharp and free cutting with a stable grinding power. This property is termed as “microfracturing” capability. It is also highly desirable to have a highly blocky shape to promote uniform wheel wear to achieve consistent gear tooth form from the start to the end of grinding wheel life. Achieving a uniform wheel wear in profile gear grinding is particularly challenging as the depths of cut and corresponding grinding forces encountered by the grits vary continuously from the top to bottom of a gear tooth flank as cited in previous attempts to model grinding forces in profile gear grinding [2].

The requirements of CBN crystals with uniform shape and lower toughness are truly unique to profile gear grinding. Generally, CBN crystal shapes and toughness are directly correlated i.e. more uniform crystals possess higher toughness and vice versa. Thus developing a crystal with lower toughness and blocky shape presents significant technical challenges. Development of such a novel CBN referred henceforth as Developmental CBN A is reported here along with grinding performance compared to a competitive CBN grade that is commercially available and used in this application.

CBN morphology and characterization

Visually, CBN A has much rougher, less well defined facets than the competitive CBN as seen from SEM micrographs in Figure 2. The rough surface morphology helps promote microfracturing ability in the crystals.