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Surface polishing of hardened grey cast iron with a compliant abrasive filament tool

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Abstract

Sliding guideways play a critical role in the accuracy and dynamic performance of machine tools. Discontinuous jerking motion occurs due to wringing if the guides are too smooth, but excessive wear results is the surface is too rough. The current fabrication approach uses large and expensive grinding machines that place logistical restrictions on production. A higher productivity milling process, using cubic boron nitride (CBN) tooling has been attempted, but this process does not achieve the necessary surface quality. Secondary finishing using a spindle mounted abrasive filament tool could be implemented as a post process to improve surface quality. This study determined the relationship between number of passes and Spk, Sk, and Svk areal functional parameters for three types of filament tools.

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Keywords: Polishing; surface analysis; manufacturing process.

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1. Introduction

Sliding guideways should have smooth uniform surfaces free of sharp peaks for optimal performance [1]. Surfaces with peaks wear more quickly during sliding contact and the abraded debris becomes trapped between the sliding guideway components. This deteriorates the soft polymer layer on the underside of the slider causing uneven contact pressure, reduced positional accuracy and shorter life for the machine tool. As a direct consequence, surface finishing methods are of key interest to machine tool builders.

Fabrication of the guideway is generally accomplished through a multistep process: the casting is milled to the desired geometric shape, heat treated to case harden the surface, and lastly ground to obtain the final roughness [2]. The last step requires very large and expensive CNC grinding centers. These machines are only installed in a select number of facilities, which increases shipping and production costs. After grinding, the casting is returned to a milling center and the ground surfaces are used as reference datums for proceeding operations that are centrally important to the performance of the machine. However, the surface finishing and subsequent milling operations could be performed by a single machine if the already required CNC milling machine could perform both the roughing and finishing operations. This would result in reduced manufacturing costs and increased productivity, since an unnecessary workpiece transfer would be avoided**.** This would also eliminate the high cost of the grinding machine, allow factories to be smaller, more numerous, and more closely located to their customers

Soshi et al. proposed an alternative CBN milling strategy in the past and found that it led to more stable static and dynamic friction coefficients over a sliding distance of 600 km [1] while also being a cost effective alternative to conventional grinding operations [2]. Yet concerns regarding the quality of the milled surface limit industry-wide adoption. It has been found that graphite flakes at the surface of the workpiece promote brittle fracture ahead of the milling tool causing random peaks and cavities to form. Example profiles are shown in Fig. 1. As a result, a post processing operation capable of removing these sharp asperities is needed.

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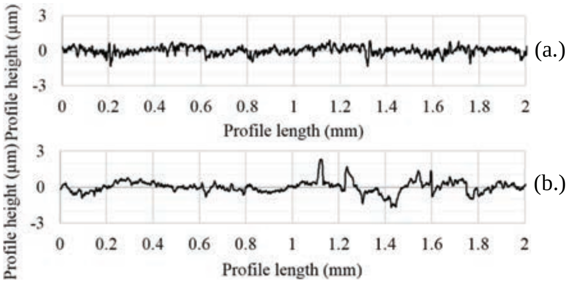

Fig. 1. surface profiles for ground (a.) and CBN milled (b.) methods.

2. Abrasive filament tools

Abrasive filament tools have been used in the past for manual and automated applications including: burr removal, reduction of micro crack propagation, and polishing [3]. The compliant bristles are made of metal or synthetic materials and conform to the shape of the workpiece, exerting small normal and shearing forces on the surface. An illustration of the tool is shown in Fig. 2. Workpiece materials include metallics, superalloys, and ceramics, while common abrasive media embedded within the bristles include silicon carbide, aluminum oxide, and poly crystalline diamond [3]. It has been found that abrasive filament tools can generate surfaces that range from Ra of 13 µm for tools made of larger diameter steel wire, to Ra of 0.40 µm for fine grit nylon/abrasive fibers [4]. However, the exact correlation between 2D or 3D surface texture parameters and tool characteristics are complex and experimentation is often needed before obtaining the desired results [5].

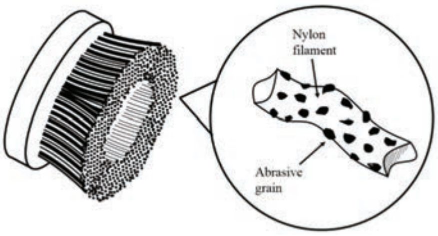

Fig. 2. abrasive filament tool and bristles.

3. Experimental setup and procedure

3.1. CBN Milling process

The workpiece material was FC300 (JIS) grey cast iron that was induction hardened and tempered to an average hardness of 47 HRC. A DMG Mori NV7000 three-axis vertical milling machine equipped with a Sumitomo RM3160R 125 mm diameter shell mill was used to mill the samples prior to polishing. The cutter had an axial rake angle of −5° and radial rake angle of −6°. All samples were milled with a single Sumitomo BN7000 insert having 90-95% volume CBN with WC-Co binder and a 20°×0.23 chamfered sharp edge. Cutting conditions for the milling operation are shown in Table 1. Each milled surface was measured five times using a Mitutoyo SJ310 contact stylus profilometer and filtered with a 0.800 mm cut-off wavelength before calculating the roughness. The average Ra value was 0.70 µm ± 11%. This surface is not ideal for sliding guideways, as Soshi et al. has shown that an Ra range of 0.3 – 0.5 µm resulted in the lowest statics and dynamic friction coefficients and lower wear rates when compared to ground sliding guideway surface [1].

Table 1. CBN milling conditions.

Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Cutter diameter (mm)
500	0.100	0.050	125

3.2. Abrasive polishing process

Three filament tools were tested for this study and were identified as Tool A, Tool B, and Tool C. Each tool was made from nylon filaments embedded with silicon carbide particles having a hardness of 2200 - 2600 HV that accounted for 10%-40% of the filament by weight [3]. The tools all had different abrasive particle sizes, bristle thickness, and bristle packing density. In general, these tool characteristics are not independent from each other but are instead coupled based on the tool manufacturing process. An increase in abrasive particle size required that a thicker filament be used to ensure proper bonding around the abrasive media, while thinner bristles allowed for greater bristle count per unit area resulting in a higher number of cutting edges making contact with the surface. The tool characteristics are shown in Table 2 and a comparison of the different filaments are shown in Fig. 3.

Table 2. Filament tool physical characteristics.

Tool type	Abrasive particle size (grit)	Particle diameter (µm)	Filament diameter (mm)	Filament length (mm)
Tool A	80	180	1.0	38
Tool B	180	63	0.9	38
Tool C	320	29	0.6	38

For the polishing tests, spindle speed and feed rate were held constant, using the tool manufacture's recommended settings [3]. No lubrication or coolant was used. Unlike milling tools that have high axial stiffness, the complaint bristles elastically bend as they contact the surface of the workpiece. The magnitude of bristle deflection is primarily controlled by the effective depth of cut of the tool and is a function of the stiffness of all the bristles making contact with the surface [4,5]. To ensure consistent contact pressure

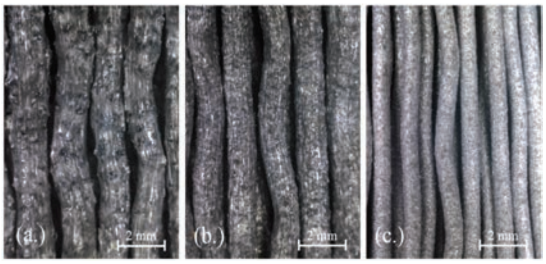

Fig. 3. abrasive filament Tool A (a.), Tool B (b.), and Tool C (c.).