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A Study on the Effect of Abrasive Filament Tool on Performance of Sliding Guideways for Machine Tools

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Abstract

Sliding guideways for machine tools require smooth, consistent surface texture for optimal performance. An excessively smooth surface causes adhesion between the moving components, while a rough surface accelerates wear. Conventional guideway fabrication uses large, expensive grinding machines. To reduce manufacturing costs while maintaining functional performance, cubic boron nitride (CBN) milling followed by abrasive surface polishing has been proposed. This study investigates the use of an abrasive filament tool to correlate the effect of polishing with lubricated static/dynamic friction coefficients. The results are compared with the sliding performance of milled and ground hardened grey cast iron samples. It was found that polishing had the largest effect on surfaces that were previously milled at higher feed rates and, if realized by industry, could increase productivity.

Keywords: Polishing; surface analysis; manufacturing process;

1. Introduction

Sliding guideways for CNC machine tools require both high geometric accuracy and consistent surface texture for optimal machine tool performance. Poor surface preparation reduces the machine's accuracy and shortens the useful life of the machine tool, while an excessively smooth surface induces a wringing effect which dramatically increase static friction [1]. As a result, the finishing process for guideways is of key interest to machine tool manufacturers. Fabrication is typically accomplished using a multistep process: milling of the raw casting, heat treatment to harden the surface, tempering to alleviate residual stresses, and grinding to obtain the final flatness and smoothness [2]. This multistep process is time consuming and results in a production bottleneck.

An alternative CBN hard milling strategy has been proposed that would improve production efficiency by replacing the conventional grinding process [1,2]. However, implementation of this finishing method has yet to be adopted in a manufacturing environment due to concerns regarding the surface quality obtained when milling hardened cast iron. It has been found that CBN milling of hardened cast iron results in a surface with sharp asperities. These asperities are liable to wear during the break in period of the machine tool and become embedded in the polytetrafluoroethylene (PTFE) slider that traverses over the guideway. In order to use CBN milling as a finishing strategy for sliding guideway production, a post processing operation capable of removing these sharp asperities is needed.

Abrasive filament tools have been widely used for manual and automated applications including: surface preparation, burr removal, and polishing [3-5]. Fig. 1 illustrates a spindle mounted abrasive disk-type filament tool. The tool is made by

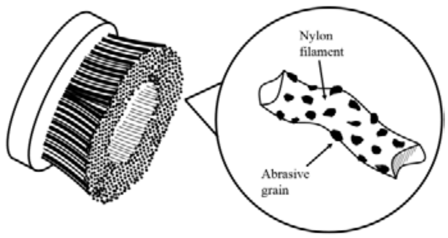

Fig. 1. Disk-type abrasive filament tool diagram.

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first mixing abrasive particles into nylon, then extruding slender filaments, and finally mounting multiple filaments into a plastic hub that can be attached to a tool holder or adapter [4].

During rotation of the disk-type tool, the tip and lateral surfaces of each bristle are dragged across the workpiece ploughing a series of grooves into the material [3]. The width and depth of these scoring marks has been associated with the magnitude of the penetration depth during polishing [5], which is the vertical displacement that the tool is lowered below the workpiece surface. As the tool rotates and translates across the surface of the workpiece, exposed abrasive particles embedded within the nylon filament act as small cutting edges that machine the surface [4]. An illustration is shown in Fig. 2.

Investigation into filament wear and surface morphology generated by circular wheel-type tools had been documented in literature [4,5], however, much less information exists regarding either the machining performance or surface quality of cast iron polished by disk-type tools with abrasive nylon filaments. Due to the great deal of uncertainty regarding the material removal performance of filament tools, serval authors have suggested that trial-and-error is often necessary prior to successful integration within a production environment [4,5]. Therefore, this study investigates the lubricated sliding performance of ground, milled, and polished workpieces in order to evaluate the effectiveness of the filament tool when used as a post process to CBN milling of hardened cast iron.

2. Experimental setup

For this study the workpiece material was FC300 (JIS) grey cast iron that was induction hardened and tempered to an average hardness of 47 HRC. Five surfaces were prepared using three different manufacturing methods: a ground sample, two CBN milled samples created with different feed rates, and two milled + polished samples that were milled with different feed rates. A summary for each sample is shown in Table 1.

Table 1. CNB milling process settings.

Sample	A	B	C	D	E
Type	Ground	Milled	Milled	Polished	Polished
Feed (mm/rev)	-	0.050	0.100	0.050	0.100

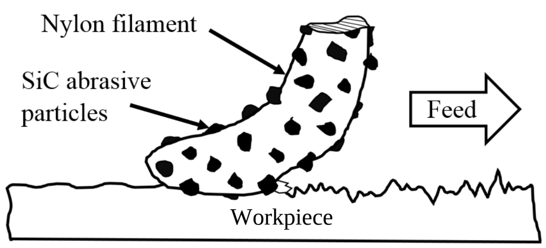

Fig. 2. Example of bristle undergoing elastic deflection during polishing.

2.1. CBN milling process

A DMG Mori NV7000 3-axis vertical machining center was used for the milling and polishing operations. A Sumitomo RM3160R 125 mm diameter shell mill with an axial rake angle of −5° and radial rake angle of −6° was used for milling. All samples were milled with a single Sumitomo BN7000 insert that was 90-95% volume CBN with WC-Co binder and had a 20° by 0.23 mm chamfered cutting edge. Previous work by Soshi et al. identified that CBN milling could be a financially viable alternative finishing process to grinding by noting that a milling with a cutting speed of 500 m/min with a feed of 0.050 mm/rev promoted longer tool life and consistent surface roughness [1].

For this study, a cutting speed of 500 m/min and depth of cut of 0.050 mm was used while the feed was varied between 0.050 mm/rev and 0.100 mm/rev to test different starting roughness conditions. The surface roughness of the four milled samples were measured with a Mitutoyo SJ310 contact stylus profilometer and filtered with a 0.800 mm cut-off wavelength to generate roughness data. When milled with 0.050 mm/ rev the surfaces had an average Ra of 0.42 μm, while a feed of 0.100 mm/rev yielded an average Ra of 0.70 μm.

2.2. Polishing with filament tool

Preliminary work done by the authors found that a disk-type filament tool with silicon carbide particles approximately 60-70 μm in diameter embed within 0.9 mm wide nylon bristles was most effective at altering both surface peaks and core roughness of the hard cast iron. Typically, an increase in abrasive particle size requires that a thicker filament be used to ensure proper bonding around the abrasive media, while thinner bristles allow for greater bristle count per unit area resulting in a higher number of cutting edges making contact with the surface [3]. The tool in this study can be considered as an intermediate between coarse and fine tools options.

Unlike rigid milling tools, the complaint bristles of the polishing tool elastically bend and deflect as they contact the surface of the workpiece. This makes it more complicated to precisely set the tool length offsets with the filament tool. The degree of bristle deflection is primarily controlled by the penetration depth of the tool, therefore axial forces applied by the tool were monitored using a spindle mounted Kistler 9124B force dynamometer to dynamically set tool length offsets after each tool change and also compensate for wear of the bristle tips. Using this method, the average axial force of 28 N ± 11 N was implemented during the polishing experiments.

A summary of the polishing process settings used for this study are shown in Table 2.

Table 2. Polishing process settings.

Spindle speed (RPM)	Feed rate (mm/min)	Dynamic axial load (N)	Number of strokes
2,000	2,000	30	40