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Effects of cryogenic treatment and refrigerated air on tool wear when machining medium density fiberboard

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ABSTRACT

Cooling of cutting tools with liquid coolants and lubricants is impractical when machining dry wood or wood composites. This study examines the combined effect of cryogenic tool treatment and using refrigerated air for cooling tools on reducing tool wear. A total of four, double-flute, solid, tungsten carbide router bits were used to machine medium density fiberboard with a CNC router. Three of the four tools were cryogenically treated to below −149 °C. During cutting, refrigerated air was applied to two tools, while the other two cut at ambient temperature. All tools were examined under the stereo light microscope to capture images in order to measure tool wear. Elemental analysis was performed using scanning electron microscopy to determine the percentage of specific elements present on clearance faces of tools after cutting was completed. Results show that less tool wear occurs when using refrigerated air and cryogenic treatment, thereby increasing tool life when cutting medium density fiberboard.

1. Introduction

The objective of this study was to examine the effects of cryogenic treatment and cooling tools with refrigerated air on tool wear when machining medium density fiberboard (MDF).

Stewart et al. (1986) found that tool wear when machining medium density fiberboard with tungsten carbide tools was caused by high-temperature corrosion and/or oxidation. These high temperatures occur due to friction during the cutting action. Further, Padilla et al. (1991) have shown that high-temperature corrosion and/or oxidation are major contributors to the deterioration and wear of tungsten carbide in machining MDF. In a follow-up study, Stewart (1992) showed that oxidation, halogenation, sulfidation, nitridation, and other corrosion reactions could occur between tungsten carbide and the MDF. Consequently tool materials, tool treatments, and/or cooling methods may be selected to reduce adverse high-temperature effects and to enhance tool life. A cryogenic treatment of C2 tungsten carbide (WC–Co) with cobalt as a binder reduced tool wear in a continuous turning test (Stewart, 2004). However, most wood machining processes are interrupted cuts. The cryogenic treatment has been successfully applied to tool steels and other alloys but application to tungsten carbide tooling has been limited.

Unlike coatings, a cryogenic treatment is a one-time, permanent treatment that affects the entire tool (Mohan Lal et al., 2001). The temperature of the tool is gradually reduced in a refrigeration chamber to below −149 °C (−300 °F) and maintained for more than 20 h before being returned to ambient temperature (Cohen and Kamody, 1998). Cryogenically treated material may also require a mild subsequent heat treatment (300–400 °F) to relieve stresses.

Another study shows that refrigerated air reduces tool wear of solid carbide router bits when machining MDF (Gisip et al., 2007). Consequently, tool wear may be further reduced by cooling cryogenically treated tools with refrigerated air.

Since tool wear may be caused by one or more of the aforementioned phenomena, easily applied techniques may reduce tool wear. The cryogenic treatment and refrigerated air were applied to solid tungsten carbide router bits as practical methods of reducing tool wear during wood machining. Cobalt is a common binder for tungsten carbide tools and it is readily affected by high-temperature oxidation/corrosion during wood machining (Reid et al., 1991). Although changes may occur in the alpha, eta, and gamma phases which may affect tool life of tungsten carbide, these changes and possible effects were not within the scope of this study. The previously mentioned wood machining studies indicate that the cobalt binder primarily, but not only, reacted through oxidation and corrosion as a major wear mechanism. Consequently, easily applied techniques, a cryogenic treatment and/or refrigerated air, were tested to demonstrate the possibility of reducing tool wear when wood machining with solid carbide router bits.

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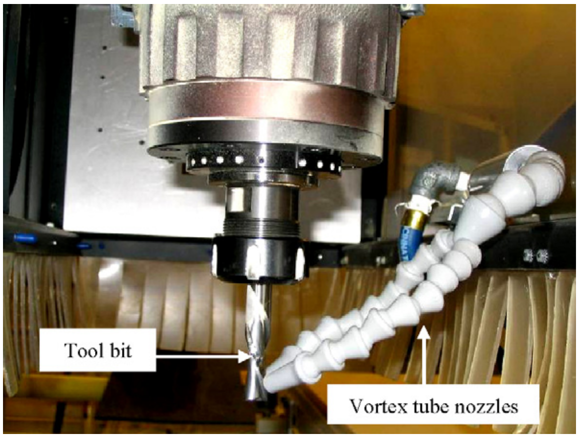

Fig. 1. Experimental setup.

Since high-temperature phenomena are considered a major wear mechanism, energy-dispersive spectroscopy (EDS) analysis was performed to simply verify the elemental agents were available for the reactions, not to determine the compounds formed on the reactions.

Actual tool wear testing requires extensive time and careful planning. A concern of tool wear testing is obtaining meaningful results from minimum testing. Consequently, the tools need to be similar and represent a population. Likewise, the workpiece material such as MDF has to be relatively uniform. Randomization of the tools (12 double-flute router bits) and a large sample of MDF (120 MDF sheets) can help assure the uniformity of the respective populations. If the tool and workpiece material are similar, respectively, then other treatments such as a cryogenic treatment of the tools and/or refrigerated air should readily exhibit a tool wear difference or no-difference in simple comparative tests. Changing the substrate of the tool, a cryogenic treatment, or cutting tool environment (refrigerated air) could have beneficial results. Hence, a cryogenic treatment and refrigerated air were evaluated for machining MDF with solid carbide router bits.

2. Materials and methods

Four double-flute, solid, tungsten carbide tools from the randomized tool population with a 12.7 mm (1/2 in.) diameter were tested in this study. The tools contained 10% of cobalt. Three of the tools were cryogenically treated to −149 °C (−300 °F). During machining, tools moved at a feed speed of 9.75 m/min and 16,000 revolutions/min. One of the three cryogenically treated tools, as well as the untreated tool, cut at the ambient temperature of 21 °C (70 °F) without the application of refrigerated air. The two remaining cryogenically treated tools had a refrigerated air of 4.4 °C (40 °F) and −6.7 °C (20 °F), respectively, applied to them during cutting. The refrigerated air was produced with a vortex tube. The experimental setup is shown in Fig. 1.

Twenty-two MDF sheets 1.24 m wide (4 ft), 2.46 m (8 ft) long and 19.05 mm (3/4 in.) thick from the randomized MDF population were cut by each tool. The average density of the MDF was 49.9 lb/ft^3. The MDF was not laminated. Each tool entered the sheet in the up-milling direction, cut across the width, retracted, and repeated the process 360 times/sheet. This produced over 166,000 m in length of cut per flute. The depth of cut was 6.35 mm (1/4 in.), or one half of the tool diameter. The machining was done on a CNC router.

The four double-flute, tungsten carbide router bits and 88 MDF sheets were selected from the randomized populations of 12 similarly manufactured and closely matched router bits and 120 MDF sheets respectively. Each flute of the two-fluted router bits represented a sample and the 22 sheets represented the MDF population (Lipka, 2005). If the limited observed data after testing is consistent for each flute, then the data represent valid tests for applying a cryogenic treatment and/or refrigerated air in these tests (Lipka, 2005). The individual flutes and MDF sheets represent their respective populations.

Tool wear was determined with an image analysis-based method (Gisip et al., 2007). With this method, each tool was placed in a holder under the stereo light microscope set to 3× magnification. A digital camera attached to the microscope captured images of the clearance face of the tool. Tool wear was quantified with image analysis and measurement software. The area from which the tool material was worn off completely was termed the wear void, and it was calculated as the difference between the area of the original clearance face and the remaining clearance face. Further, the area of the remaining clearance face was divided into two regions, an area which begins to show wear through scratches and rounding (termed the wear scar area) and an area which does not exhibit any tool wear (termed the unworn area). In order to compare wear between different tools and treatments, tool wear was expressed as a percentage of the original clearance face area. The total tool wear was defined as a ratio of the sum of wear void and wear scar areas to the original clearance face area.

It has been shown (Gisip et al., 2007) that power consumption, sound level and edge quality of the cut MDF depend on tool wear. We took measurements of these variables throughout the experiment and found that neither cryogenic treatment nor refrigerated air had an adverse effect on them and therefore they are not reported in this paper.

Scanning electron microscopy allowed for the examination of the microstructure and surface morphology of tool cutting edges for the presence of cobalt binder, fissures, pits, depressions, and other characteristics of edge surface quality. To identify and quantify the elemental composition of the sample areas, energy-dispersive spectroscopy analysis was performed as mentioned previously. Readings were taken at ten different locations on the clearance face, each one progressively further removed from the cutting edge.

3. Results and discussion

3.1. Tool wear

The overall results for wear void, wear scar, and total wear are shown in Tables 1 and 2. Two-way ANOVA of total wear showed that cryogenic treatment was significant ($p = 0.0001$). Cryogenic treatment reduced the total wear from 76.2% to 46% of the original clearance face area (Table 1). Temperature was also a significant fac-

Table 1
Average wear void, wear scar and total wear as a percentage of the original clearance face area for untreated and cryogenically treated tools cutting at 21 °C.

	Temperature (°C)	Wear void (%) ($p = 0.006^*$)		Wear scar (%) ($p \leq 0.0001^*$)		Total wear (%) ($p \leq 0.0001^*$)	
		Mean	Standard deviation	Mean	Standard deviation.	Mean	Standard deviation.
Untreated	21	32.1	3.0	44.1	0.1	76.2	3.1
Treated	21	20.7	8.0	25.3	2.4	46	5.6

* These p-values correspond to H_0: No treatment effect.