Cryogenic treatment of tungsten carbide reduces tool wear when machining medium density fiberboard

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Abstract

A cryogenic treatment (-306° F) was applied to C2 tungsten carbide (WC -6% Co) and compared with untreated carbide to determine if tool wear could be reduced during turning tests with medium density fiberboard (MDF). Both the tool force data and observation of the cutting edges indicate that tool wear was reduced. The cryogenic treatment appeared to have an effect upon the cobalt binder by changing phase or crystal structure so that more cobalt binder was retained during cutting.

High-temperature corrosion/oxidation has been shown to be a major contributor to the wear of tungsten carbide when machining medium density fiberboard (MDF) (Stewart 1992). Consequently, a change in the properties of the tool material to resist wear from the adverse wood machining environment needs to be investigated. A deep cryogenic treatment shows promise as a tool material treatment for increasing tool life.

A cryogenic treatment gradually reduces the tool temperature in an air-tight refrigeration dry chamber to below minus 300°F, after which the tool is slowly returned to room temperature (Cohen and Kamody 1998). Cryogenic treatment has been successfully applied to die and high speed steel (HSS) ferrous alloys.

The cryogenic process enhances the conversion from one phase (austenite) to another phase (martensite), which is a common change in ferrous metals as a result of heat treating and now cryogenic treating (Barron 1982, Batzer 2002). The cryogenic treatment increases hardness and wear resistance of ferrous alloys.

Tungsten carbide tool materials generally have a cobalt binder. Cobalt is next to iron in the periodic table as part of the VIII B group, has the same valences, and forms similar phases in crystalline structures. The tungsten carbide is a fairly stable and constant crystal structure under many conditions. Consequently, a cryogenic treatment of tungsten carbide tool material may have some effect upon the cobalt binder to enhance tool life. Since the cryogenic treatment hardens and toughens a HSS, the material is probably more chemically inert at high temperatures.

Previous results (Stewart 1991) have shown that tool wear can be reduced by selecting tool materials, coatings, or treatments that are chemically inert at high temperatures when cutting MDF. Cryogenically treated tungsten carbide was tested in a wood machining turning test with MDF to demonstrate that a cryogenic treatment may enhance tool life.

Methods

Turning tests were conducted on 3/4-inch-thick MDF with C2 tungsten carbide (WC -6% Co) tool material at 0.005 ipr and 550 rpm with a 15-degree rake angle and a 10-degree clearance angle. Three pieces of C2 were untreated and three pieces were cryogenically treated to -306° F. Thus, the treated and untreated tungsten carbide samples were replicated three times. The turning test turned 20 disks at approximately 18,000 inches per disk for a total length cut of 360,000 inches. The test procedures have been previously described (Stewart 1985).

Previous results (Stewart 1989) have shown that tool forces are linearly related to edge recession. Thus, tool forces after a predetermined length of cut were selected as a tool wear index for comparison of the treated and untreated C2. The measured dependent variables were the normal (F_n) and parallel (F_p) tool force components. The tool force components parallel and normal to the direction of tool travel relative to the workpiece were recorded by an oscilligraphic

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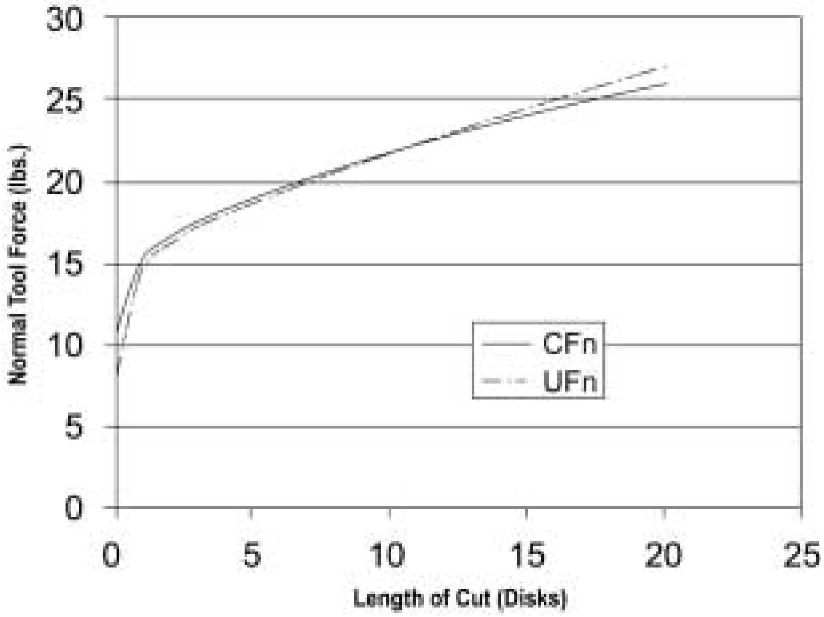


Figure 1. — The fitted non-linear normal force regression curves for the cryogenic-treated (CF_n) and untreated (UF_n) tungsten carbide with 10-degree clearance and 15-degree rake angle, respectively.

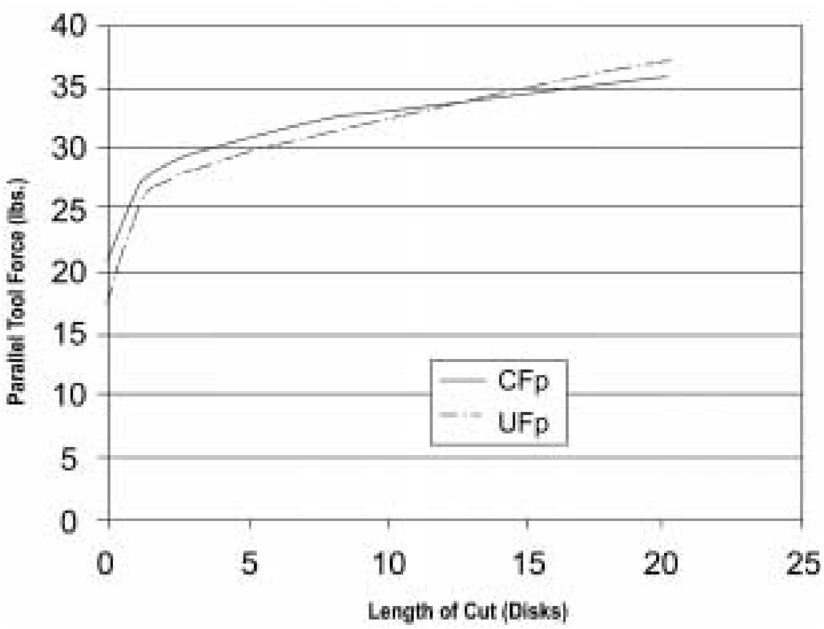


Figure 2. — The fitted non-linear parallel force regression curves for the cryogenic-treated (CF_p) and untreated (UF_p) tungsten carbide with 10-degree clearance and 15-degree rake angles, respectively.

recorder attached to a lathe dynamometer. The forces were recorded for the beginning and end of the first disk and at the end of each disk for the following nineteen disks. The dependent variables (F_n, F_p) were related to the length of cut (disks) with the model $Y = ax^b c^x + d$ where a, b, and c are regression coefficients and d is a constant. The coefficients and constant were determined by nonlinear regression techniques. The results are summarized in **Tables 1** and **2** and shown in **Figures 1** and **2**. In addition, scanning electron micrographs show the wear of the treated and untreated C2 in **Figures 3** and **4**.

Results and discussion

The tool force results (**Tables 1** and **2** and **Figs. 1** and **2**) indicate cryogenic-treated tungsten carbide wears less and slower than the untreated tungsten carbides. Since the r^2 values for the cryogenic-treated carbides are less than for the untreated carbide, some transformation or changes probably resulted from the cryogenic treatment. Also, the tungsten carbide (WC) crystal is a stable structure; therefore, the change probably occurred in the 6 percent cobalt (Co) binder. The closeness of the tool force curves (**Figs. 1** and **2**) indicate the change may be small and in just the binder.

Although the curves for cryogenic-treated and untreated C2 tungsten carbide may appear similar in **Figures 1** and **2**, **Tables 1** and **2** show the curves are different. The coefficients of determination (r^2) (**Table 1**) show exceptionally good correlations between length of cut and tool forces, which have been related to edge recession (Stewart 1989). Additionally, the tool forces increase 25 to 30 percent more for the untreated C2 than for the cryogenic-treated C2 in these tests, which indicates a faster wear rate (**Table 2**). Although these tests may not be considered conclusive, they indicate a cryogenic treatment of tungsten carbide may reduce tool wear. The greater initial forces (**Table 2**) for the cryogenic-treated material further suggests a change at and/or near the knife edge. Since the tool force change or increase was much less for the cryogenic-treated material than for the untreated material, the wear rate for the cryogenic-treated carbide was less than for the untreated carbide for these tests. At the end of the tests, **Figures 1** and **2** show the tool force components to be diverging and the tool forces increasing more for the untreated carbide than for the cryogenic-treated carbide. These tool force trends appear to extend beyond the scope of these tests.

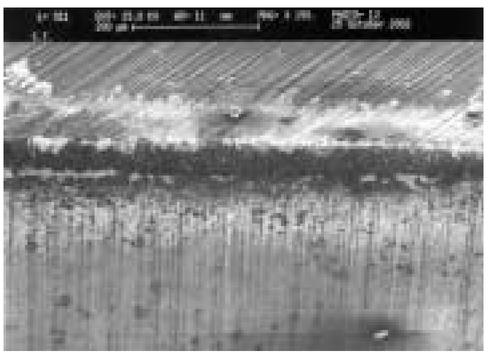
The tool wear is also shown to be more (**Figs. 3** and **4**) for the untreated carbide than for the cryogenic-treated carbide. The wear scar or zone is wider as shown for the untreated carbide at 150Δ. The figures at 2,000Δ also show more cobalt binder retention among the tungsten carbide grains for the cryogenic-treated carbide. These observations tend to substantiate that some phase or structure transformation occurred in the 6 percent cobalt binder of the tool material. The transformation produced a more refractory structure of the binder.

Table 1. — Regression coefficients (a, b, c) and constant (d) for relating variation of the normal (F_n) and parallel (F_p) forces as the dependent variable (Y) relates to the independent variable length of cut (x) with the model $Y = ax^b c^x + d$ for cryogenic-treated and untreated C2 tungsten carbide (WC -6% Co).

		a	*b*	*c*	*d*	r^2
Cryogenic C2	F_n	5.286	0.3207	1.007	9.9	0.847
	F_p	5.692	0.3139	0.997	21.7	0.810
Untreated C2	F_n	8.079	0.2158	1.014	6.5	0.918
	F_p	7.608	0.2250	1.011	18.3	0.949

Table 2. — The initial, final, and change for the normal and parallel forces for cryogenic (CF_n, CF_p) and untreated (UF_n, UF_p) tungsten carbide calculated from the relationship $Y = ax^b c^x + d$ with values from Table 1 for a, b, c, and d, respectively.

	CF_n	UF_n	CF_p	UF_p
Initial value	9.9	6.5	21.7	18.3
Final value	25.8	26.9	35.4	36.9
Change (*D*)	15.9	20.4	13.7	18.6



3a
150x
C.T.

3b
500x
C.T.

3c
2,000x
C.T.

Figure 3. — The worn knife edge at a) 150× , b) 500×, and c) 2,000× after cutting 360,000 inches (20 disks) length of cut in MDF at 0.005 ipr and 550 rpm with cryogenic-treated C2 tungsten carbide.

Summary and conclusions

Previous results (Reid et al. 1991) have shown that the chemical degradation of WC -6 percent CO tool material was at least a two-stage process when machining MDF. Subsequent research (Padilla et al. 1991, Stewart 1992) has shown additional wear mechanisms occur. These mechanisms include sulfidation, halogenation, and oxidation. One dominant reaction is the chemical degradation of the cobalt binder at lower temperatures. At higher temperatures, oxidation of both the WC grains and cobalt matrix occurs. The cryogenic treatment apparently reduces the chemical degradation of the cobalt matrix at the lower temperatures.

Consequently, alloying the cobalt binder, such as the new corrosion/oxidation-resistant carbide grades, substantially reduces tool wear. In addition, other tool materials, coatings, treatments, or combinations should be evaluated, which reduce the chemical degradation found in the WC-cobalt/ MDF system. Although the WC-cobalt/ MDF system was the objective of this investigation, the results imply the importance of chemical degradation of tool materials when machining dry wood as well as reconstituted wood products and perhaps many other materials (plastics, graphite components, etc.). These tests indicate cryogenic treating of tungsten carbide with a cobalt binder may enhance tool life. Additional tests will be needed to determine the economic feasibility of cryogenic treatments of tungsten carbide tool materials for other wood machining combinations.

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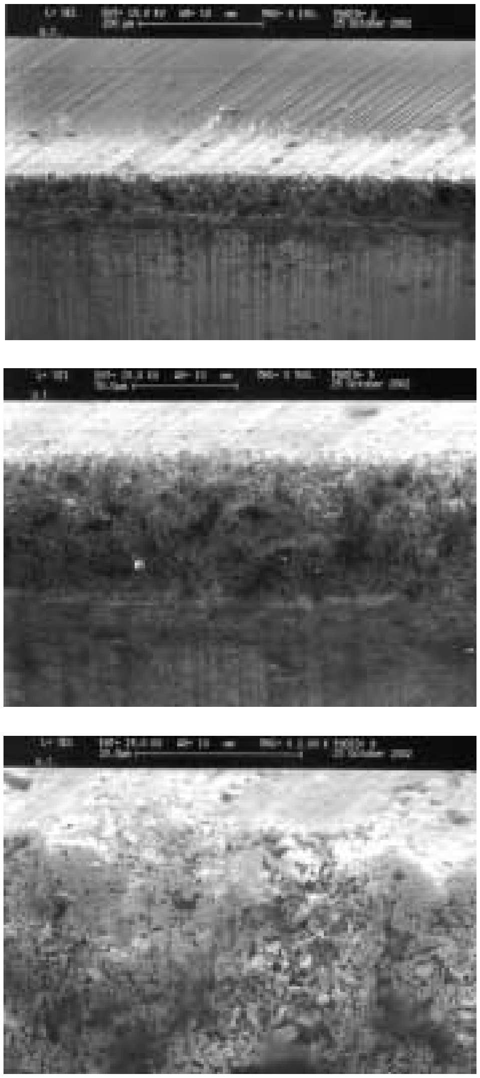

4a
150x
U.T.

4b
500x
U.T.

4c
2,000x
U.T.

Figure 4. — The worn knife edge at a) 150×, b) 500×, and c) 2,000× after cutting 360,000 inches (20 disks) length of cut in MDF at 0.005 ipr and 550 rpm with untreated C2 tungsten carbide.

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