Vapor boron treatment of composites reduces tool wear

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Abstract

Various composites, including oriented strandboard and medium density fiberboard, were treated via vapor boron technology. Treated samples were compared to untreated composites using a tool force measuring technique. Tool forces measured with a dynamometer indicated that boron addition has a positive effect on cutting tool wear. Visual and scanning electron microscopy (SEM) examination indicated a wider wear zone on the cutting edge of the tool for the untreated material. Boron transfer to the tool material was confirmed by SEM.

Numerous investigators have reported on the properties of composites treated with boron compounds (Barnes et al. 1989; Burton et al. 1990; Bergervoet et al. 1992; Hashim et al. 1992, 1994; Laks and Palardy 1993; Murphy et al. 1993). The damaging effects of vapor boron treatment (VBT) have generally been limited to high retentions (Hashim et al. 1994). The objective of this work was to ascertain the effect of the treatment on tool wear for composites treated using VBT. One way to indicate tool wear is to monitor the cutting forces associated with the cutting tool. When the normal forces exceed the parallel force, this indicates that the knife is very dull (Stewart 1985). Tool forces have been linearly related to edge recession (Stewart 1989). Greater cutting forces indicate more tool wear. The treatment of tool material with boron in a process known as boriding has been shown to increase tool life (Stewart 1987). It is hypothesized that boron treatment of wood may have the same result.

Materials and methods

Materials

Oriented strandboard (OSB) manufactured from mixed southern pine and southern hardwood furnish (SO) or from mixed northeastern conifer and hardwood furnish (NE) was acquired from commercial producers. The SO-OSB was bonded with liquid phenol-formaldehyde resin and the NE-OSB was bonded with a powdered phenol-formaldehyde resin. Commercial medium density fiberboard (MDF) intended for the siding market and manufactured from SO or northern hardwood furnish (NO) was included in the study. The SO-MDF was a wet process board and the NO- MDF was a dry process board. Both were bonded with a phenol-formaldehyde resin.

Treatment

The composites were vapor phase treated with trimethyl borate as has been described elsewhere (Hashim et al. 1992,1994). Each type of composite was treated to different retention levels in a 0.8-m^3 treatment vessel (**Tables 1** and **2**). Samples were separated by 3-mm stickers and loaded into the vessel. The vessel was evacuated to 5 mbar and a metered amount of trimethyl borate sufficient to achieve the target retentions was admitted. Gas contact time was 8 hours for the high retention and 40 minutes for the medium retention level. One additional treatment level (LOW) was utilized for some of the boards in this study. For these samples, the vapor boron contact time was 40 minutes. Boron retentions were calculated by weight gain as %w/w boric acid equivalent (BAE).

Testing methods

The tool wear test compares cutting parameters by monitoring cutting forces

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Table 1. — *Tool wear results for oriented strandboard from two mills.*

Treatment level-disk no.	Boric acid equivalent	Parallel force	Normal force
	(% w/w)	- - - - - - - - - - - - (lbf) - - - - - - - - - - - -	
Southern mill			
Control-0[a]	0	12	5
Control-1	0	23	22.5
Control-2	0	27	28.5
Control-3	0	30	31
Low-0[a]	0.11	12	5
Low-1	0.11	24	32
Low-2	0.28	28	30
Low-3	0.5	30	33
Medium-0[a]	0.94	12	4
Medium-1	0.94	22	14
Medium-2	0.86	24	18
Medium-3	0.78	27	20
High-0[a]	5.81	13	3
High-1	5.81	30	22
High-2	7.19	26	24
High-3	6.68	32	26
Northeastern mill			
Control-0[a]	0	13.5	3
Control-1	0	16	8
Control-2	0	19	10.5
Control-3	0	20.5	11.5
Low-0[a]	0.43	12	4
Low-1	0.43	14	6
Low-2	0.53	14	7
Low-3	0.55	17	7
Medium-0[a]	0.78	12	3.5
Medium-1	0.78	15.5	6
Medium-2	0.97	15.5	6.5
Medium-3	0.77	16	8
High-0[a]	7.01	11	4
High-1	7.01	15	5.5
High-2	7.35	15.5	7.5

[a]Initial reading of disk 1.

for a long continuous cut with a single knife-edge (Stewart 1985). Samples tested were rounded into roughly 11-inch circles and mounted onto a lathe. The lathe tool for turning the disks had a single 25-mm knife edge (standard C2 tungsten carbide) with a 15-degree positive rake angle and a 10-degree clearance angle. This tool was held in a force transducer that measured the parallel and the normal forces simultaneously. The forces were recorded continuously. For analysis and presentation purposes, the initial and final readings for the first disk of each combination and the final reading for the subsequent disks are presented in **Tables 1** and **2**. The total length of cut was dependant on the number of disks, which varied, for each combination of composite and treatment level. Comparison was with untreated controls. The total length of cut was 18,000 inches per disk at a constant crossfeed (depth of cut) of 0.005 inches per revolution. Turning speed was constant at 550 rpm. After completion of the machining operations, the knives were examined with scanning electron microscopy (SEM) in order to visually examine the knife edges for wear and boron transfer.

Results and discussion

Data for parallel and normal forces for the OSB boards are shown in **Figure 1**. These are typical curves for OSB. According to the tool forces for the NE board, the control showed more severe dulling compared to the treated samples. Stewart (1985) stated that a normal force greater than the parallel force indicates a dull knife. All treated samples had less effect on tool forces than the controls. The reduced tool forces in the NE board indicated a positive effect of boron addition on tool wear. For the SO control boards, the tool forces indicated that the tool dulled after cutting the first disk and more so after the next two disks. The low treatment level had the worst effect on tool forces, indicating more rapid dulling of the tool after the first disk. The medium treatment level proved to be the optimum level for tool forces, although none of the medium or high treatment level specimens appeared to dull the tool. Data for OSB are shown in **Table 1**.

The addition of boron to OSB from both mill locations improved the workability of the material, but the NE boards dulled less than the SO boards. The SO boards had a slightly higher density than the NE boards and this could have affected the results.

Tool wear data are shown in **Table 2** for medium density fiberboard and the typical force curves are shown in **Figure 2**. None of the treated specimens appeared to completely dull the knife according to force assessment. For the SO boards, an optimum treatment level for tool forces existed for the medium retention level. At this retention, the six medium treatment level disks tested dulled the knife less than the high retention level samples. Higher retention levels did not appear to completely dull the knife, but according to force assessment, had a less positive effect. This would indicate that a finite amount of boron addition will have a positive effect on tool wear, after which the beneficial effect is reduced.

The control samples of NO had a more negative effect on tool forces than the treated samples. Six control samples were tested. After four disks were tested, the normal force was greater than the parallel force, indicating a higher degree of dulling. The low retention level specimens had slightly lower forces than the controls. As with the SO samples, the medium treatment level results indicated an optimum level for tool wear.

In both types of MDF, the control specimens had greater wear characteristics than the treated samples. The extent of tool wear appears to decrease to a minimum with increasing treatment

Table 2. — Medium density fiberboard tool wear results for two mill locations.

Treatment level-disk no.	Boric acid equivalent	Parallel force	Normal force
	(% w/w)	---------- (lbf) ----------	
Southern mill			
Control-0[a]	0	21	22
Control-1	0	26.5	26
Control-2	0	27	27
Medium-0[a]	1.41	11.5	4
Medium-1	1.41	17	9
Medium-2	1.22	19	11.5
Medium-3	1.36	18.5	13
Medium-4	1.25	22	16
Medium-5	1.36	22.5	17
Medium-6	1.38	23	18.5
High-0[a]	4.36	12	4
High-1	4.36	18.5	12
High-2	3.99	20	15
High-3	3.96	20	17
High-4	3.86	23	19.5
High-5	4.08	24	21
High-6	6.19	23	21
Northeastern mill			
Control-0[a]	0	9	3.5
Control-1	0	14	10.5
Control-2	0	16.5	15
Control-3	0	17.5	16.5
Control-4	0	18	19
Control-5	0	19.5	19.5
Control-6	0	20.5	24.5
Low-0[a]	0.47	13	4
Low-1	0.47	17.5	10
Low-2	0.48	20.5	12.5
Low-3	0.47	22	16
Low-4	0.48	23	17
Medium-0[a]	1.1	13	11
Medium-1	1.1	18.5	18
Medium-2	1.17	21	20.5
Medium-3	1.22	19	20
Medium-4	1.21	18.5	22
High-0[a]	7.24	10	3
High-1	7.24	20	17

[a]Initial reading of disk 1.

level and then increase for subsequent boron addition. As with results for OSB, this suggests that there is a finite amount of boron in MDF that is beneficial to reducing tool wear. These tests show that VBT treatment actually improves the machinability of medium density fiberboard.

The reduction of tool wear can be seen most clearly in the SEM micrographs shown in **Figure 3** for treated and untreated MDF. Note the much wider wear zone on the control knife edge shown in the upper micrograph compared with that for VBT MDF below. Not only is the wear zone wider, less of the cobalt binder has been removed from around the tungsten carbide grains at the knife edge after machining the treated MDF. This can be seen even better in **Figure 4**. The boron appears to have bonded with and perhaps diffused into the cobalt and formed cobalt borides. As previously indicated, the cobalt borides are chemically stable. Consequently, tool wear from machining VBT composites is reduced. In **Figure 4** (upper), note the tungsten carbide grains with missing cobalt binder between them. In the lower micrograph, the grains are less evident with cobalt filling the interstices. The borided cobalt also has a lower coefficient of friction, which would further reduce the forces and wear.

Conclusions

This study has shown that treating composites with VBT reduces the tool wear associated with machining. Analysis of cutting tool forces coupled with visual observations of the knife edges confirmed this positive effect.

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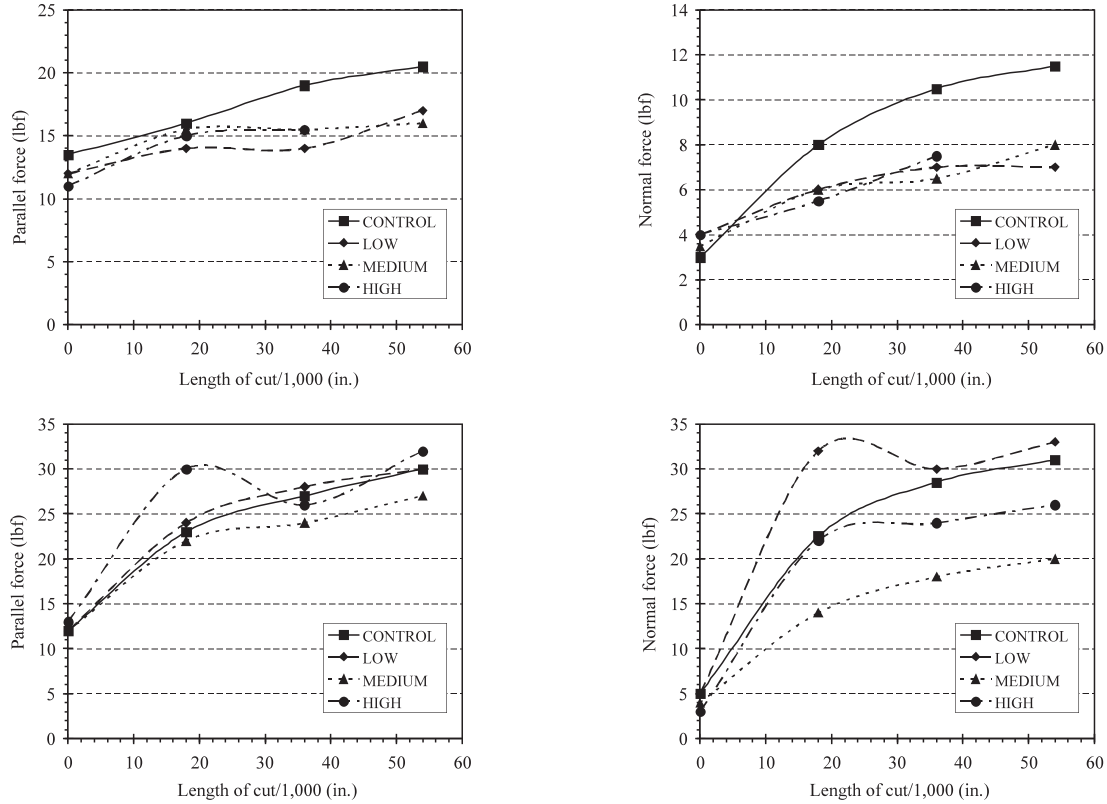

Figure 1. — Effect of boron addition on the parallel (left) and normal (right) tool force components for OSB from northeastern (upper) and southern (lower) U.S. mills.

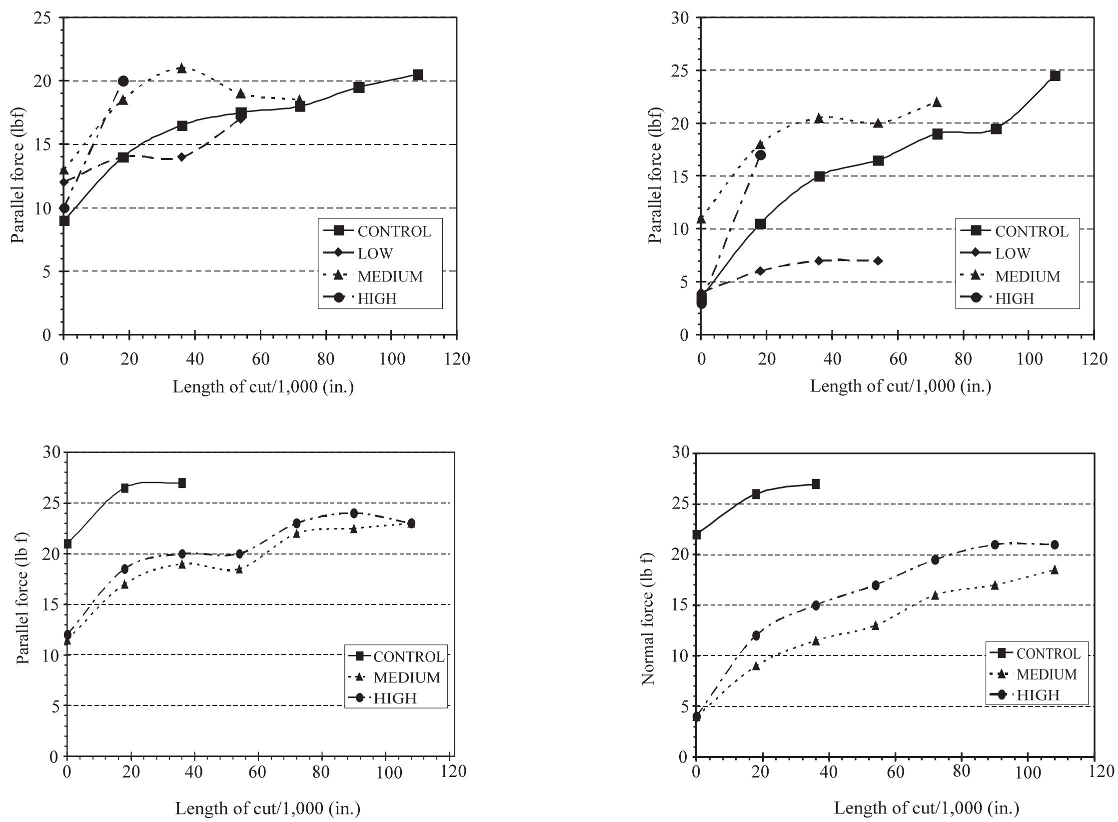

Figure 2. — Effect of boron addition on the parallel (left) and normal (right) tool force components for MDF from northern (upper) and southern (lower) U.S. mills.

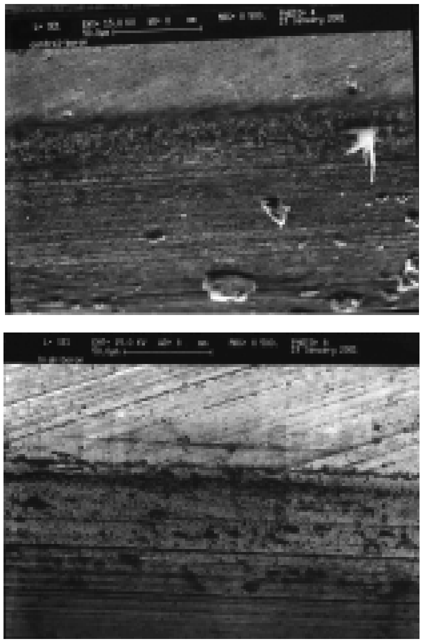

Figure 3.— SEM micrograph of knife edge wear zones for control (upper) and boron-treated (lower) MDF.

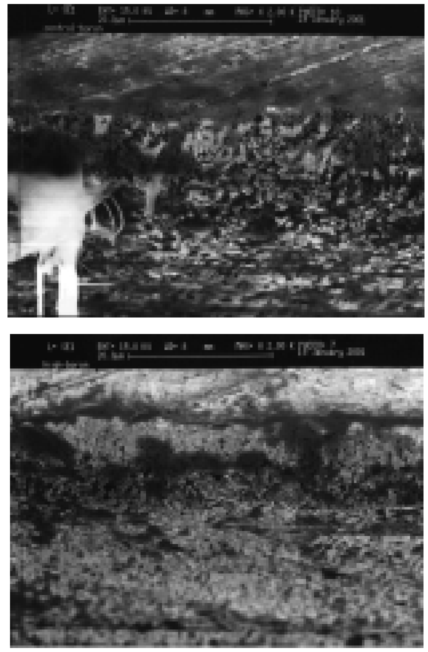

Figure 4.— High magnification of the wear zone of knife edges used to machine untreated (upper) and VBT-treated (lower) MDF.