

Tool Wear When Cutting Wood Fiber–Plastic Composite Materials

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Abstract

Wood fiber–plastic composite materials, a relatively new material, are finding applications mainly in the US residential and commercial construction markets. Thus, the volume of material produced and used is steadily increasing while the range of applications keeps expanding. So far, attention has been paid mainly to primary production processes of wood fiber–plastic materials, while secondary manufacturing processes have attracted less attention. However, with the broadening applications of such materials and their increasing use, secondary manufacturing processes for wood fiber–plastic materials are gaining importance.

This study investigated the performance of five commercially available wood fiber–plastic composite materials and solid wood (eastern white pine) with respect to tool wear and resulting material surface roughness. Large performance differences between different wood fiber–plastic composite materials and between solid wood and wood fiber–plastic composite materials with respect to tool wear were found. Solid wood did wear the exchangeable tungsten carbide knives with a standard cobalt binder and ultrafine carbide grain knives used for the tests 12 to 42 times less than the wood fiber–plastic composite materials. However, some wood fiber–plastic materials were found to have a smoother surface than solid wood after 38.2 m of cutting. As this research showed, different wood fiber–plastic composite formulations behave differently when subjected to secondary manufacturing processes, and more research is needed to better understand the underlying causes for those observations.

While wood fiber–plastic (WPC) composite materials are dominantly used to replace pressure-treated lumber applications, this new material can potentially replace a large array of products mainly made from wood in the future. New products include boardwalks, docks, automotive applications, railing systems or transportation devices, aerospace, aviation, and construction (Morton 2000, Smith and Wolcott 2005, Jordens et al. 2010). Indeed, many future applications have not yet been commercialized or conceived but are sure to be brought to market within a short time period. These largely untapped market opportunities helped the industry achieve double-digit growth prior to the onset of the recession in 2008. Today, with the US housing market at low levels of activity not seen in decades (Buehlmann and Schuler 2009) and future market prospects uncertain due to an excessive inventory and credit hard to come by, the industry's outlook remains clouded. However, when the current housing market problems have been worked out, the industry is expected to thrive once again.

With WPC materials being used in ever-wider ranges of applications, new processing requirements for the final product are emerging. Already, WPC decking boards are cut and shaped when being installed, as are other WPC products

such as rails and stair treads. Potentially, the future will bring forward WPC profiles that require the shaping and planing of surfaces from a raw block of material. Thus, tool performance becomes important because it is an important economic determinant of a business' market success.

Tool costs are often assumed to be determined only by the cost of sharpening the blades or their respective replacement costs. However, the true costs of tool wear include, in addition to sharpening or replacing dull blades, the costs incurred from interrupting production processes, tool and machine setup costs, plus all the administrative costs involved in handling tool sharpening or replacement. Additionally, depending on the material processed, more

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expensive tool materials are being used to lengthen the intervals between blade replacement cycles. Thus, manufacturers are understandably sensitive to the rate of tool wear related to any material they process.

Buehlmann et al. (2009) investigated the performance of WPCs subjected to abrasive machining. Five commercially available decking products (Choicedek, Fiberon, Smartdeck, Trex, and Carefree) were subjected to abrasive machining. Material removal rate (MRR; in grams per minute), the material surface roughness (R_q ; in micrometers), and the belt life (minutes) were measured. Large differences in MRR were detected among the products tested. The best performing material (Fiberon) had an MRR almost three times as large (6.35 g/min) as the worst performing product (Choicedek, 2.27 g/min). The MRR performance of the different products was found to be weakly correlated to the products' density. However, other sources, such as impurities in the material, do also influence MRR. R_q was found to be less variable among the five materials tested, but differences still existed. Trex, with an R_q of 10.71 μm , was found to have the roughest surface, while Choicedek had the smoothest ($R_q = 7.67 \mu\text{m}$). Belt life varied widely, from 38 minutes for Choicedek to 150 minutes for the Fiberon product.

Thus, these abrasive machining tests indicated that differences between materials when performing tool wear tests could be found. According to Klamecki (1979) "the wear of woodcutting tool is the process which makes a usable tool unfit for continued use." Stewart (1991) found that tool wear can be reduced by selecting tool materials, coatings, or treatments, while Lemaster et al. (1985, 2000) showed the importance of continuously monitoring tool wear and showed methods and systems to perform in order to determine tool wear.

The objective of this research, then, was to describe the characteristics and behavior of six commercially available WPC materials and a solid wood material when subjected to tool wear tests. A series of tests was undertaken to measure the tool wear and the resulting R_q of the seven materials.

Materials and Methods

Our study used commercially available materials and standard methods to investigate the tool wear from machining WPC materials. In particular, this section elaborates on the materials and testing methods used.

Measurements and analysis

Many different methods to cut materials exist. Routing is often used to compare different materials' wear on knives. North Carolina State Universities' Wood Machining and Tooling Program (WMTRP) developed a standardized testing method to measure tool wear for wood products (Sheikh-Ahmad and McKenzie 1997). Using this test, different materials can be compared with regard to their impact on knife sharpness. Figure 1 displays the test conditions used for this study and executed on the WMTRP's Thermwood Model 40 Turret Router with single insert tool holder, specimen fixtures on the router table, and test specimen being worked on. The WPC material was obtained in 3.78-m (8-ft) lengths and cut into four equally spaced sections. The tool wear was checked after every 10 cutting passes ($\sim 9.6 \text{ m}$). Before and after tests, standard blade wear measurement procedures were followed for



Figure 1.—Tool wear test conditions: router table, single insert tool holder, specimen fixture, and test specimen.

measuring nose width (NW) of the blades under investigation using a microscope. Figure 2 shows details of NW measurement procedures. The measurement procedures were as follows.

For each test, blade measurements were taken at five positions along the working knife edge (at 0, 500, 1,000, 1,500, and 2,000 μm from the edge that worked in the material). (1) Measure new blade's NW at five positions (necessary, because NWs of new blades can vary between 5 and 10 μm), and (2) measure tool wear at four places after 9.6, 19.1, 28.7, and 38.2 m of cutting through the material.

While tool wear (NW) was measured prior to cutting and at four intervals (9.6, 19.1, 28.7, and 38.2 m), R_q of the wood fiber–plastic material was measured after 38.2 m of

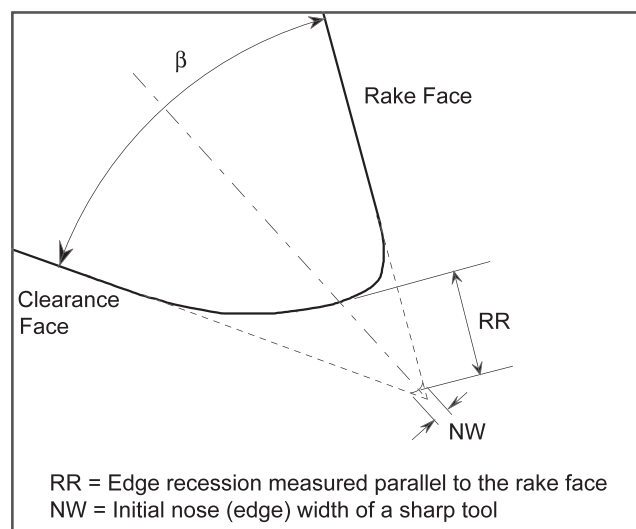


Figure 2.—Semantic explanation of nose width (NW; in micrometers) measurement after each test cycle.

cutting. Locations for surface roughness measurements were (1) across the cut (i.e., perpendicular to the tool movement), (2) lengthwise at the edge of the material along the cut, and (3) lengthwise at the center of the material along the cut.

At each location three randomly placed measurements were taken, and the averages of these three measurements are reported in this publication.

Materials

Commercially available, standard decking materials were used for this study. For comparison reasons, softwood was also tested to assess wood fiber–plastic materials’ fit as a substitute for lumber in decking applications. In particular, the study investigated and compared the following materials: (1) eastern white pine (*Pinus strobus*; specific [SP] gravity, 0.35), (2) Choicedek (A.E.R.T. Inc., Springdale, Arkansas; SP gravity, 0.98), (3) Excel decking (Cox Industries, Inc., Orangeburg, South Carolina; SP gravity, 1.19),¹ (4) Fiberon (Fiber Composites Corporation, New London, North Carolina; SP gravity, 1.11), (5) Smartdeck (US Plastic Lumber, Boca Raton, Florida; SP gravity, 0.99), and (6) Trex (Trex Company, Winchester, Virginia; SP gravity, 0.91).

Two samples, each 0.6 m long, were prepared for each material. The samples were oriented along the longitudinal axis of the wood fiber–plastic decking material and parallel to the grain for eastern white pine. No changes to the thickness or the width of the material were made. From each decking material, two 0.6-m-long pieces were prepared. All samples were stored under controlled conditions at 12 percent equilibrium moisture content (EMC). The eastern white pine material’s EMC was determined to be 12 percent prior to the tests.

Prior to any processing with the blades used for the tests, a clean cut was made longitudinally along both edges of the material using a blade not involved in these tests. Once a clean, even edge was cut roughly two-thirds through the material’s thickness, a new blade, whose NW was measured and recorded, was inserted and used. Sixteen passes along one edge were made (16 passes equal 9.6 m), after which another 16 passes were made along the material’s second edge. The third and fourth set of cuts (four sets total, for a total cutting length of 38.2 m), were done the same way on the second specimen from the same material.

Blades

Exchangeable tungsten carbide knives with a standard 3 percent cobalt binder and an ultrafine carbide grain (0.5 to 0.9 mm) were used for these tests. Tungsten carbide tooling is frequently used in wood machining applications (Feld et al. 2005). As indicated above, the nose (cutting edge) of each blade was checked and measured prior to cutting. Blades with an original NW of more than 10 μm were rejected. Useable blades were inserted into a single insert tool holder by Leitz and mounted on a hydro chuck by ETP, Inc., on the router.

¹ The Excel product, due to its hollow core, was measured at slightly different positions; however, for Excel as for all other materials tested, the average of four measurements is reported.

Router

The WMTRP’s Thermwood router, model 40 turret with a 9-hp spindle, was used for the tests. Individual test specimens were clamped on a special fixture mounted on the router table (Fig. 1). Prior to testing, a clean cut at a minimum of 1.6 mm deep was made along the test specimen’s edges to ensure that all contaminants and material impurities along the edge have been removed. The test specimens were clamped into a special fixture. Prior to cutting with the test knives, a cut at a minimum of 1.6 mm deep was made along the outside of the specimen to remove potential contaminants. Table 1 shows the test conditions.

Microscope

To measure NW, a Keyence video optical microscope with digital picture capturing and measuring capabilities was used.

Profilometer

A stylus-type Mitutoyo profilometer was used to assess the surface quality of the tool wear samples. The surface quality was determined by measuring the Rq, which is a measurable characteristic and is defined as the average of the irregular vertical deviations from the nominal surface over a specified surface length (Kalpakjian and Schmid 2001, Groover 2002, Saloni et al. 2005). The root-mean-square average Rq (in micrometers) is the measure for Rq used in this research.

Procedure

The following procedure was consistently followed for the tool wear tests: (1) identify the test specimen, (2) fix specimen into specimen holder of router and fix the blade used for the first edge cleaning cut into the blade holder, (3) reset the router program to zero position, (4) do first cut to clean the edge and then stop the router, (5) exchange cleaning blade with the appropriate blade from the test series, (6) let the router make 16 passes on the edge of the specimen in the clamp, (7) remove blade and measure NW, and (8) change test specimen according to experimental plan and then repeat steps until all tests are done.

Results and Discussion

Figure 3 displays the results of the NW after 0, 9.6, 19.1, 28.7, and 38.2 m for the six materials (eastern white pine, Fiberon, Excel, Smartdeck, Trex, ChoiceDek) tested. Eastern white pine wore the blade’s NW after 38.2 m of cutting to 10 μm (average of four measurements), only

Table 1.—Test setup at the router for the tool wear measurements.

Parameter	Setting
Spindle speed (rpm)	18,000
Feed speed (m/min)	8.9
Depth of cut (mm/pass)	1.6
Blade carbide grade	Sandvik H3F
Length of cut (m/pass)	0.6
No. of cuts per test	16
No. of tests	4
Mode of cut	Conventional (up milling)

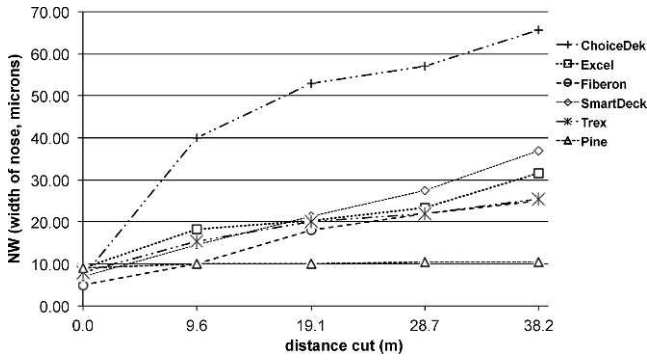


Figure 3.—Nose width (NW; in micrometers) for all six materials tested at 0.0, 9.6, 19.1, 28.7, and 38.2-m cutting length.

marginally larger than prior to the tests (9 μm). However, tool wear was considerably lower in white pine compared with the other materials. Fiberon, the most benign Wood fiber–plastic material on tool sharpness, wore the blade to an average NW of 25 μm after 38.2 m of cutting. This was five times the NW measured prior to the test (5 μm). All the other wood fiber–plastic material wore the blade more aggressively than did Fiberon. ChoiceDek was the material that produced the greatest amount of tool wear of all materials tested. ChoiceDek wore the blade’s NW after 38.2 m to 65 μm (Fig. 4), more than twice the NW from Fiberon (25 μm) and more than six times the NW from eastern white pine (10 μm ; Fig. 5). The three other wood fiber–plastic materials (Excel, Smartdeck, and Trex), which produced NWs of 31.5, 37.0, and 25.4 μm , respectively, were in-between these two materials.

To assess whether the location of a cut along the material’s edge has an influence on tool wear (i.e., knife NW), five measurements were taken along the blade. These five points were located, measuring from the extreme corner of the blade (e.g., the one who worked the material at the end of the blade), at 0 μm , and at 500, 1,000, 1,500, and 2,000 μm . In fact, the average of these five measurements along the blade edge that was engaged in the material was used to report the NW for each material and test run. However, the WPC materials did not display consistent

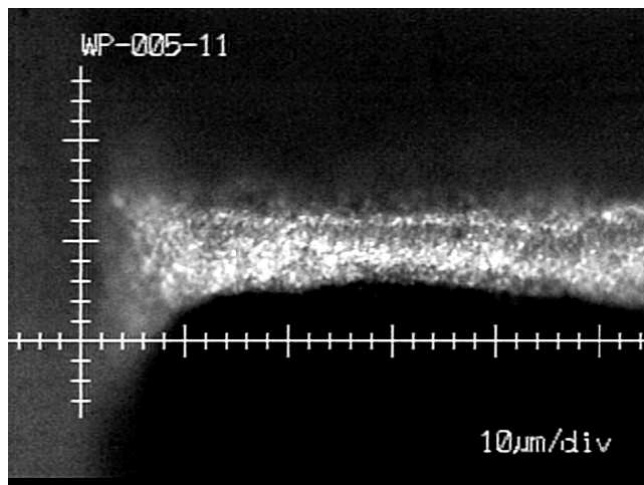


Figure 4.—Top view on blade nose used to cut the ChoiceDek material after 38.2 m of cutting (nose width, 65 μm).

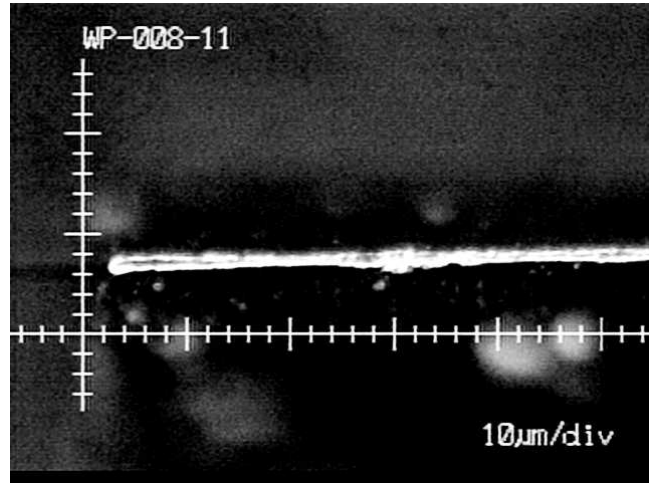


Figure 5.—Top view on blade nose used to cut the eastern white pine material after 38.2 m of cutting (nose width, 10 μm).

differences in wear depending on the depth of the cutting position, as would be expected if the materials had density gradients over their thickness or changes in material composition over their thickness. ChoiceDek, the material causing the most extensive wear on the knife; can be used to illustrate the observations made. Figure 6 shows the NW (in micrometers) of the knife used to cut the ChoiceDek after 0, 9.6, 19.1, 28.7, and 38.2 m of cutting at five different depths (0, 500, 1,000, 1,500, and 2,000 μm) along the knife’s cutting edge. NW after 38.2 m of cutting at the five different depths (0, 500, 1,000, 1,500, and 2,000 μm) along the knife’s cutting edge were 50, 58, 85, 70, and 65 μm , respectively (Fig. 6). No pattern of wear was detected. Evidence gathered from inspecting the knife’s entire cutting edge indicates that the wear is randomly dispersed along the edge and mostly caused by impurities in the WPC material.

Rq was measured perpendicular to and lengthwise to the cut for all six materials. However, the Rq for Excel, a product with a hollow core, could only be measured lengthwise at the edge of the material, because the product’s ridges did not offer enough space for the measurement perpendicular to the cut and no material at all for the measurement lengthwise in the center to take place. Table 2 shows the results for the Rq tests performed for all six

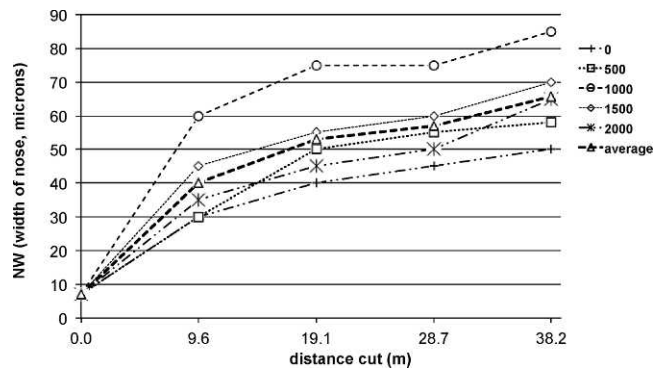


Figure 6.—Nose width of knife used to cut ChoiceDek wood fiber–plastic composite after 0, 9.6, 19.1, 28.7, and 38.2 m of cutting at five different positions (0, 500, 1,000, 1,500, and 2,000 μm) along the knife’s cutting edge.

Table 2.—Surface roughness (Rq) perpendicular and lengthwise to the cut for all six materials tested.

Material	Perpendicular Rq (µm)	Lengthwise Rq (µm)	
		Edge	Center
ChoiceDek	7.02	5.65	4.25
Excel	NA ^a	2.85	NA
Fiberon	2.95	1.75	1.80
Smartdeck	6.33	5.08	5.36
Trex	6.20	3.85	3.86
Eastern white pine	4.57	5.27	6.21

^a NA = not applicable.

materials. Fiberon, a material made using virgin plastic, which performed well in the knife wear tests (e.g., caused less wear than other materials except eastern white pine), also did well in the Rq tests. Rq perpendicular to the cut for Fiberon was found to be 2.95 µm, the smoothest surface of all materials including eastern white pine. The other materials' Rq were 4.57, 6.20, 6.33, and 7.02 µm for eastern white pine, Trex, Smartdeck, and ChoiceDek, respectively. No measurement for the Excel material was obtained as discussed above. Lengthwise at the border, Fiberon again had the smoothest surface, followed by Excel (the only measurement that could be taken), Trex, Smartdeck, eastern white pine, and ChoiceDek with values of 1.75, 2.85, 3.85, 5.08, 5.27, and 5.65 µm, respectively. As shown in Table 2, at the center, lengthwise to the cut, the Rq for Fiberon, Trex, ChoiceDek, Smartdeck, and eastern white pine were 1.80, 3.86, 4.25, 5.36, and 6.21 µm, respectively. No measurement for the Excel material could be taken.

The Rq of WPC materials was found, in some instances, to be lower than for solid wood (eastern white pine). Fiberon, the material made from virgin materials, had the smoothest surface of all materials tested (2.95, 1.75, and 1.80 µm perpendicular, lengthwise at the edge, and in the material's center, respectively; Table 2). ChoiceDek had, with the exception of the measurement lengthwise in the material's center, the roughest surface of all materials tested (7.02, 5.65, and 4.25 µm perpendicular, lengthwise at the edge, and in the material's center, respectively; Table 2). Smartdeck had the roughest surface measured lengthwise in the center (5.36 µm; Table 2), which may be explained by what appeared to be a lower density of the material in the center. A potential source for Rq could be the moisture content uptake of the wood fibers freshly cut by the knife. Since these fibers are dried below the ambient equilibrium moisture content prior to being encapsulated in the plastic, it would appear that these fibers, when again coming into contact with the environment, would take up moisture and thus swell. This would lead to rougher surfaces over time until the moisture content of the freshly exposed wood fibers is in equilibrium with its surrounding environment.

As shown in the preceding paragraphs, there are differences in tool wear and Rq between different commercially available wood fiber–plastic products and between these products and solid wood (eastern white pine). As WPC materials find new applications, the need for secondary modifications to the shape, length, or surface of these materials increase, calling for a better understanding of the tool wear–material relationship to improve the performance of these materials when cut. Future research should specifically investigate the role of individual

components of the wood fiber–plastic material compound and their relationship to tool wear and Rq. In addition, the influence of using recycled materials for the production of such composite materials needs to be investigated. Such efforts to improve our understanding of these new materials will help industry to overcome the obstacles in implementing these materials and open new, more competitive alternative uses for wood fiber–plastic materials for a wide variety of products.

Conclusions

This study found differences in tool wear among the six commercially available materials (eastern white pine, Fiberon, Excel, Smartdeck, Trex, ChoiceDek) tested. Tool wear was smallest when cutting the eastern white pine sample, with NW increasing from 9.00 to 10.40 µm after 38.2 m of cutting, while NW increased from 7.00 to 65.60 µm after 38.2 m of cutting for the material that wore the tool the most, ChoiceDek (Fig. 3). The most benign wood fiber–plastic material on tool wear, Fiberon, wore the tool from 5.00 to 25.00 µm after 38.2 m of cutting, or almost 15 times the wear from cutting eastern white pine. Still, Fiberon did much better than ChoiceDek, whose wear was almost 42 times the wear of solid wood (eastern white pine). It is speculated that the composition of wood fiber–plastic materials, in particular the fillers and color pigments used for the plastic component of the material, are responsible for a part of the increased wear compared with solid wood. Fiberon, a wood fiber–plastic material made from virgin plastic, is a case in point. Since virgin material is used, contamination from other sources is nonexistent. For materials using recycled content such as, for example, ChoiceDek, increased wear can be attributed to the pigments, the fillers, and the contamination of the recycled material with materials such as silicates or metals.

Rq of the machined material surface was found to be less variable among the six materials (eastern white pine, Fiberon, Excel, Smartdeck, Trex, ChoiceDek) tested. Most notably, solid wood had a rougher surface than the smoothest wood fiber–plastic product, Fiberon. Solid wood's surface roughness perpendicular to the cut was more than one and one-half times (4.57 µm) the roughness of Fiberon (2.95 µm), the smoothest wood fiber–plastic material investigated. Lengthwise Rq (both at the edge and in the center) was also found to be larger for eastern white pine than for Fiberon, but lengthwise Excel, Trex, and Smartdeck were smoother than solid wood, too. Even ChoiceDek had a smoother surface roughness in the center than eastern white pine (Table 2). Solid wood Rq is largely determined by the annual rings and the grain of wood's structure, whereas a wood fiber–plastic material's Rq is determined by the size of the wood fiber used and the type of fillers added.

Only by gaining a better understanding of these new materials and their respective behavior when subjected to secondary manufacturing processes can these products be made a competitive alternative for a wide variety of applications. Without a doubt, WPC materials offer a viable alternative for many applications, especially applications with increased demands on wear and/or biodeterioration resistance. A better understanding of the performance of these materials when subjected to secondary manufacturing processes therefore is of importance.

Acknowledgments

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