Performance of helical router bit in milling of composite boards

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Abstract. An extreme inclination angle of helical cutting tool edge has been developed in milling of new commercially composite boards. The purpose of this research was to investigate wear resistance, chip formation, surface roughness, and noise level of helical edge router bits in milling composite boards. The composite boards of wood plastic composite, laminated veneer lumber, and strand board were cut by the helical edge router bits (helical angle 15°, 30°, 45°, 60°, and 75°) in a computer numerical control router. The results show that the helical edges provide better wear resistance, smoother surface of machined composite boards, and lower noise emission compared to the conventional edge (0°). Edge wear, surface roughness, and noise level decreased with increasing helix angle of the edge router bits. The differences in structure among the composite boards resulted in the difference in cutting tool wear, chip formation, surface roughness, and noise level phenomenon. The 75° inclination angle of router bit provided the highest wear resistance, better surface of machined composite board, and the lowest noise level.

1. Introduction

Composite board is an alternative wood product that manufactured from wood waste or low-quality of wood with combination of an artificial resin and additives of different kinds. Nowadays, composite boards such as Wood Plastic Composite (WPC), Laminated Veneer Lumber (LVL), and Strand Board (SB) have become popular products because of their good in strength, durability, and aesthetic for building construction and decorative purposes. In the composite board manufacturing industry, where the composite boards are machined using a cutting tool, a shape design of cutting tool edge becomes an important economic parameter. The right design of cutting tool edge would optimize and improve the cutting operation resulting better efficiency, stability, accuracy, and tool life during the cutting processes.

Today conventional designs of router bit with straight cutting edge is widely used in the wood working industry for milling purposes. However, the use of straight configuration of cutting tool edge produces several problems during milling. The straight cutting tool edge hits and intermittently engages the surface of the work piece generating a high noise emission, a dull cutting tool edges, and an extreme flight speeds of the formed chips which causes dust emission [1,2]. In addition, this straight configuration also leads to machined surface quality problem due to high splitting, compressing, and damaging the wood cell structure near the surfaces, which causes a costly sanding procedure is needed [2].

An innovation in minimizing the problems of the straight cutting tool edge configuration with a new design of helical edge has been developed. Some research works and investigations were done to find out the effect of inclination angles of the helical cutting tool edge for wood cutting applications. The research on the investigation of dust, chip, and noise behaviors in milling operation using helical cutting tool edge with inclination angles between 0° to 45° were reported [3,4]. It was noted in these studies that inclination angles between 5° and 10° were considered to be useful in lowering dust emissions. Inclination angles larger than 10° lead to chip compression resulting in high axial forces on the cutting tool. The increase in the inclination angle from 0° to 8° leads to a significant decrease in noise emissions. It was found in another study that helical cutting tool edge with inclination angle of 0° to 8° did not provide a significant difference in the chips morphology when milling with shank tools of small diameter.
In addition, the helical edge design of a milling tool improves the quality of machined surface compared to straight cutting edge [6]. It could be considered that when cutting tool edge with the helical configuration engages the surface of the workpiece gradually, it is expected that the tools will be always under contact, stability will be improved, and the vibration will be reduced during the milling operation. Due to the unique geometry of cutting tool edge, the workpiece chips will be easily deformed and the resulting machined surfaces will be flat and smooth. Considering the fact that the previous researches were limited to the helix angles between 0° and 45°, a new design of helical edge of router bits with extreme inclination angle has been worked and their performance was tested in this research. The aim of this research was to investigate the effect of inclination angles on the edge wear, chip formation, surface roughness, and noise emission of the extreme helical router bit in milling composite boards.

2. Materials and Methods

2.1. Materials

Router bits of High Speed Steel (HSS) with helical edges were 80 mm in total length and 12 mm in cutting circle diameter. The router bits consisted of two solid cutting edges with helix angles of 0° (straight edge), 15°, 30°, 45°, 60°, and 75° (Figure 1). Other geometries of the helical router bits are shown in Table 1. The composite boards routed was WPC, LVL, and SB with density of 135 kg/m³, 83 kg/m³, and 59 kg/m³, respectively.

![Figure 1. Helical router bits for investigation](image)

| Router bit material | High-speed steel |
|---------------------|-----------------|
| Cutting circle diameter | 12 mm |
| Shank diameter | 12 mm |
| Number of cutting edges | 2 |
| Total length of router bit | 80 mm |
| Length of cut | 40 mm |
| Geometry of the edges | |
| Helix angle | 0° (straight edge), 15°, 30°, 45°, 60°, 75° |
| Orthogonal rake angle | 22° |
| Orthogonal clearance angle | 15° |
2.2. Methods

2.2.1. Milling test
Milling tests were set up on a commercial Computer Numerical Control (CNC) router. Up-milling and down milling processes were performed by setting the rotation of the router spindle in clockwise direction and by feeding the lumber samples in the proper direction with rotation of the spindle. The samples were routed along the length on their side surfaces. Conditions of the milling are shown in Table 2.

| Table 2. Milling test conditions |  |
|----------------------------------|--|
| Adjusted parameters | Cutting condition |
| Milling process | Up-milling, down-milling |
| Cutting speed (m/s) | 12.6 |
| Spindle speed (rev/min) | 20,000 |
| Feed speed (mm/min) | 4000 |
| Cutting width (mm) | 1 |
| Cutting depth (mm) | 20 |

2.2.2. Wear measurements.
The router bits were inspected before testing to ensure that there are no surface cracks and chippings on cutting edge under an optical video microscope. In this work, the wear resistance was determined by measuring the progress in edge radius at every end of cutting (60 cm). The captured images of the cutting edges were analysed under the ImageJ software for measurements of the radius.

2.2.3. Chip distribution
Investigation of the chip distribution was carried out by mesh analysis of the formed chips. The deposited chips on the CNC table were collected and documented. The collected chips were sieved by steel screens of 10 mesh (diameter of holes 2.0 mm), 20 mesh (diameter of holes 0.8 mm), 40 mesh (diameter of holes 0.4 mm), and 80 mesh (diameter of holes 0.2 mm). The distribution of chips was analyzed according to the weight percentage of each screened chip.

2.2.4. Surface quality measurement
The machined surface was evaluated in the Ra value of surface roughness. The surface roughness tester SJ-210 was used to measure the roughness on the surface of the machined composite boards. The Ra was measured across the cutting direction of samples with a diamond tip radius of 5 μm. The tracing length was 15 mm and the cut off was 2.5 mm. Five points for roughness measurement were diagonally marked on the routed surface of the samples.

2.2.5. Noise measurement
A precision sound level metre Sanfix 356 was used for measurement of the sound level of the audible cutting noise on the A scale, which is usually used for measuring the peak of sound pressure level. The sound level metre was set up at the height of the cutting tool edge (about 1 m above ground level) and at a distance of about 1 m along a straight line extending from the cutting tool edge. The noise level was recorded per 1 second at every milling test, and the values was transferred to a computer for analysis.

3. Results and Discussion

3.1. Wear resistance
The results in Figure 2 indicate that the conventional router bits (straight edge/inclination angle 0°) provided lower wear resistance compared to the helical router bit when milling WPC, LVL, and SB. The edge radius wear decreased with increasing inclination angle of router bits. It could be considered that a larger inclination angle would involve a gradual step wise engagement on the surface of machined composite boards. It could eliminate sudden impacts and decrease mechanical loads on the edge surface of router bit.
Figure 2. Helical router bits wear when cutting composite boards

The amount of edge radius wear resulted from milling the composite boards was different. The average edge radius wear in milling WPC, LVL, and SB were 12.7 μm, 9.6 μm, and 6.3 μm, respectively. The highest density of WPC (135 kg/m³) compared to LVL (83 kg/m³) and SB (59 kg/m³) could be the reason for this phenomenon. In addition, it was noted that the main components of WPC are plastic polymer, lignocellulose materials, fillers (mostly crystalline silicates, titanium dioxide, and other heavy metals), stabilizers and other additives [7,8]. The presences of abrasive materials and additives in the WPC lead to severe mechanical wearing on the cutting tool edge tested [9].

3.2. Chip distribution

The results in Table 3 show that the chip of WPC was more uniform in size compared to the chip of LVL and SB. The chip of WPC mostly netted on 20 mesh sieves. The chip of LVL varied on 20 mesh to pass through 40 mesh sieves. The chip of SB mostly netted on 40 mesh and pass through 40 mesh sieves. It was reported that the chip type netted on 10 mesh, 20 mesh, 40 mesh, and pass through 40 mesh were spiral or splinter, flow, thin, and granule chips, respectively [5,10]. A large amount of granule chips of SB was observed to cause various problems. First, the granule chips tended to adhere and harden on the cutting tools surface which would affect the subsequent cutting. Second, the chips led to produce serious air pollution in the work area.

In Table 3, it was found that the spiral or splinter chip (netted on 10 mesh sieve) generated from cutting composite boards using larger inclination angle of router bits. With increasing of the inclination angle, the spiral or splinter chip was more generated. This chip type was formed from incompletely severed chips through compression on the surface of composite boards. The spiral or splinter chip of WPC was generated only using 75° helical router bit. In milling of LVL, it was generated using 60° and 75° helical router bit. It was generated in milling SB using 45° to 75° helical router bit. This result indicated that the spiral or splinter chip was easier to generate from milling of SB compared to other composite boards. The lowest density and the irregularity in sizes and orientation of the strands in SB could be the reasons for this phenomenon.
Table 3. Weight percentage of chips generated during up-milling process

| Composite board/ Incitation angle (°) | Weight percentage (%) |                |                |                |
|--------------------------------------|------------------------|----------------|----------------|----------------|
|                                      | 10 mesh (> 2 mm)       | 20 mesh (0.8-2 mm) | 40 mesh (0.4-0.8 mm) | >40 mesh (< 0.4 mm) |
| WPC                                  |                        |                |                |                |
| 0                                    | 0.0                    | 94.8           | 4.1            | 1.1            |
| 15                                   | 0.0                    | 91.0           | 7.6            | 1.4            |
| 30                                   | 0.0                    | 74.6           | 19.5           | 5.9            |
| 45                                   | 0.0                    | 93.9           | 4.4            | 1.8            |
| 60                                   | 0.0                    | 97.1           | 2.0            | 0.9            |
| 75                                   | 5.3                    | 90.4           | 3.4            | 0.9            |
| LVL                                  |                        |                |                |                |
| 0                                    | 0.0                    | 27.7           | 37.2           | 35             |
| 15                                   | 0.0                    | 34.5           | 37.7           | 27.8           |
| 30                                   | 0.0                    | 40.2           | 34.0           | 25.8           |
| 45                                   | 0.0                    | 39.1           | 33.5           | 27.4           |
| 60                                   | 0.3                    | 48.3           | 29.2           | 22.2           |
| 75                                   | 0.4                    | 25.0           | 38.1           | 36.5           |
| SB                                   |                        |                |                |                |
| 0                                    | 0.0                    | 5.2            | 41.4           | 53.4           |
| 15                                   | 0.0                    | 7.3            | 41.3           | 51.4           |
| 30                                   | 0.0                    | 7.8            | 43.1           | 49.1           |
| 45                                   | 0.5                    | 7.2            | 41.0           | 51.3           |
| 60                                   | 1.0                    | 7.5            | 38.6           | 52.9           |
| 75                                   | 2.4                    | 8.1            | 37.8           | 53.4           |

3.3. Surface roughness

The result in Figure 3 shows that the roughness of machined composite boards (Ra) decreased with increasing inclination angle of router bits tested for both down-milling and up-milling process. This phenomenon could be due to the decrease in router bit wear with increasing the inclination angle. The mechanical abrasion of cutting tools resulted in an irregularity on the cutting edge, which led to irregularities on the surface of wood composites [11]. It was also found in Figure 3 that up-milling process generated rougher surface compared to down-milling process. It was reported in previous another study that the down-milling process is better for workshop application than the up-milling process because the higher periodic cutting force in the latter is considered to be more damaging to the surface [12].
Figure 3. Behaviour of surface roughness with respect to the inclination angles of milling cutters at down-milling (a) and up-milling (b) process

The smoothest surface of machined composite board was retained by WPC. The very fine structure of WPC led to generate the smoothest surfaces. However, the surface roughness value of SB was unmeasurable since the Ra of SB much high beyond the maximum range that could be measured by the surface roughness tester. It was caused by the porous in SB structure due to the irregular in sizes and orientation of the strands in the board (Figure 4c).

Figure 4. Appearance of WPC (a), LVL (b), and SB (c) machined using 75° helical router bit in down-milling process

3.4. Noise level
The results in Figure 5 indicate that the conventional router bits generated higher noise levels compared to helical router bits during milling of composite boards. The higher noise level generated by conventional router bit is caused by intermittent hammering and hit of its straight edge into the surface of the composite boards. The noise level decreased with increasing of inclination angle of router bits tested for both down-milling and up-milling process. The noise level remarkable reduced when cutting composite boards using the 45° helical router bit, and then decreased gradually when cutting composite boards using the 75° helical router bit. The helical edge of router bit engaged and penetrated gradually into the surface of the composite boards, which caused the noise to decrease.
It was also found in Figure 5 that up-milling process (77 dB) tended to generate higher noise level compared to down-milling process (75 dB). It could be considered that up-milling process caused a large impact forces being imposed on the edge router bits [13]. It appears in Figure 5 that the highest and the lowest noise level were generated in cutting WPC (78 dB) and SB (75 dB), respectively. This fact was caused by the highest density of WPC and the lowest density of SB.

In conclusion, both in up-milling and down-milling, the helical router bit provide better wear resistance, better surface quality, and lower noise emission compared to the router bit with conventional edge. The characteristics of composite boards structure would affect the behavior of wear resistance, chip formation, quality of machined surfaces, and noise emission during cutting. The investigations have clearly confirmed that the helical edge is considered to be a valuable design to improve upon the performance of the conventional router bit for composite board milling applications.

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