18 Hasil tes turnitin indian the chips

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ORIGINAL ARTICLE

The chips generated during up-milling and down-milling of pine wood by helical router bits

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Abstract Machining aspects with helical edge router bits (helix angle 15°, 30°, 45°, and 60°) with a cutting circle diameter of 8 mm were studied. The purpose of the research work was to investigate chip formation and surface roughness characteristics in milling pine wood by the straight and helical edge bits. The chips generated could be classified into four types by sieving into spiral chip (5 mesh), flow chip (10 mesh), thin chip (30 mesh), and granule chip (< 30 mesh). The experimental results show that spiral chips were generated most often (on a weight percentage basis) by the bits during down-milling process. More flow and thin chips were produced by the bits during up-milling process. Better surface roughness was produced by bits during down-milling compared to up-milling. With increasing helix angle of the bits, the amount of spiral and flow chips increased and granule chips were reduced. The machined surface produced was better in roughness (lower Ra values) as the helix angle of the bits increased both in up-milling and down-milling processes.

Keywords Pine wood · Straight and helical bits · Up- and down-milling · Chip type · Surface roughness

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Introduction

Design of cutting tool edge involved in the cutting processes should be very important. Today conventional design of router bits with two or more straight cutting edges are widely used in the wood working industry for milling purposes. The manner of contact between this straight configuration of cutting edge and the work piece is a piecewise continuous curve. The straight cutting edge hits and intermittently engages the surface of the work piece during milling. This straight configuration leads to machined surface quality problem due to high splitting, compressing, and damaging the wood cell structure near the surfaces.

One approach dealing with a new design of helical edge was being attempted. Some research works and investigations have been done to find out the effect of helix angles of the helical cutting tool edge for wood cutting applications. Mostly, the research works had been focused on energy behavior, cutting forces, dust emissions, and noise emissions with respect to the varied helix angles. A general overview was investigation of helical edge design with helix angles up to 18° for wood milling application (Heydt and Tuffentsammer 1979). They noted that an increase in the helix angle led to an increase in the passive force (axial direction); however, the vibration and the noise levels are lowered. Noise reduction in more than 10 dB(A) was observed when cutting wood with helical edge milling tools of 18° helix angle. It was reported in another study that helical edge design of a bit provides better surface quality compared to straight edge (Cyra et al. 1998). In milling wood against the grain, the greater the helical angle, the smoother is the machined surface.

Research activities on the investigation of dust, chip, noise, and force behaviors in planing operation using helical edge with helix angles between 0° and 10° were reported (Heisel and Weiss 1989; Heisel et al. 1993). It was noted in these studies that helix angles between 5° and 10° are considered to be useful in lowering the dust emissions. The increases in the helix angle from 0° to 8° lead to a significant decrease in noise emissions. New design of helical edge of milling cutter with extreme helix angles (45°–85°) had been developed at the Technische Universität Dresden (Dresden University of Technology) (Fischer et al. 2005, 2006), and their performance in planing wood was reported by Darmawan et al. (2011). The helical edges compared to the conventional edge of milling cutter provide better chip flow with nearly axial in direction and low flight velocity, which lead to easier handling and less power requirements for suction system. Though the extreme helical edges (65°, 75°, 85° helix angles) generate slightly larger cutting power than the conventional edge (straight edge), they are considerably much better in reduction in the cutting noise. The helical edge milling cutters are better in wear resistance, suffer less edge fractures, and produce better surface quality than the conventional edge milling cutter. The investigations have clearly confirmed that the helical edge is considered to be a valuable design to improve the performance of the conventional milling cutters for wood machining application. The results on the influence of the helix angle of bits (0°–8°) on the chip type and distribution and the specific energy in conjunction with either the feed speed or the cutting depth were reported (Su and Wang 2002). The chip types are classified into four groups (flake type, splinter type, flow type and granule type) according to chip sizes and shapes. The proportion of flow-type chips increases, and that of the flake and splinter types decreases with a decrease in cutting depth. The chip-type distribution and the specific energy at different feed speeds or different cutting depths seem not to be affected by the helix angle. The specific energy per volume removed can be expressed as a negative power function of either the feed speed or the cutting depth.

CNC routers appear to be the most popular woodworking machine. There are promising solutions dedicated to CNC operations in solid wood working (Cyra et al. 1996; Iskra and Hernandez 2010), which involve on-line feed rate adaptation based on monitoring of acoustic emission. Another approach involves experimental determination of optimal machining parameters for particular wood species, equipment and parts to be processed (Supadarattanawong and Rodkwan 2006). A mathematical model and computational procedure were also developed to allow for significant reduction in processing time of CNC milling operation of solid wood (Gawronski 2013). These approaches for wood milling are essential to gain high productivity and to take full advantage of machine capabilities. However, it is known that milling woods by the CNC router always produces a large quantity of chips, which are collected through a dust pipe usually mounted on the cutting spindle of the CNC router. There may be some problems during such milling. For instance, very tiny chips in the air create a serious health hazard for workers. Because of smaller diameter of the router bit, the chips generated during milling will be quite different from that while planing or shaping operation and investigations on chip formation during milling wood are limited. Considering the fact that the previous research works on chip formations were limited to the helix angles between 0° and 8° (Su and Wang 2002), a new design of helical edge of router bits with larger helix angles (0°–60°) has been attempted in cooperation with Kanefusa Japan and their performance was tested in this research. Though the theoretical principle of the helical bits has a great potential to solve the outlined problems when milling wood, investigations and tests need to be carried out for better description of the performance, and to prove the potential of the developed new helical bits in the near future. The purpose of this research work was to investigate the effect of helix angles on the chip formation, and surface roughness characteristics of the large helical edges of the bits in milling wood.

Materials and methods

Helical edge of router bits and work materials

Bits with helical edges were produced for the experiment in a standard production line by Kanefusa. These bits of K10 tungsten with helical edges were 75 mm in total length and 8 mm in cutting circle diameter. The bits consisted of two solid cutting edges with helix angles of 0° (straight edge), 15°, 30°, 45°, and 60° (Fig. 1). Other geometries of the helical bits are shown in Table 1. The wood species routed was pine (*Merkusii pine*) of 12% moisture content. Wood samples routed were in the form of lumber of size 50 mm × 150 mm × 1000 mm. Because pine woods contain a lot of tight knots, the lumber samples were chosen carefully and knots were not allowed in the surfaces of the lumber sample.

Milling test

Milling tests were set up on a commercial 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. Five samples each were routed along the length on their side surfaces. The

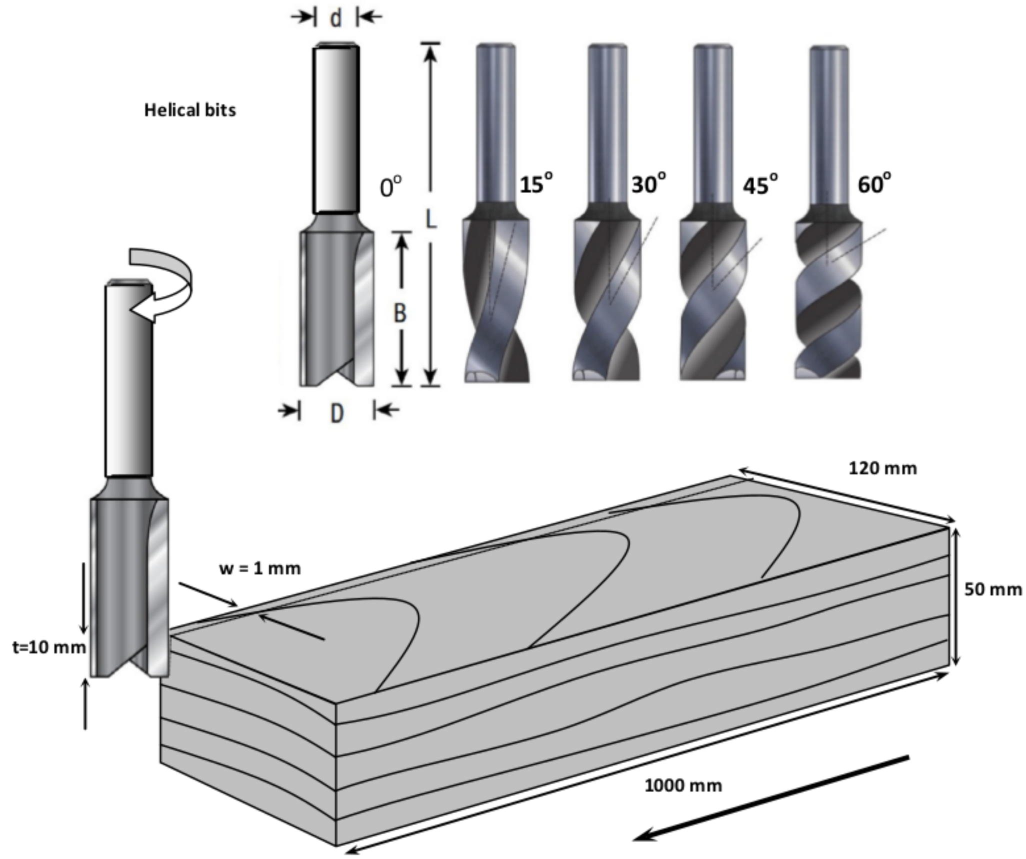


Fig. 1 Schematic diagram of the milling process and helical bits for investigation

Table 1 Specifications of conventional and helical bits used in the study

Bit tool material	K10 Tungsten carbide
Hardness	63 HRC
Cutting circle diameter *d*	8 mm
Shank diameter *D*	8 mm
Number of cutting edges *z*	2
Total length of bit *L*	70 mm
Length of cut *l*	25 mm
Geometry of the edges	
Helix angle	0° (straight edge), 15°, 30°, 45°, 60°
Orthogonal rake angle	22°
Orthogonal clearance angle	15°

lumber samples were routed for the same condition. Schematic diagrams of the milling tests are depicted in Fig. 2, and conditions of the milling are shown in Table 2. Cutting speed of 25 m/s was performed by setting the bit rotation at 10,000 rpm and feed speed of the table at 2000 mm/min. The depth of cut (*t*) and width of cut (*w*) were determined to be 10 mm and 1 mm.

Chip flow and shape investigation

Investigations on chip flow and shape were carried out by mesh analysis of the formed chips and by digital camera monitoring. Digital video camera was focused at a distance of 1 m from the point of the cutting action. Video images were continuously taken during feeding of 5 lumber samples for each helical edge tested. The deposited chips on the table of the machine were collected and documented. The chip shapes in this work were classified according to the method suggested by Su and Wang (2002). The collected chips were sieved by steel screens of 5 mesh (diameter of holes 11.32 mm), 10 mesh (diameter of holes 5.66 mm), and 30 mesh (diameter of holes 0.59 mm). The sieved chips were analyzed according to the chip type and the weight percentage of each chip type.

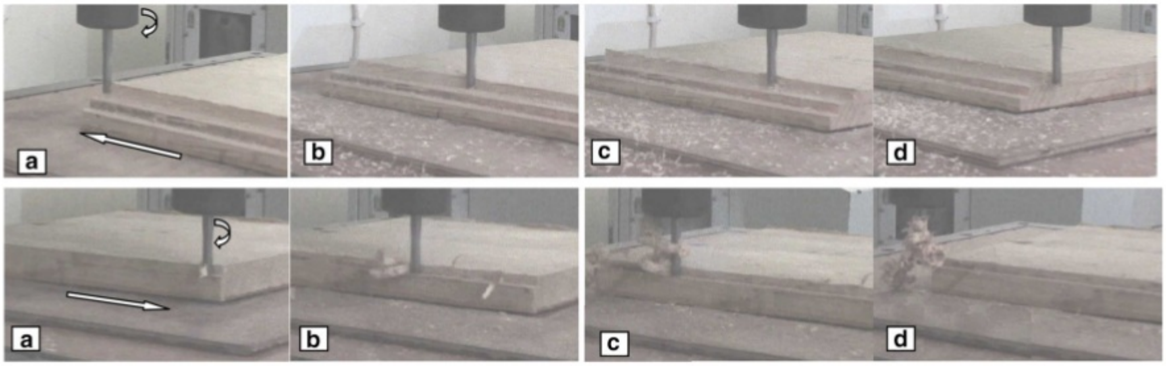


Fig. 2 View on chips formation during up-milling (upper) and down-milling (lower) using straight edge bit at beginning of cut (**a**), middle of cut (**b, c**), and end of cut (**d**)

Table 2 Milling test conditions

Adjusted parameters	Conditions for
Milling process	Up-milling and down-milling
Bit revolution (rpm)	10,000
Cutting speed (m/s)	25
Feed speed (mm/min)	2000
Depth of milling *t* (mm)	10
Width of milling *w* (mm)	1

Surface quality measurement

The surface roughness tester SJ-210 was used to measure the roughness on the surfaces of the routed lumber. Samples for roughness measurement in the length of 50 mm were cut from the routed lumbers. Roughness values of Ra were measured across the grain of samples with a diamond tip radius of 5 µm. The tracing length was 15 mm, and the cutoff was 2.5 mm. The measuring force of the scanning arm on the surfaces was 4 mN, which did not significantly damage the surface according to the roughness tester SJ-210 user manual (Surftest Test SJ-210 2009). Ten points for roughness measurements were diagonally marked on the surface of the samples. Measurements were made perpendicular to the fiber direction of the samples. Measurements were repeated whenever the stylus tip generated an error during the tests.

Results and discussion

Chips formation and flow

The straight bits tested produced different behaviors of chip flow between up-milling (Fig. 2-upper) and down-milling process (Fig. 2-lower). In up-milling, the bits rotate against direction of feed. The chip width size is zero at initial cut which increases with feed and would be maximum at the end of the feed. During up-milling (Fig. 2a–d upper), the cutting chips were carried outward due to upward force by the tool bits. A large area of flow and high speed of flow were observed at beginning of cut up to end of cut. As a result, the chips tended to scatter around the cutting point and the table of the CNC machine (Fig. 2c–d upper). In down-milling process, the chip width size is maximum at start of cut and decreases with the feed and would be zero at the end of feed. During down-milling (Fig. 2a–d lower), the cutting chips were carried outward due to downward force by the tool bits. It was observed that continuous chips were produced from beginning of cut up to end of cut. The continuous chips twisted upward (Fig. 2b lower) and rolled up before falling at the end of the cut (Fig. 2c–d lower). The sector area of the continuous chips flow became smaller, and the investigated speed of the continuous chip flow was decreased. This result gives an indication that the down-milling process could create more-friendly environment compared to up-milling process.

A similar phenomenon was observed in milling using helical bits both for up-milling and down-milling processes (Fig. 3). Completely severed chips were produced by the helical bits during up-milling process (Fig. 3a–d upper); continuous chips were produced by the helical bits during down-milling process (Fig. 3a–d lower). However, it was observed in up-milling and down-milling that the chips flowed in a regular direction with lower area of flow and lower speed of flow, when the lumber samples were routed using the helical edges. With a further increase in helix angle, the chips left the cutting zone in an upwards direction, and the most regular and lowest speed were generated by using bits with 60° helix angle. Darmawan et al. (2011) observed that the chips move in a regular parabolic way

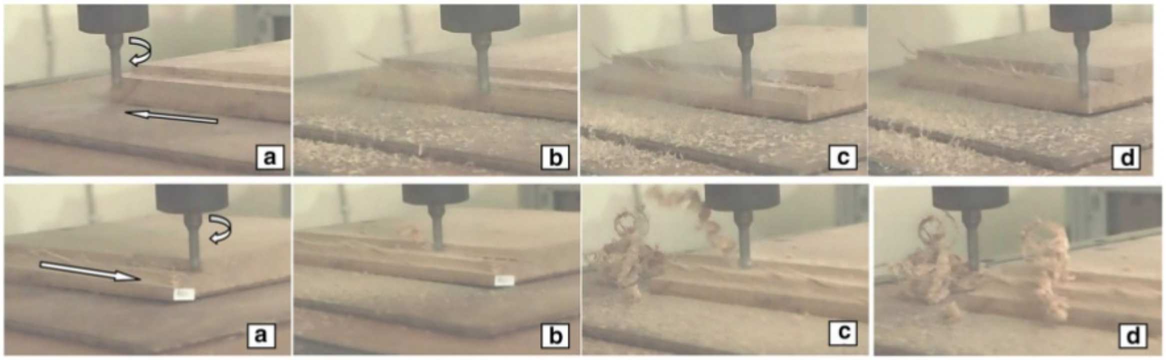


Fig. 3 View on chips formation during up-milling (upper) and down-milling (lower) using helical edge bit (15° helix angle) at beginning of cut (**a**), middle of cut (**b, c**), and end of cut (**d**)

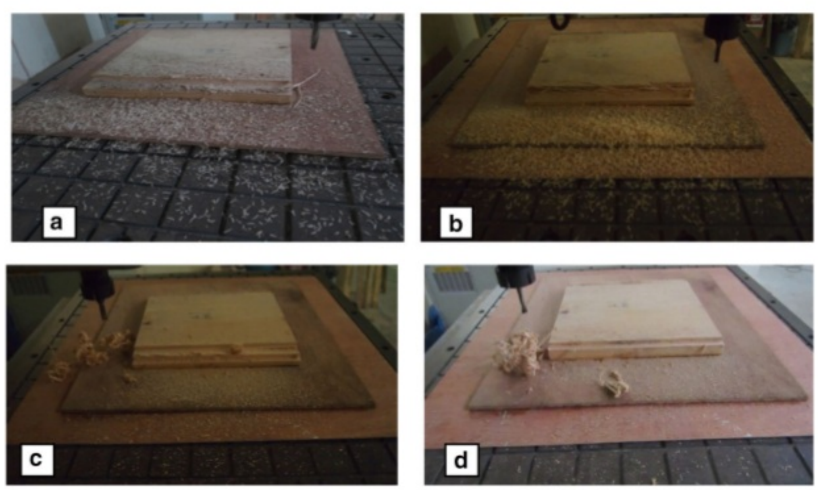
during up-milling using milling cutters with extreme edge helix angles (65°, 75°, and 85°). The chips flow velocity decreases rapidly when increasing the edge helix of the tool from 37 m/s (helix angle 0°) to approximately 16 m/s (helix angle 85°). Rudak et al. (2018) reported that with helix angle of bits less than 11°, the chips move in a plane perpendicular to the axis of the spindle rotation. When the helix angle of bit is 45°, the chips move upward at an angle of 22°. Speed of chips movement at 0° helix angle is about 26 m/s and decreases to be 16 m/s at 60° helix angle.

The results in Fig. 4 show the chips produced and collected during up-milling (upper) and down-milling (lower) using bit with helix angle of 15° (Fig. 4a, c) and 45° (Fig. 4b, d). During up-milling with 45° (Fig. 4b) compared to 15° (Fig. 4a) helical bit, the chips were falling in a more regular way and deposited in a place at a distance closer to the cutting point. Darmawan et al. (2011) reported that the chips are collectively deposited in a place at a distance from about 30 cm to 50 cm away of the cutting point during planing lumber with milling cutter of 65°, 75°, and 85° helix angles. Down-milling with higher helix angle of bits tended to produce continuous chips with less discontinuous chips compared to lower helix angle. Figure 4d gives an indication that bit of 45° helix angle produced less discontinuous chips (dusts) compared to 15° helix angle (Fig. 4c) during cutting. Su and Wang (2002) reported that the number of small chips under the larger helix angle is reduced. It may thus solve the problem in the chip suction system during milling with a conventional bit by using bits with higher helix angles. This can lead to a complete capture of dusts and chips with savings in energy consumption for the required suction system with a proper hood placed around the sector of expected chip flow.

Chip shapes

Analysis of chip sizes generated during the milling showed that the bits produced similar types and sizes of chips both

Fig. 4 Comparison in behaviors of chips flight between helix angle 15° (**a**, **c**) and helix angle 45° (**b**, **d**) in up-milling (upper) and down-milling (lower)



in up-milling and down-milling processes (Fig. 5). The collected chips in Fig. 5 were sieved for classification of the chip shapes, and the results are shown in Fig. 6. The chip shapes were determined as spiral chips (Fig. 6a) netted on 5 mesh sieve, flow chips (Fig. 6b) netted on 10 mesh sieve, thin chips (Fig. 6c) netted on 30 mesh sieve, and granule chips (Fig. 6d) passed through 30 mesh sieve. Spiral and granule chips were found in the down-milling process. The flow, thin, and granule chips were found in up-milling process. Lower downward force imposed on the chips during down-milling would result in incompletely severed chips through compression; a higher upward force imposed on the chips during up-milling would result in chip separation through tension perpendicular to the grain. Therefore, longer chips or continuous chips were produced during down-milling, and tended to roll up to form spiral chips and then fall at the edge of the lumber sample. The flow chip and thin chips produced during up-milling matched the shape of the chips reported by Su and Wang (2002). During up-milling and down-milling parallel to grain, the initial cut is substantially parallel to the grain, but the subsequent cut has a considerable angle to the grain. The subsequent cuts may relate to the generation of granule chips during parallel to grain.

The weight percentage distributions of different chip sizes sieved by the three screen sizes are shown in Table 3 for up-milling and down-milling processes. The distributions were different among the helix angles of the bits. Most of the chips generated in up-milling process were flow type for almost all helix angles. Other chips were thin and granule chips. The increase in helix angle caused an increase in the percentage of flow chip and a decrease in the thin and granule chips (Table 3). The flow chip was 54% with 0° helix angle and 75% with 60° helix angle. The percentage of thin and granule chips for 0° helix angle was 22% and 24%, respectively, and for 60° helix angle was 15% and 10%, respectively (Table 3). The major shape of chips in 5 mesh sieve was the spiral chip (Fig. 6a) generated by all bits during down-milling of the pine wood. The increase in helix angle caused an increase in the percentage of spiral chip. The spiral chip was 78% with 0° helix angle and 92% with 60° helix angle. The percentage of granule chips decreased from 22% at helix angle of 0° to 8% at the 60° helix angle (Table 3). The chips were generated by an intermittent engagement of the straight bit during milling in which the chips could be torn easily. Therefore, the chips obtained from the straight bit would contain larger percentage of smaller chips (thin and granule chips) than those produced by the helical bits. When using cutting edges with the helical configuration, the cutting edge penetrated gradually into the lumber samples with a step-wise force increase, which resulted in less granule chips. Burek et al. (2017), Chen and Lai (2002), and Izamshah et al. (2013) reported that when cutting edges engaged the surface of the work piece gradually, the resultant cutting forces will be lower, the tools will be always under contact, stability will be improved, vibration and noise will be reduced, and the required machine power during the milling operation will be lowered.

Surface roughness

Machined surface roughness of various tree species has been reported. Malkocoglu (2007) investigated planing properties and surface roughness of Scots pine (*Pinus sylvestris* L.). Hiziroglu et al. (2013) determined surface

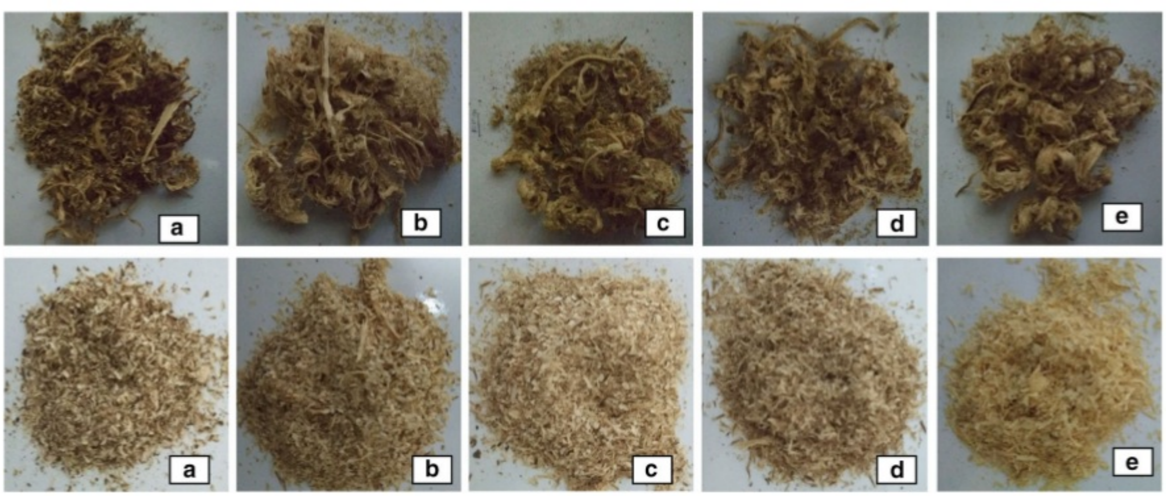


Fig. 5 The chips generated in down-milling (upper) and up-milling (lower) using straight bit (**a**) and helical bits of 15° (**b**), 30° (**c**), 45° (**d**), and 60° (**e**)

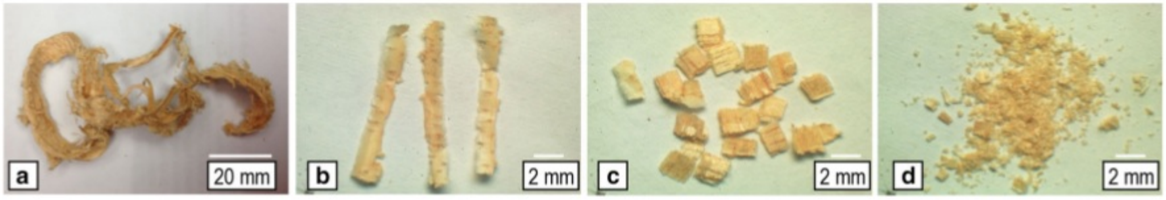


Fig. 6 Classification of the chips in 4 shapes: spiral (**a**), flow (**b**), thin (**c**), and granule (**d**)

Table 3 Classification of chips generated during up-milling and down-milling processes

Milling process	Helix angle of bits	Type of chips			
		Spiral	Flow	Thin	Granule
Up-milling	0	–	54	22	24
	15	–	58	20	22
	30	–	62	18	20
	45	–	69	19	12
	60	–	75	15	10
Down-milling	0	78	–	–	22
	15	80	–	–	20
	30	85	–	–	15
	45	88	–	–	12
	60	92	–	–	8

roughness in the sanding of pine (*Pinus strobus*), borneo camphor (*Dryobalanops* spp.), and meranti (*Shorea* spp.). Zhong et al. (2013) evaluated surface roughness in various commercially produced composite panels including particleboard, medium density fiber board (MDF), and plywood in addition to ten different solid wood species which are commonly used in furniture production. Producing proper surface finish is an important part in the wood machining processes. The final surface roughness of lumber is considered as the sum of independent effects of geometry of tool, linear speed and feed rate, and wood characteristics. Geometry of tool, such as tool edge helix angle that is important in producing surface roughness, could be studied in the present experiment. Figure 7 shows the effect of helix angle of bits on machined surface roughness for up-milling and down-milling processes. The machined surface roughness for up-milling process was higher than that for down-milling process. The cutting forces in up-milling are generally higher than in down-milling. In down-milling process, the load from the cutting edge would be reduced, leaving a better surface finish. The higher force and excessive compression may produce material crushing at the surface and deteriorate surface finish in up-milling. Guo et al. (2015) reported that maximum negative force has great impact in machined surface roughness. Machined surface roughness increased with the increase in the maximum negative force. Another study revealed that the down-milling process is better for workshop application

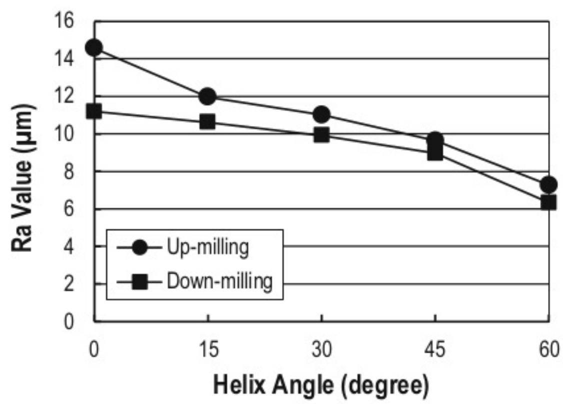


Fig. 7 Behavior of Ra values with helical edge bits in up-milling and down-milling at the feed rate of 2000 mm/min

than the up-milling process because the higher periodic cutting force in the latter is considered to be more damaging to the surface (Ozoegwu et al. 2013). The effect of chip type on surface finish could also be important in determining the surface roughness. The continuous chips generated during down-milling process (Fig. 5) indicate that steady cutting conditions existed and hence a better surface finish was obtained. The discontinuous chips in up-milling process created force fluctuations which would cause more frequent marks on the machined surface.

It also appears from the result in Fig. 7 that the roughness of lumber (Ra) decreased with increasing in the helix angle of the bits. The straight cutting edge hit and intermittently engages the surface of the work piece during milling leading to lesser surface quality due to high splitting, compressing and damaging the wood cell structure near the surfaces. Among the helical edge bits, the 60° helix angle tended to produce the smoothest surfaces. Baowan et al. (2017) noted that the TiAlN-coated end mill with a high helix angle of 60° offered high-quality surface finish with long tool life time and will be more useful for dry milling of stainless steels. It could be considered that when using cutting edges with the helical configuration, the cutting edge penetrate gradually into the work piece with a step-wise force increase, reaching a maximum value that would be lower than that achieved with a straight cutting edge. The present result confirms the previous report, in which increase in the helix angle of milling cutters during planing wood resulted in the decrease in the roughness of wood surface produced (Darmawan et al. 2011; Fernando de Moura and Hernández (2006). In another study, Izamshah et al. (2014) noted that because of the use of the unique geometry of helical cutting edges, the chips are easily deformed and the resulting machined surfaces are flat and smooth.

Conclusions

Both in up-milling and down-milling, the helical edges provide better chip flow and low flight velocity leading to easier handling compared to the straight edges of router bit. Severed chips were produced by the helical bits during up-milling process, and continuous chips were produced by the helical bits during down-milling process. The chip types could be distinguished into four groups (spiral, flow, thin, and granule type) according to chip sizes and shapes. The portion of spiral chip was the highest in down-milling process, and that of flow chip was highest in the up-milling process. Both the spiral and flow chips increased and the granule chip decreased as the helix angle increased from 0° to 60°. The helical edge bits produce better surface quality than the straight edge bit. The increases in the helix angle cause decrease in the roughness of the machined surface. The investigations have clearly confirmed that the helical edge is considered to be a valuable design to improve upon the performance of the straight edge for wood milling applications.

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