PLANING PROCESS OF MALAYSIAN TIMBERS 1. EFFECT OF VARIOUS CUTTING FACTORS ON PLANING QUALITY

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ROSLAN ALI, AMANO R. & SAID AHMAD. 1991. Planing process of Malaysian Timbers 1. Effect of various cutting factors on planing quality. In this study, specimens of air dried kempas (*Koompassia malaccensis*), keruing (*Dipterocarpus* sp.) and mata ulat (*Kokoona* sp.) were planed under the combination of various conditions of cutting angle, width of knife marks and depth of cut. The surface qualities of timber under each test were visually evaluated for the appearance of chipped grain, fuzzy grain and woolly grain defects. The results show that chipped grain was the most prominent type of defect but its appearance can be minimised by reducing cutting angle, width of knife marks and depth of cut.

Key words: Cutting factors - chipped grain - woolly grain - fuzzy grain

Introduction

Surface defects, such as chipped, fuzzy and woolly grain which appear during planing, affect the quality of planed timber. The frequency of appearance and degree of severity of these visible defects on a given batch of planed timber vary. The characteristics of the materials and the mechanics of the planing process are causes of such defects (Davis & Nelson 1954). The species variation and the sawing pattern are referred to as characteristics of materials while mechanics of the planing process include knife cutting angle, width of knife marks and depth of cut. In this study, these factors were tested and the planing quality of materials was observed and analysed. Fractional design by using orthogonal arrays procedure was adopted in designing the testing method. This method is widely accepted as an effective way to carry out experiments involving a large number of factors (Okuno 1968).

Materials and methods

The experiment to determine the effect of various cutting factors on planing quality of timber was made using a TAIHEI B11-H 600 *mm* single surface planer with three knives in 120 *mm* diameter cutterhead. Four cutting factors at three different levels were investigated, namely cutting angle, width of knife marks, depth of cut and species of timbers. Their specifications are as shown in Table 1.

Table 1. Choice of cutting factors

Factors	Level		
	1	2	3
A. Cutting Angle (deg)	30	20	10
B. Width of knife marks(*mm*)	3.0	2.0	1.3
C. Depth of cut (*mm*)	1.5	1.0	0.5
D. Species	kempas	keruing	mata ulat

The knife used was made of high speed steel (SKH3). Since cutting angle of the knife was fixed by the cutting block at 30°, 20° and 10° modified cutting angles were obtained by bevelling in front of the knife edge as shown in Figure 1.

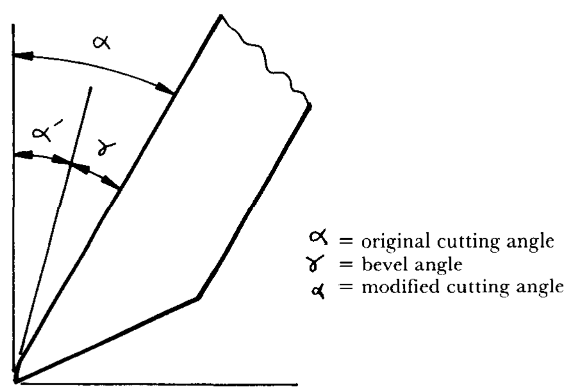


Figure 1. Cutting angle of a bevelled knife

The feed speed of the planer was linearly variable from 0 to 50 $m\ min^{-1}$ and its spindle speed was fixed at 6000 rpm. To get a consistent width of knife marks on the planed timber surface, only the tested knife was projected out to make the cut. The other two knives were set below the cutting circle. The 3.0, 2.0 and 1.3 *mm* width of knife marks were obtained by varying the feed speed as shown in the formula:

$$e = \frac{F \times 1000}{nN}$$

where, e = width of knife marks (*mm*), F = feed speed (*m* min^{-1}), n = number of effective knives and, N = spindle speed (rpm).

The 1.5, 1.0 and 0.5 *mm* depth of cut were obtained by varying the height of the feed table. The physical properties of the three air dried timber species are as given in Table 2. For each species 20 specimens for each radial and tangential surfaces were prepared. The specimen dimensions were 75 × 75 × 1000 *mm*. The feeding direction of each specimen was coincided with its fibre and longitudinal directions.

Table 2. Physical properties of test specimens

Species	Moisture content (%)	Specific gravity
Kempas	20	0.90
Keruing	20	0.82
Mata ulat	18	0.93

The cutting conditions for the experiment were selected from the combination of the various factors as previously shown in Table 1. Since there were four factors with each having three different levels, the possible combinations of all factors at different levels to be investigated would be 81.

But such a large number of test conditions were considered not necessary because only rough estimates of the effect of each factor on the planing quality of the timber specimens were required. To get a smaller number of test conditions then that required by the complete factorial design, the assignment of the number of the cutting factors and their interactions was made by using the "Table of Orthogonal Arrays". The technique to design experiment by using orthogonal array has been discussed by Taguchi (1962). This experiment was designed as one third fractional replicate of 3^4 factorial, where only 27 test conditions were needed. The table shown in Table 3 was used to assist in the systematic assignment of the test conditions. List of test conditions generated by the $L_{27}3^{13}$ Orthogonal Arrays Table is then as shown in Table 4. For each test condition, 20 specimens of radial and tangential surfaces timber respectively were repeatedly planed.

After each test, the surfaces of the specimens were visually assessed for the presence of machining defects such as type of chipped, woolly and fuzzy grains. The apparatus as shown in **Figure 2** was used in the visual assessment of defects.

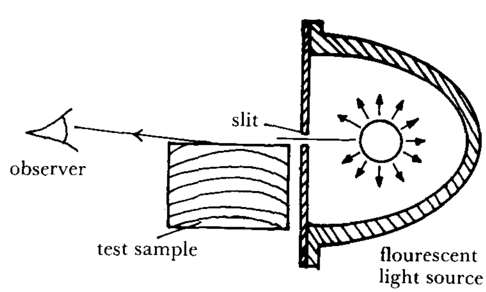


Figure 2. Apparatus to enhance **the appearance** of machining defects

Table 3. $L_{27}3^{13}$ Orthogonal Array Table

Number	Array 1	 2 3 4	 5 6 7	 8 9 10	 11 12 13
1	1	1 1 1	1 1 1	1 1 1	1 1 1
2	1	1 1 1	2 2 2	2 2 2	2 2 2
3	1	1 1 1	3 3 3	3 3 3	3 3 3
4	1	2 2 2	1 1 1	2 2 2	3 3 3
5	1	2 2 2	2 2 2	3 3 3	1 1 1
6	1	2 2 2	3 3 3	1 1 1	2 2 2
7	1	3 3 3	1 1 1	3 3 3	2 2 2
8	1	3 3 3	2 2 2	1 1 1	3 3 3
9	1	3 3 3	3 3 3	2 2 2	1 1 1
10	2	1 2 3	1 2 3	1 2 3	1 2 3
11	2	1 2 3	2 3 1	2 3 1	2 3 1
12	2	1 2 3	3 1 2	3 1 2	3 1 2
13	2	2 3 1	1 2 3	2 3 1	3 1 2
14	2	2 3 1	2 3 1	3 1 2	1 2 3
15	2	2 3 1	3 1 2	1 2 3	2 3 1
16	2	3 1 2	1 2 3	3 1 2	2 3 1
17	2	3 1 2	2 3 1	1 2 3	3 1 2
18	2	3 1 2	3 1 2	2 3 1	1 2 3
19	3	1 3 2	1 3 2	1 3 2	1 3 2
20	3	1 3 2	2 1 3	2 1 3	2 1 3
21	3	1 3 2	3 2 1	3 2 1	3 2 1
22	3	2 1 3	1 3 2	2 1 3	3 2 1
23	3	2 1 3	2 1 3	3 2 1	1 3 2
24	3	2 1 3	3 2 1	1 3 2	2 1 3
25	3	3 2 1	1 3 2	3 2 1	2 1 3
26	3	3 2 1	2 1 3	1 3 2	3 2 1
27	3	3 2 1	3 2 1	2 1 3	1 3 2
Array	a	b a a	c a a	b a a	b a a
Label		b b^2	c c^2	c b b^2 c c^2	c^2 b^2 b c c^2
Factorial effect	A	B A A x x B B	C A A x x C C	B D e x C	B e e x C
Group number	1	2		3	

The severity of each machining defect was determined by comparing with standard defect samples. Consistency of the assessment was ensured by allowing only one person to do the assessment. The degree of severity of each defect was recorded according to the rating as shown below:

0 = free
1 = slight
2 = moderate
3 = severe

Prior to the visual assessment, 100 imaginary sections of equal dimensions were assigned on the radial surface specimens and another 100 on the tangential surfaces specimens. Each section represents single appearance of each type of machining defect at any one of the four degrees of severity.

Hence, total frequency of appearance of any of the three machining defect types at various degrees of severity on either the radial or tangential specimens was equal to 100.

Table 4. List of test conditions generated by $L_{27}3^{13}$ Orthogonal Array Table

	$L_{27}3^{13}$ factors	Testing condition			
	ABC D	Cutting angle (°)	Width of knife marks (*mm*)	Depth of cut (*mm*)	Species
Array number	1 2 5 9	1	2	5	9
Test number					
1	1 1 1 1	30	3.0	1.5	kempas
2	1 1 2 2	30	3.0	1.0	keruing
3	1 1 3 3	30	3.0	0.5	mata ulat
4	1 2 1 2	30	2.0	1.5	keruing
5	1 2 2 3	30	2.0	1.0	mata ulat
6	1 2 3 1	30	2.0	0.5	kempas
7	1 3 1 3	30	1.3	1.5	mata ulat
8	1 3 2 1	30	1.3	1.0	kempas
9	1 3 3 2	30	1.3	0.5	keruing
10	2 1 1 2	20	3.0	1.5	keruing
11	2 1 2 3	20	3.0	1.0	mata ulat
12	2 1 3 1	20	3.0	0.5	kempas
13	2 2 1 3	20	2.0	1.5	mata ulat
14	2 2 2 1	20	2.0	1.0	kempas
15	2 2 3 2	20	2.0	0.5	keruing
16	2 3 1 1	20	1.3	1.5	kempas
17	2 3 2 2	20	1.3	1.0	keruing
18	2 3 3 3	20	1.3	0.5	mata ulat
19	3 1 1 3	10	3.0	1.5	mata ulat
20	3 1 2 1	10	3.0	1.0	kempas
21	3 1 3 2	10	3.0	0.5	keruing
22	3 2 1 1	10	2.0	1.5	kempas
23	3 2 2 2	10	2.0	1.0	keruing
24	3 2 3 3	10	2.0	0.5	mata ulat
25	3 3 1 2	10	1.3	1.5	keruing
26	3 3 2 3	10	1.3	1.0	mata ulat
27	3 3 3 1	10	1.3	0.5	kempas

Results and discussion

Ratios of severity of appearance of chipped, fuzzy and woolly grain defects as observed on the radial and tangential specimens are shown in Table 5 and Table 6 respectively.

Total sums of their appearance show that chipped grain defect was more dominant than fuzzy or woolly grain. The chipped grain was the most common type of machining defect found on tropical hardwoods, because most tropical hardwoods have interlock grain. The chipped grain occurred when the planer knife cuts against the grains, during which splitting of woodfibres occurred below the path of the knife edge. For interlock grain timber, cutting against the grain cannot be avoided, since the slope of grain alternately change from the

Table 5. Ratio of severity of appearance of various machining defect types on radial surfaces of test specimens at various test conditions

*	Chipped grain				Fuzzy grain				Woolly grain			
** / ***	0	1	2	3	0	1	2	3	0	1	2	3
1	0	0	7	93	75	25	0	0	100	0	0	0
2	58	27	15	0	68	31	1	0	100	0	0	0
3	4	20	34	42	100	0	0	0	100	0	0	0
4	97	3	0	0	55	37	8	0	100	0	0	0
5	12	23	63	2	90	10	0	0	100	0	0	0
6	0	4	36	60	66	1	30	3	100	0	0	0
7	50	43	7	0	82	18	0	0	100	0	0	0
8	11	7	50	32	5	14	30	51	100	0	0	0
9	97	3	0	0	62	38	0	0	100	0	0	0
10	71	20	9	0	91	9	0	0	100	0	0	0
11	4	5	51	40	100	0	0	0	100	0	0	0
12	1	1	12	86	85	3	7	0	100	0	0	0
13	38	29	29	4	100	0	0	0	100	0	0	0
14	5	8	26	61	100	0	0	0	100	0	0	0
15	94	5	1	0	95	5	0	0	100	0	0	0
16	24	35	12	29	100	0	0	0	100	0	0	0
17	100	0	0	0	91	6	3	0	100	0	0	0
18	59	38	3	0	100	0	0	0	100	0	0	0
19	6	30	38	26	100	0	0	0	100	0	0	0
20	7	3	17	73	100	0	0	0	69	0	14	17
21	92	8	0	0	83	17	0	0	67	33	0	0
22	26	4	29	3	99	1	0	0	62	7	13	18
23	100	0	0	0	83	17	0	0	100	0	0	0
24	53	33	11	3	100	0	0	0	100	0	0	0
25	100	0	0	0	71	24	5	0	100	0	0	0
26	85	13	2	0	100	0	0	0	100	0	0	0
27	74	10	14	2	38	43	19	0	82	7	7	4

Legend : * - defect type, ** - degree of defect severity, *** - test number

positive to negative along the cutting length of the timber. Figure 3 shows the distribution of positive and negative slope of grain along the cutting length of the test specimens, which were obtained by tallying their appearance on 100 equal sections on both sides of each test specimens. The pattern of their distribution shows that all the three species possessed interlock grain characteristics. Table 7 shows that the ratios of appearance of negative slope over positive slope at each section of the test specimen are greater on the radial surface than on the tangential surface. It also shows that kempas specimens have the greatest ratio of appearance of negative slope over positive slope, followed by mata ulat and keruing. These show that the severity of interlock grain characteristics varies according to sawing pattern as well as the species type.

Figure 4 (a) shows the pattern of chipped grain defect as appeared on the radial and tangential surfaces of each species. Kempas specimens show the highest ratio of appearance of chipped grain defect followed by mata ulat and keruing. The graph also shows that chipped grain defect is more prone on the radial surface than on the tangential surface. The variation in the appearance of chipped defect against the three species was very significant when tested at 99% confidence limit.

Table 6. Ratio of severity of appearance of various machining defect types on tangential surfaces of test specimens at various test conditions

*	Chipped grain				Fuzzy grain				Woolly grain			
**	0	1	2	3	0	1	2	3	0	1	2	3
***												
1	13	26	29	32	96	4	0	0	100	0	0	0
2	88	10	1	1	93	7	0	0	100	0	0	0
3	49	26	22	3	100	0	0	0	100	0	0	0
4	98	1	0	1	60	34	6	0	100	0	0	0
5	10	26	12	2	100	0	0	0	100	0	0	0
6	44	13	39	4	100	0	0	0	100	0	0	0
7	91	7	2	0	98	2	0	0	100	0	0	0
8	92	6	2	0	10	29	31	30	100	0	0	0
9	99	1	0	0	62	33	5	0	100	0	0	0
10	92	6	1	1	98	2	0	0	100	0	0	0
11	21	37	29	14	100	0	0	0	100	0	0	0
12	41	7	25	25	94	6	0	0	100	0	0	0
13	89	8	2	1	100	0	0	0	100	0	0	0
14	56	32	11	11	100	0	0	0	100	0	0	0
15	98	1	1	0	97	3	0	0	100	0	0	0
16	79	20	1	0	100	0	0	0	100	0	0	0
17	100	0	0	0	100	0	0	0	100	0	0	0
18	82	16	2	0	100	0	0	0	100	0	0	0
19	51	23	19	7	100	0	0	0	100	0	0	0
20	53	12	26	9	100	0	0	0	85	9	6	0
21	99	0	1	0	100	0	0	0	100	0	0	0
22	81	16	3	0	97	3	0	0	91	7	2	0
23	99	1	0	0	99	0	1	0	100	0	0	0
24	80	13	6	1	100	0	0	0	100	0	0	0
25	100	0	0	0	91	7	1	1	100	0	0	0
26	87	10	3	0	100	0	0	0	100	0	0	0
27	95	5	0	0	91	9	0	0	95	5	0	0

Legend : * - defect type; ** - degree of defect severity, *** - test number

The patterns of appearance of the other two types of defects, that is fuzzy and woolly grains, on both the radial and tangential surfaces against the various species are shown in Figures 4 (b) and 4 (c) respectively. Compared to chipped grain, the variation of fuzzy grain and woolly grain appearances against the various species is not significant but fuzzy grain appearance in kempas is higher than in other species (Figure 4b). This analysis shows that the severity of interlock grain characteristics of the test specimens has direct effect on the pattern of appearance of chipped grain defect but not on the pattern of appearance of fuzzy of woolly grain.

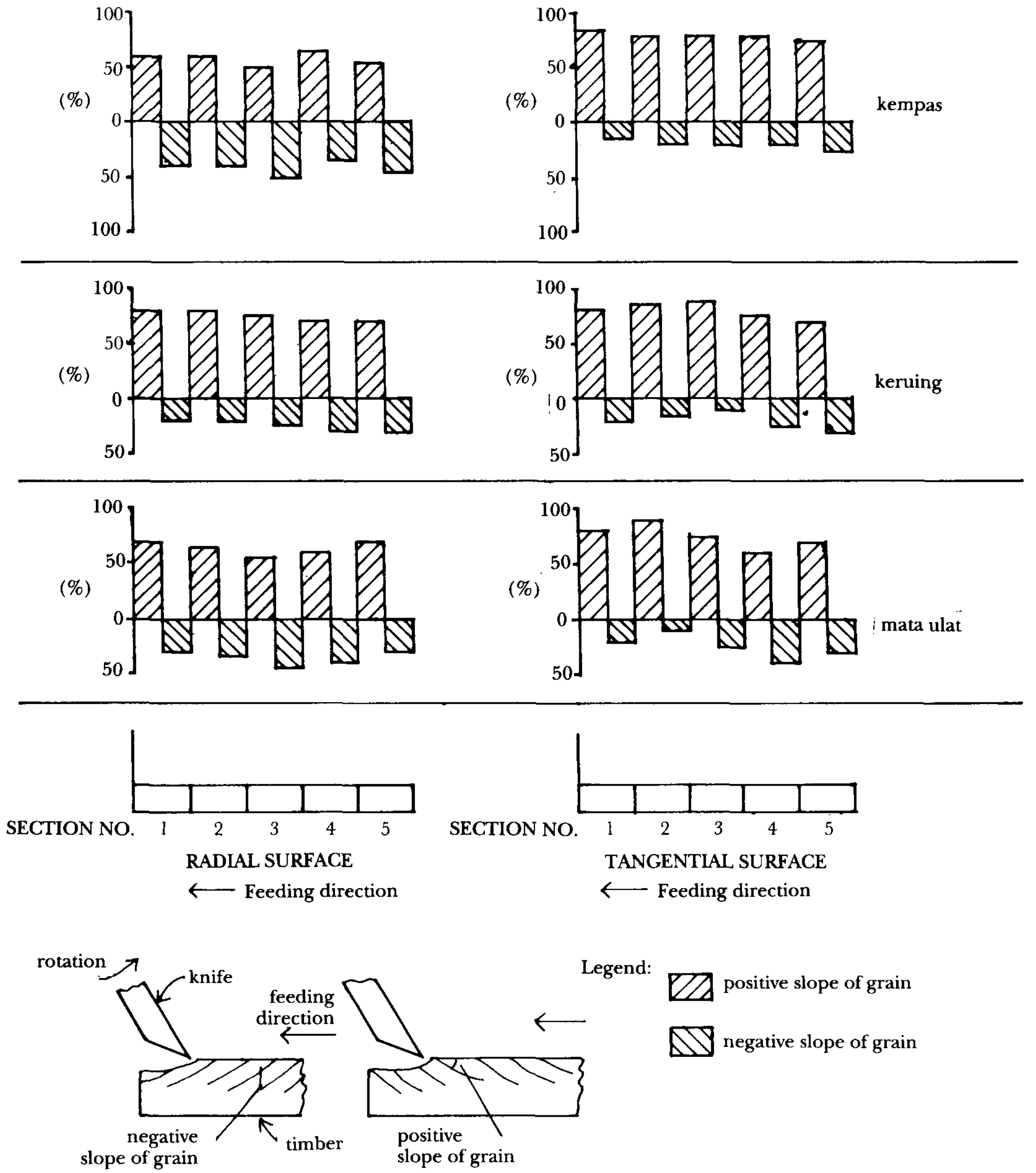


Figure 3. Distribution of positive and negative slope of grain on the sides of each section of kempas, keruing and mata ulat specimens

Table 7. Ratio of percentage of appearance of negative slope over positive slope of grains at each section of test specimens

Species		Section 1	2	3	4	5
Kempas	Radial	0.67	0.67	1.0	0.54	0.82
	Tangential	0.18	0.25	0.25	0.25	0.33
Keruing	Radial	0.25	0.25	0.33	0.43	0.43
	Tangential	0.25	0.18	0.11	0.33	0.43
Mata ulat	Radial	0.43	0.54	0.82	0.67	0.43
	Tangential	0.25	0.11	0.33	0.67	0.43

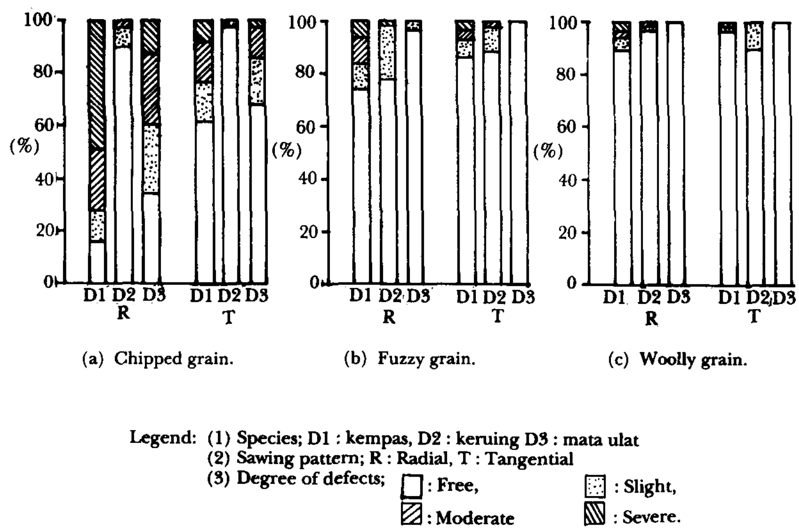


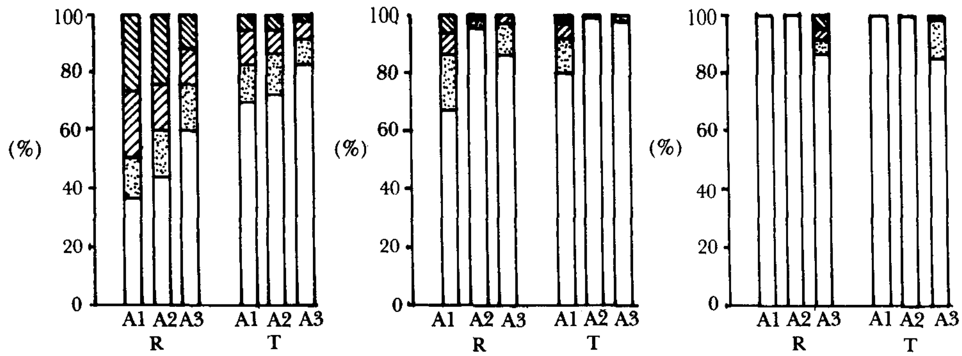
Figure 4. Ratios of appearance of various degrees of machining defects against the species

Effect of cutting angle

From the analysis of variance it was found that the appearance of chipped grain was highly sensitive to the change in cutting angle, but only on the radial surface. On the tangential surface, the appearance of chipped grain defect varies significantly only when the change in cutting angle interacts with the change in the depth of cut. On both the radial and tangential specimens, the appearance of chipped grain defect was reduced as the cutting angle was reduced from 30° to 10° as shown in Figure 5 (i)(a). The appearance of fuzzy and woolly grain was not sensitive to the change in cutting angle. Fuzzy grain only appeared at 30° of cutting angle while woolly grain at 10° of cutting angle [Figures 5 (i) (b) and 5 (i) (c)].

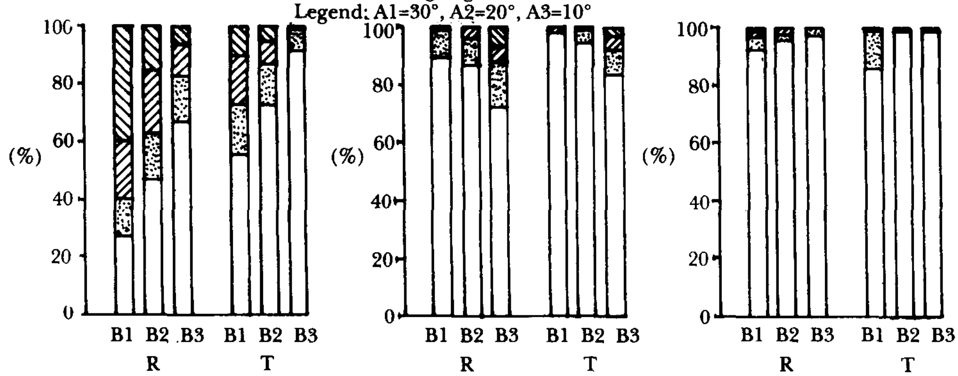
Effect of width of knife marks

The appearance of chipped grain was highly sensitive to the change in the width of the knife marks on both the radial and tangential specimens. Figure



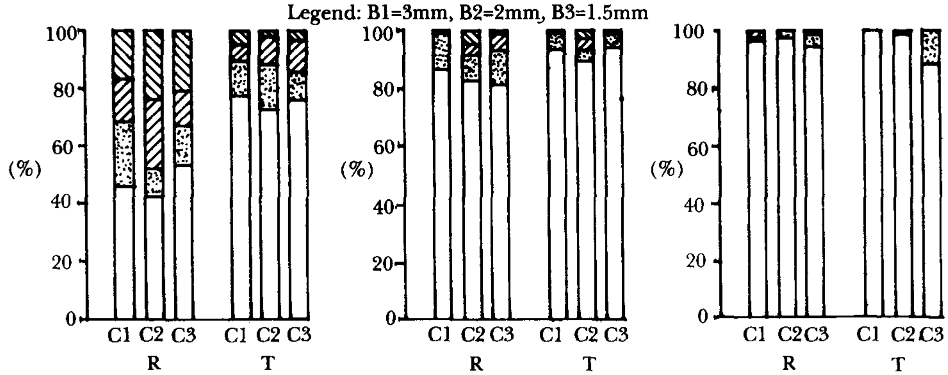
(a) Chipped grain. (b) Fuzzy grain. (c) Woolly grain.

(i) effect of cutting angle
Legend: A1=30°, A2=20°, A3=10°



(a) Chipped grain. (b) Fuzzy grain. (c) Woolly grain.

(ii) effect of width of knife marks
Legend: B1=3mm, B2=2mm, B3=1.5mm

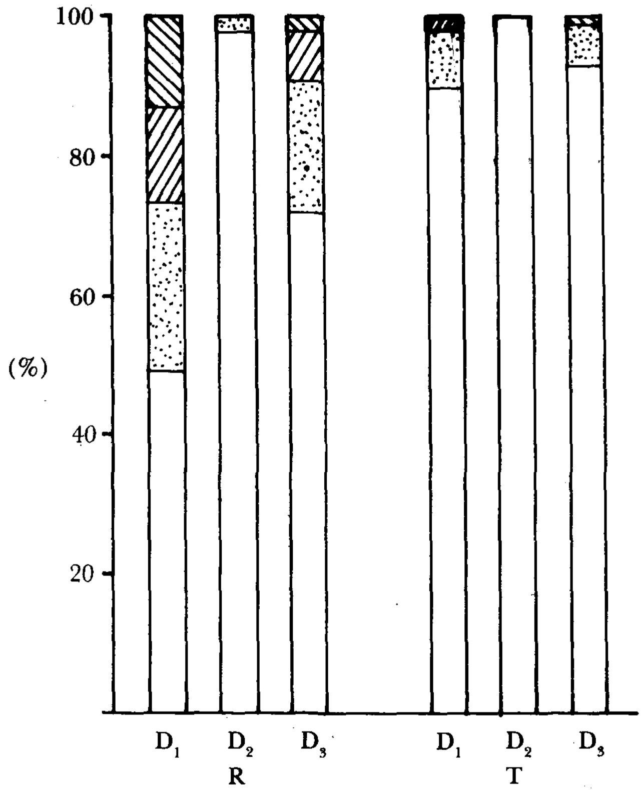


(a) Chipped grain. (b) Fuzzy grain. (c) Woolly grain.

(iii) effect of depth of cut
Legend: C1=1.5mm, C2=1.0mm, C3=0.5mm

Common legend: (1) Sawing pattern ; R : radial, T : tangential.
(2) Degree of defects; □ : Free, ⬚ : Slight, ▨ : Moderate, ▧ : Severe

Figure 5. Relationship between ratios of appearance of various degrees of machining defects against various cutting factors



Legend : (1) species ; DI : kempas, D2 : keruing, D3 : mata ulat
(2) Degree of defects; : Free, : Slight, : Moderate, : Severe

Figure 6. Ratios of appearance of chipped grain defects on the various species when planed under the optimum cutting condition of 10° cutting angle, 1.3 *mm* width of knife marks and 0.5 *mm* depth of cut

5 (ii) (a) shows that the appearance of chipped grain defect was reduced as the width of knife marks was reduced from 3.0 to 1.3 *mm*. The appearance of fuzzy and woolly grain was not sensitive by the change in width of the knife marks, since trends of the pattern of their appearance were not very clear as shown in Figure 5 (ii) (b) for fuzzy grain and Figure 5 (ii) (c) for woolly grain.

Effect of depth of cut

The patterns of appearance of all the three types of defects on the various species were not sensitive to the change in depth of cut as shown in Figure 5 (iii) (a) for chipped grain, Figure 5 (iii) (b) for fuzzy grain and Figure 5 (iii) (c) for woolly grain. But the interactions of the change in cutting angle with the change in depth of cut have significant effect on the pattern of appearance of chipped grain defect on the various species.

From this experiment, it can be seen that cutting angle, width of knife marks as well as interaction of depth of cut with cutting angles have controlling effect on the appearance of chipped grain defects in planing kempas, keruing and mata ulat, but not on the appearance of fuzzy of woolly grain. By reducing cutting angle from 30° to 10°, width of knife marks from 3.0 to 1.3 *mm* and depth of cut from 1.5 to 0.5 *mm*, the appearance of chipped grain defects can be minimised on any of the three species. The patterns of the appearance of the chipped grain defect on the various species when planed under the above mentioned optimum cutting condition are shown in Figure 6. The figure also shows that keruing still gives the least chipped grain defect followed by mata ulat and kempas and that the tangential surface always gives less chipped grain defect than the radial surface.

Conclusions

From the above discussions, it can be concluded that chipped grain is the most dominant type of machining defect to appear on the test specimens as compared to fuzzy and woolly grains. Severity of interlock grain of the timber varies according to the species as well as to the sawing pattern of the specimens and is directly related to the severity of appearance of chipped grain defects. Kempas has the highest rates of chipped grain defect followed by mata ulat and keruing. The radial surface has higher ratio of chipped grain defect than the tangential surface. Ratio of appearance to chipped grain defect can be controlled by varying the three cutting factors, such as cutting angle, width of knife marks and depth of cut. Ratio of appearance of fuzzy and woolly grains defects cannot be controlled by any of the three cutting factors mentioned. Ratio of appearance of chipped grain defect is reduced as the cutting angle, width of knife marks and depth of cut are reduced.

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