CHEMICAL AND MECHANICAL WEARING OF HIGH SPEED STEEL AND TUNGSTEN CARBIDE TOOLS BY TROPICAL WOODS

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DARMAWAN, W., RAHAYU, I. S., TANAKA, C. & MARCHAL, R. 2006. Chemical and mechanical wearing of high speed steel and tungsten carbide tools by tropical woods. This paper presents the chemical and mechanical wearing of high speed steel and tungsten carbide tools by some tropical woods. In the first part of the experiment, weight losses of tool materials of JIS SKH51-A, JIS SKH51-H and JIS WC-12%Co after reacting with wood extracts of coconut, oil palm, teak, red meranti and pasang were studied. In the second part, the amount of wear on the clearance face of AISI M2, AISI K5 and AISI K10 tungsten carbide bits was measured when routing these woods. The tools suffered highest percentage of weight loss when soaked in both the extractive and wood powder solution of pasang. The WC-12%Co suffered smaller percentage of weight loss compared with SKH51-A and SKH51-H. The SKH51-A suffered slightly higher percentage of weight loss than SKH51-H. The bits suffered the largest clearance wear and wear rate when used for routing oil palm wood. The wear of M2 bit was twice larger than that of K5 and K10 when routing the same wood species.

Keywords: routing, extractive, silica, weight loss, clearance wear, tool bit

DARMAWAN, W., RAHAYU, I. S., TANAKA, C. & MARCHAL, R. 2006. Penghausan kimia dan mekanik bahan pisau keluli dan karbida tungsten yang beroperasi pada kelajuan tinggi oleh kayu tropika. Kertas kerja ini mengkaji penghausan bahan pisau-pisau keluli dan karbida tungsten pada kelajuan tinggi oleh beberapa kayu tropika. Penghausan kimia dan mekanik dikaji. Dalam bahagian pertama uji kaji, kehilangan berat bahan pisau JIS SKH51-A, JIS SKH51-H dan JIS WC-12% Co disukat selepas tindak balas dengan ekstrak-ekstrak kayu kelapa, kayu kelapa sawit, kayu jati, kayu meranti merah dan kayu pasang. Dalam bahagian kedua, jumlah haus pada mata bit AISI M2, AISI K5 dan AISI K10 disukat selepas ia digunakan untuk memotong kelima-lima kayu di atas. Bahan pisau yang direndam dalam ekstrak dan larutan habuk kayu pasang mengalami peratusan kehilangan berat yang paling banyak. Bahan pisau WC-12% Co mengalami peratusan kehilangan berat yang lebih rendah berbanding dengan SKH51-A dan JIS SKH51-H. Kehilangan berat pada SKH51-A lebih tinggi daripada JIS SKH51-H. Mata bit mengalami haus yang paling besar apabila digunakan untuk memotong kayu kelapa sawit. Bit M2 mengalami jumlah haus dua kali lebih besar berbanding dengan bit K5 dan K10 apabila memotong kayu yang sama.

INTRODUCTION

Investigations on the wear of woodworking cutting tools have been concerned mainly with mechanical factors. Rapid mechanical wearing of the tools has often been attributed to the presence of silica and other abrasive agents in wood (Huber 1985, Porankiewicz & Gronlund, 1991). However, chemical wear due to extractives in wood, such as gums, fats, resins, sugars, oils, starches, alkaloids and tannins, has been reported as an important factor in determining the wear characteristics of woodworking cutting tools (Kirbach & Chow 1976, Murase 1984, Fukuda *et al.* 1992 and Morita *et al.* 1999). Considering that extractives and abrasive agents vary in chemical composition, amount and reactivity among wood species, their impact on cutting tools during cutting would also vary.

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High speed steel and tungsten carbide cutting tools are widely used in the woodworking industry in Indonesia for machining both natural and plantation woods which are mostly high in extractives and ash content. Extractives, that are found in the heartwood, are extractable with neutral organic solvents (ethanol, acetone, benzene, dichlorobenzene) and/or water.

About 400 wood species are commercially processed for wood construction and wooden furniture in Indonesia. A few studies on chemical components of some Indonesian commercial wood species have been done. It was reported that the extractive contents ranged from 1.4 to 13.8% by weight and the ash contents ranged from 0.1 to 5.0% by weight (Martawijaya *et al.* 1989).

Woods are usually machined before use in construction or furniture making. The machining required, when wood is cut, planed and shaped into useful products, is a significant cost factor in the wood products industry. Despite the extensive use of cutting tools in the wood industry, knowledge of their wearing characteristics on Indonesian wood is limited.

A study was conducted to investigate the effects of selected Indonesian woods on the chemical and mechanical wear characteristics of high speed steel and tungsten carbide cutting tools.

MATERIALS AND METHODS

In the first part of the study, the following procedures were performed to investigate the interaction between wood extractives and cutting tool materials.

Ethanol/benzene extractives were extracted from 8 g of 50 mesh wood powders of coconut (*Cocos nucifera*), oil palm (*Elaeis guineensis*), teak (*Tectona grandis*), red meranti (*Shorea* sp.) and pasang (*Querqus* sp.) using TAPPI T204 om-88 procedures (TAPPI 1991a). The extractive contents were calculated based on the percentage of extract dry weight to powder dry weight. The TAPPI T211 om-85 procedures were then applied to determine the ash and silica content of these woods (TAPPI 1991b). The acidity (pH) of wood samples was determined by dissolving 5 g of 50 mesh wood powders in 50 ml distilled water. The solution was heated on the water bath for about 30 min until it reached 80 °C. After cooling, the pH of the solution was measured by using the pH meter. In order to produce 3 g of dry solid extracts, the extraction process was made repeatedly. However, this was only performed for red meranti and pasang. Extractive solution of 10% was prepared by dissolving 1 g of dry solid extract of red meranti and pasang in each 10 ml distilled water. New tips of annealed SKH51 (SKH51-A), hardened SKH51 (SKH51-H) and WC-12%Co (Table 2), which were characterized by Japan Industrial Standard (JIS), were reacted with the prepared extractive solutions in a stirred slurry. The mixtures were allowed to react for 48 hours at 80 °C. After that, the tips of the tool materials were cleaned with chloroform and dried, and the weight losses were determined.

Wood powders of 50 mesh were prepared from coconut, oil palm, teak, red meranti and pasang (Table 1). New tips of the tool materials were soaked in stirred slurry containing 100 ml hot water and 20 g wood powder of each wood species. The mixtures were allowed to react for 48 hours at 80 °C. After that, the tips were rinsed with chloroform to remove any residue wood powder and dried. The weight losses were determined.

In the second part of the study, wood samples were routed in up milling direction (feeding direction of wood samples counter rotation direction of the router spindle) on the Computer Numerical Control (CNC) Router using M2 high speed steel, K5 and K10 tungsten carbide bits, which were characterized according to American Iron and Steel Institute (AISI). The bits specification and routing conditions are summarized in Tables 3 and 4 respectively. Schematic diagram of the routing is presented

Table 1 Specifications of wood species

Property	Wood species				
	Coconut	Oil palm	Teak	Red meranti	Pasang
Air-dry density (g cm^{-3})	0.44	0.45	0.65	0.67	0.90
Moisture (%)	14.5	13.0	12.5	15.5	16.0

in Figure 1. The amount of wear on the clearance face of the bits was measured every 7 min cutting time up to 70 min cutting time. The method for the wear measurement was described in the previous paper (Darmawan *et al.* 2001a). The wear patterns were also characterized under an optical video microscope.

RESULTS AND DISCUSSION

Chemical wearing of tool materials

Extractive and silica contents in the woods, and the percentage of weight loss of the tool materials after 48 hours reaction at 80 °C are presented in Tables 5 and 6 respectively. The amount of chemical wear was determined by the percentage of weight loss of the tool materials. Table 5 shows that the woods tested are acidic and vary slightly in extractive content. Oil palm had the highest silica content.

The tool materials suffered the highest percentage of weight loss when they were soaked

Table 2 Specifications of cutting tool materials

Tool material	Specification			
	Dimension	Metal component (% wt)	Heat treatment	Hardness (HRA)
JIS Annealed SKH51 (JIS SKH51-A)	2 × 10 × 20 mm	Fe = 81.63, C = 0.88, Si = 0.25, Mn = 0.30, Cr = 4.04, W = 6.13, Mo = 4.92, V = 1.85	Annealed at 900 °C	61.5
JIS Hardened SKH51 (JIS SKH51-H)	2 × 10 × 20 mm	Fe = 81.63, C = 0.88, Si = 0.25, Mn = 0.30, Cr = 4.04, W = 6.13, Mo = 4.92, V = 1.85	Hardened at 1220 °C followed by two times of one hour tempering at 560 °C	83.7
JIS K30 Tungsten carbide	2 × 10 × 20 mm	WC = 88, Co = 12	–	88.5

Table 3 Specifications of router bits

Specification	Router bits		
	AISI M2 high speed steel	AISI K5 tungsten carbide	AISI K10 tungsten carbide
Bit diameter	12 mm	12 mm	12 mm
Number of knives	2	2	2
Rake angle	10°	10°	10°
Clearance angle	15°	15°	15°
Hardness	83.9 HRA	93.1 HRA	92.5 HRA
Thermal conductivity	25 W/m.K	100 W/m.K	80 W/m.K
Metal composition	Almost same as JIS SKH51	WC-5%Co	WC-6%Co

Table 4 Routing conditions

Cutting speed	550 m min^{-1}
Feed rev.	0.1 mm rev^{-1}
Spindle speed	14560 rpm
Feed speed	1460 mm min^{-1}
Width of cut	5 mm
Depth of cut	3 mm

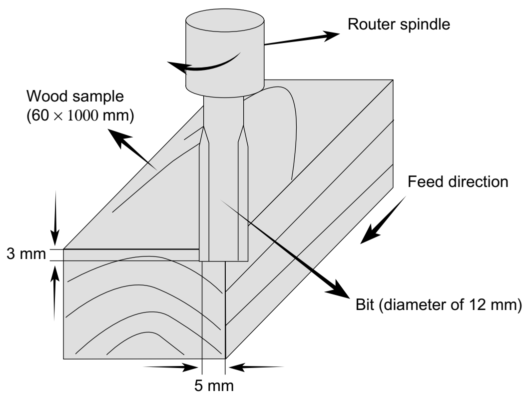

Figure 1 Routing on the edge of a wood sample

in both extractive and wood powder solution of pasang, although the amounts of extractive per unit oven dry volume were almost the same with other woods (Table 6). This indicated that the chemical compounds in pasang were more reactive to elements in the tool materials. The percentages of weight loss were larger in extractive soaking than in the wood powder soaking for both pasang and red meranti (Table 6).

The SKH51 tool materials suffered a higher percentage of weight loss compared with tungsten carbide for all wood species. This is a result of the wide variety of metal components in SKH51, which were susceptible to chemical attack rather than the unvaried compound of WC and Co in the tungsten carbide (Table 2).

The SKH51-H, which underwent complete heat treatments (annealing, austenitizing, quenching and tempering), attained percentage weight loss that was slightly lower than the SKH51-A. This could be due to the fact that the microstructure of the hardened steel tools, which consists mainly of austenitic and martensitic matrix, was more stable and more resistant to chemical reaction than that of the annealed steel tools, which consist mainly of ferritic (Pippel *et al.* 1999).

Mechanical wearing of tool bits

The amount of mechanical wear was determined by the amount of knife-edge recession of the bits on the clearance face.

Oil palm wore the router bits faster compared with the other wood species (Figure 2). This was due to the higher content of silica in oil palm (Table 5).

Red meranti and pasang had the same silica content, but they were different in density (Tables 1 and 5). A higher wear rate of the bits when cutting pasang compared with red meranti could be due to the higher density of pasang. The clearance wear (Figure 2) and the wear rate (Table 7) of the M2 bit were twice larger than those of the tungsten carbide bits when cutting the same wood species.

Higher hardness of the K5 and K10 carbide bits compared with that of M2 (Table 3) was the reason. However, there was no significant difference in clearance wear and wear rate between the two carbide bits.

The results in Figure 3 gave an indication that wear patterns of the bits were the same for all wood species. Considering the results in the previous paper (Darmawan *et al.* 2001b) and that

Table 5 Chemical characteristics of wood species

Wood species	pH	Extractive (%)	Ash (%)	Silica (%)
Coconut	5.82	8.3	1.8	0.2
Oil palm	4.93	8.2	1.3	1.2
Teak	4.10	10.9	1.4	0.4
Red meranti	3.51	7.6	1.1	0.3
Pasang	4.01	8.4	1.1	0.3

Table 6 Percentage of weight loss of tool materials after 48 hours reaction at 80 °C with extractive and with wood powder solution

Tool material	Wood species				
	Coconut	Oil palm	Teak	Red meranti	Pasang
SKH51-A	0.59	0.06	0.11	0.26 (0.32)	0.79 (0.91)
SKH51-H	0.30	0.04	0.10	0.25 (0.28)	0.67 (0.88)
K 30 tungsten carbide	0.02	0	0.01	0.01 (0.03)	0.04 (0.09)

Values in parentheses are values for extractives.

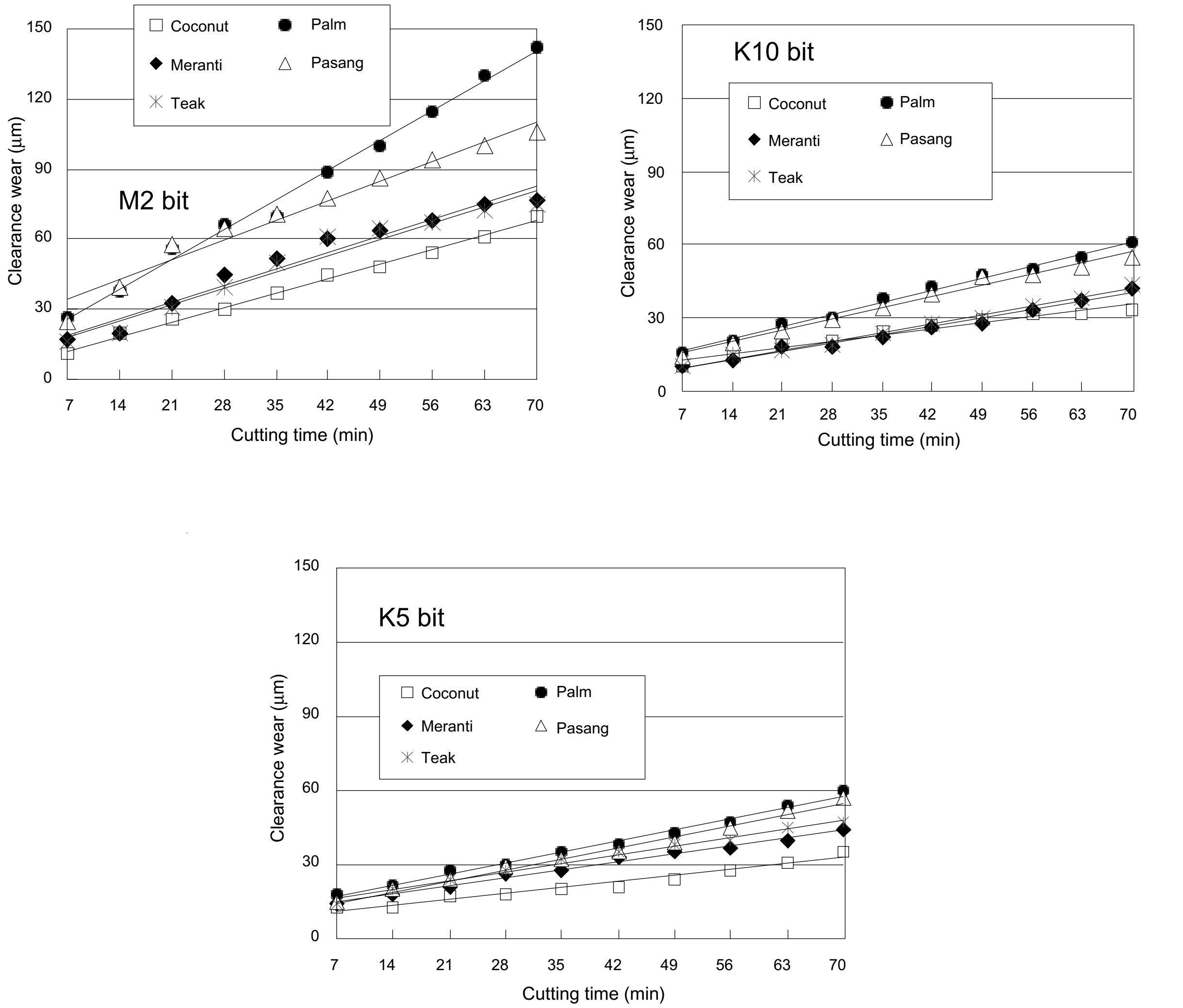

Figure 2 Clearance face wear of the bits as a function of cutting time for routing some tropical woods

Table 7 Rate of wear (µm min^{-1}) of the router bits

Bits	Wood species				
	Coconut	Oil palm	Teak	Red meranti	Pasang
M2	0.88	1.81	1.01	1.01	1.21
K5	0.34	0.64	0.51	0.46	0.64
K10	0.36	0.70	0.51	0.49	0.66

the wood species tested were air dried and were routed at a low cutting speed, the wears of the bits were primarily caused by mechanical abrasion.

CONCLUSIONS

Wood extractive was important in the chemical wearing of tool materials. Among the wood species, pasang caused the highest percentage of weight loss of the tool materials. Annealed SKH51 (SKH51-A) tool material was more susceptible to wear by extractive compared with the hardened SKH51 (SKH51-H) tool material. Wood silica content was important in determining the mechanical wearing of the cutting tool. Oil palm with high silica wore tool bits faster compared with other woods. High

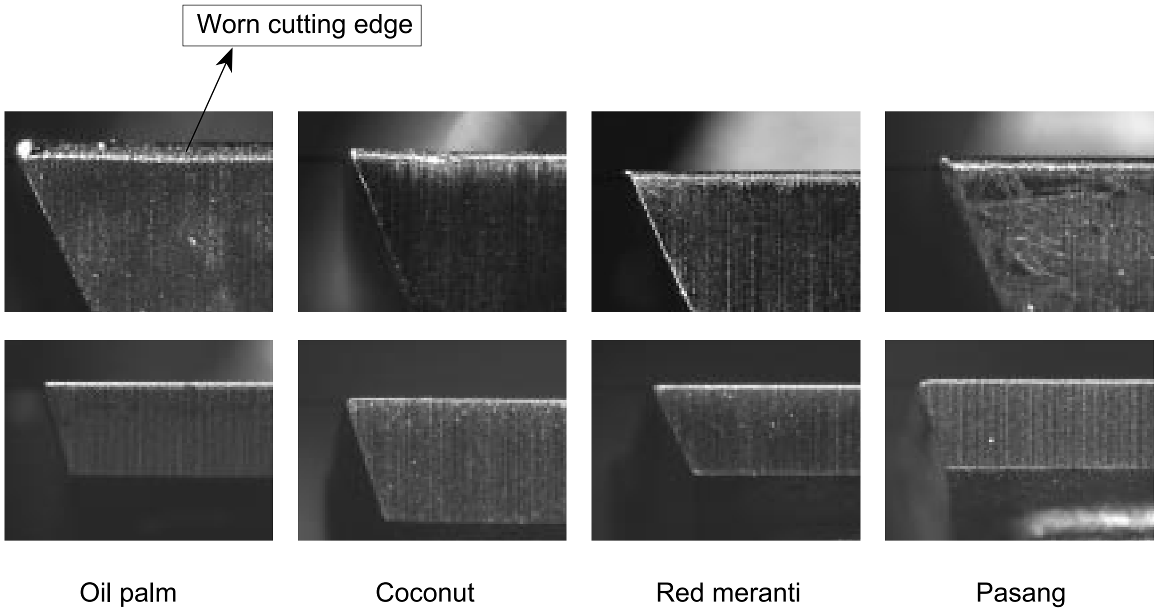

Figure 3 Wear patterns of the M2 (first row) and K10 (second row) bits when routing the various wood species

speed steel tool materials assisted chemical wearing by wood extractive and mechanical wearing by silica.

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