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WEAR CHARACTERISTICS OF WOOD CUTTING TOOLS CAUSED BY EXTRACTIVE AND ABRASIVE MATERIALS IN SOME TROPICAL WOODS

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DARMAWAN W, RAHAYU I, NANDIKA D & MARCHAL R. 2011. Wear characteristics of wood cutting tools caused by extractive and abrasive materials in some tropical woods. Tropical woods and wood-based materials are processed in large and increasing quantities in many countries for building constructions and decorative purposes. In the secondary wood manufacturing industry, where wood and wood-based materials are machined extensively, tool wear becomes an important economic parameter. Therefore, investigating the machining characteristics of the wood and wood-based materials will lead to making better choices of cutting tool materials used to cut them. For many wood cutting processes, the interest in high speed tool steels and tungsten carbides remains very important because of their good tool edge accuracy and easy grinding. This paper presents the wear characteristics of SKH51 high speed steel and K10 tungsten carbide caused by extractive and abrasive materials present in Indonesian tropical timbers of mersawa, oil palm, white meranti, damar laut and ulin. Experimental results showed that extractive and silica contained in the woods affected wearing of both cutting tools. Mersawa contained an extractive that was the most corrosive to the cutting tools. Mersawa and oil palm, which are also high in silica content, caused severe damages to the cutting edge of the SKH51 high speed steel. However, K10 tungsten carbide tool retained high wear resistance in cutting the tested woods.

Keywords: Wear resistance, high speed steel, tungsten carbide, silica, cutting edge

DARMAWAN W, RAHAYU I, NANDIKA D & MARCHAL R. 2011. Ciri kehausan perkakas potong kayu akibat bahan-bahan ekstraktif dan pelelas dalam sesetengah kayu tropika. Kayu tropika dan bahan berasaskan kayu diproses dalam kuantiti yang besar dan semakin meningkat di banyak negara bagi tujuan pembinaan bangunan serta hiasan. Dalam industri penghasilan kayu sekunder, kayu dan bahan berasaskan kayu dimesin dengan banyak. Justeru hausan perkakas merupakan parameter ekonomi yang penting. Kajian tentang ciri pemesinan dapat membantu dalam pemilihan bahan yang digunakan untuk perkakas potong. Proses pemotongan kayu banyak menggunakan keluli perkakas tahan lasak dan tungsten karbida kerana ketepatan mata perkakas yang baik serta mudah untuk dicanai. Artikel ini melaporkan ciri kehausan keluli tahan lasak SKH51 dan tungsten karbida K10 yang disebabkan oleh bahan-bahan ekstraktif serta pelelas yang wujud dalam kayu tropika di Indonesia iaitu mersawa, kelapa sawit, meranti putih, damar laut and ulin. Keputusan kajian menunjukkan bahawa bahan esktraktif dan silika dalam kayu mempengaruhi hausan kedua-dua perkakas potong yang diuji. Mersawa mengandungi ekstraktif yang paling kuat mengkakis perkakas potong. Mersawa dan kelapa sawit yang mempunyai kandungan silika yang tinggi mengakibatkan kerosakan teruk pada mata pemotong keluli tahan lasak SKH51. Bagaimanapun tungsten karbida K10 menunjukkan rintangan hausan yang tinggi semasa memotong kayu yang diuji.

INTRODUCTION

Tropical woods and wood-based materials are machined in large and increasing quantities in many countries for building constructions and decorative purposes. Extensive machining has made wear of cutting tools an important economic parameter. However, knowledge of wearing characteristics of cutting tools is limited and any additional information regarding these characteristics will lead to making better choices of cutting tool materials for cutting tropical woods. High speed steel and tungsten carbide cutting tools are widely used in the woodworking industry throughout Indonesia for machining woods which are mostly high in extractives and abrasive materials. There are about 400 wood species which are commercially processed for

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wood constructions and wooden furniture in Indonesia (Martawijaya et al. 1989). Extractive contents of some of these species range between 1.4 and 13.8% and their ash contents, between 0.1 and 5.0%.

Rapid mechanical wearing of high speed steel cutting tools has often been attributed to the presence of silica and other abrasive agents in the woods (Porankiewicz & Gronlund 1991). However, the authors did not explain in detail the importance of silica content and its distribution on the wearing phenomenon of the high speed steel cutting tool. At the same time, chemical wear due to extractives in the woods, such as gums, fats, resins, sugars, oils, starches, alkaloids and tannins, has also been reported as an important factor in determining wear characteristics of the woodworking cutting tools (Kirbach & Chow 1976, Krilov 1986, Fukuda et al. 1992, Morita et al. 1999). Considering that extractives among tropical wood species vary in chemical composition, amount and reactivity the possibility of their chemical impact on cutting tool materials during cutting would also be varied.

This work was aimed at investigating the effects of extractive and silica contained in some Indonesian tropical woods on chemical and mechanical wear characteristics of high speed steel and tungsten carbide cutting tools. A better understanding on the wearing phenomenon of high speed steel and tungsten carbide cutting tools would be useful in cutting some Indonesian tropical woods. The knowledge would in turn be used to produce an improved cutting tool, which will reduce processing cost for wood manufacturers.

MATERIALS AND METHODS

In the first part of the experiment, we studied the interaction between wood extractives and cutting tools materials. The species used in the study were mersawa (*Anisoptera* spp.), oil palm (*Elaeis guineensis*), white meranti (*Shorea* spp), damar laut (*Hopea dryobalanoides*) and ulin (*Eusideroxylon zwageri*). Densities and moisture contents of the study species are given in Table 1. The pH of each wood tested was determined by dissolving 10 g of 50-mesh wood powders in 50 ml distilled water. The solution was heated in a water bath for 30 min at a temperature of 80 °C. After cooling, the solution was filtered using filter paper no 10. The pH of the solution was measured by using a pH meter.

Extractive contents of woods were determined using ethanol/benzene extraction method. For each species, ethanol/benzene extractives were extracted from 10 g of 50-mesh wood powder 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.

Ash and silica contents of the woods were determined according to TAPPI T211 om-85 procedures (TAPPI 1991b). A total of 10 g of 50-mesh wood powder of each species were heated in a furnace at a temperature of 600 °C for six hours. Ash content was calculated based on the percentage of ash weight to powder dry weight. The ash was then added to 20 ml HCl 4 N and heated in a water bath at 80 °C. The ash solution was diluted with water distillate and then washed using $AgNO_3$ indicators. The solid sediment was heated at 105 ± 3 °C to obtain the constant weight of silica. Silica content was calculated based on the percentage of silica weight to powder dry weight. In order to determine the silica distribution in the wood, wood samples of 2 × 2 × 2 cm on the radial section were analysed under scanning electron microscope/energy dispersive spectroscopy (SEM/EDS).

New tips of SKH51 high speed steel and K10 tungsten carbide (Table 2), which were classified according to the Japan Industrial Standard (JIS), were reacted with the prepared extractive solutions (10 g of 50-mesh wood powder in 100 ml ethanol/benzene) in stirred slurry. The

Table 1 Specification of wood species

Property	Wood species				
	Mersawa	Oil palm	White meranti	Damar laut	Ulin
Density (g cm^{-3})	0.54	0.71	0.62	0.70	0.92
Moisture (%)	11.7	12.2	12.5	14.4	12.0

mixtures were allowed to react for 48 hours at 80 °C by considering the fact that, for cutting speed of about 20 m s^{-1}, chemical wear due to oxidation or corrosion would have started at the initial stage of cutting and at temperature below 100 °C (Darmawan et al. 2001). After termination of reaction, the tips of the tool materials were dried and analysed under SEM/EDS to characterise the possible corrosion on the surface of the tip of the tool materials. Then the tips were cleaned with chloroform and dried, and their weight losses determined.

In the second part of the investigation, all wood species studied were routed in up milling (conventional milling) direction on the Computer Numerical Control (CNC) Router using SKH51 high speed steel and K10 tungsten carbide bits. Wood samples routed were selected from heartwoods of mersawa, white meranti, damar laut and ulin. Samples of oil palm wood were taken from the outer part of the stem. The specification of bits and routing conditions are summarised in Tables 3 and 4 respectively. Schematic diagramme of the routing in the up milling direction is presented in Figure 1. Amount of wear on the clearance face of the bits was measured intermittently at every 0.2 km cutting length up to 2 km (Figure 2). Their wear patterns were also characterised under an optical video microscope and scanning electron microscope.

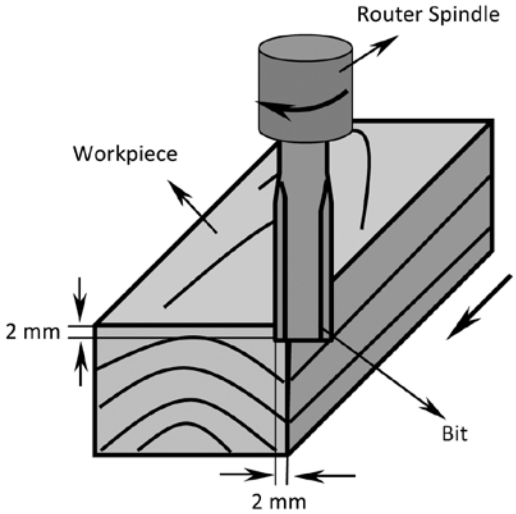


Figure 1 Schematic diagram of routing on the edge of the workpiece

Table 2 Specification of cutting tool materials

Tool material	Specification			
	Dimension	Metal components (% wt)	Heat treatment	Hardness
SKH51 high speed steel	2 × 10 × 20 mm	C = 0.88, Si = 0.25, Mn = 0.30, P = 0.02, S = 0.001, Cr = 4.04, W = 6.13, Mo = 4.92, V = 1.85, Fe = the balance	Hardened at 1220 °C followed by two times of one hour tempering at 560 °C with cooling in air	815 $HV_{0.5}$
K10 tungsten carbide	2 × 10 × 20 mm	WC = 94, Co = 6	-	1450 $HV_{0.5}$

C = carbon, Si = silica, Mn = manganese, P = phosphorus, S = sulphur, Cr = chromium, W = tungsten, Mo = molybdenum, V = vanadium, WC = tungsten carbide, Co = cobalt, Fe = iron

Table 3 Specification of router bits

Specification	Router bit	
	SKH51 high speed steel	K10 tungsten carbide
Bit diameter	16 mm	16 mm
Number of knife	1	1
Rake angle	10°	10°
Clearance angle	15°	15°
Hardness	815 $HV_{0.5}$	1450 $HV_{0.5}$

Table 4 Routing conditions

Variable	Condition
Cutting speed	17 m s^{-1}
Feed	0.1 mm rev^{-1}
Spindle speed	20000 rpm
Feed speed	2000 mm min^{-1}
Width of cut	2 mm
Depth of cut	2 mm

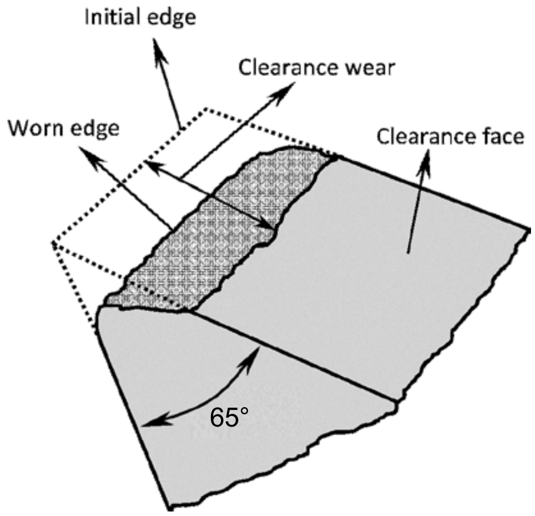


Figure 2 Schematic diagramme of wear measurement on the clearance face of cutting tool

RESULTS AND DISCUSSION

Chemical wearing caused by extractives

Values for pH and extractive, ash and silica contents in the tested tropical woods and percentage of weight loss of the tool materials after 48 hours reaction with wood extracts at 80 °C are presented in Tables 5 and 6 respectively. The percentage of weight loss of the tool materials will determine the amount of chemical wear. Results in Table 5 showed that samples were acidic and varied slightly in extractive content. Oil palm wood had the highest extractive content while mersawa had the highest silica content.

All SKH51 tool materials suffered weight losses (Table 6). The high acidity of these woods could be the reason for the chemical wear of the tool materials. High acidities of western red cedar (Kirbach & Chow 1976) and eucalyptus (Krilov 1986) caused corrosion of steel cutting tools. Both SKH51 and K10 tool materials suffered the highest percentage of weight loss when they were soaked in wood extract of mersawa. This indicated that chemical compounds in the extract of mersawa were more reactive to elements of the tool materials compared with the rest of the wood extracts. After soaking in mersawa extract, the

Table 5 Chemical characteristics of the experimented woods

Wood species	pH	Extractive (%)	Ash (%)	Silica (%)
Mersawa	5.4 ± 0.3	6.3 ± 0.6	2.6 ± 0.6	2.1 ± 0.2
Oil palm	5.1 ± 0.7	8.2 ± 0.7	2.1 ± 0.5	1.4 ± 0.2
White meranti	4.9 ± 0.5	6.0 ± 0.6	1.4 ± 0.5	0.9 ± 0.1
Damar laut	3.5 ± 0.6	3.6 ± 0.4	0.6 ± 0.3	0.1 ± 0.05
Ulin	4.0 ± 0.4	6.2 ± 0.4	1.1 ± 0.4	0.3 ± 0.08

Table 6 Weight loss of tool materials after 48 hours reaction at 80 °C with wood extract

Tool material	Wood extract									
	Mersawa		Oil palm		White meranti		Damar laut		Ulin	
SKH51	1.831[1]	1.821[2]	1.829	1.821	1.833	1.831	1.835	1.828	1.830	1.827
	0.55[3]		0.44		0.11		0.38		0.16	
K10	2.084	2.082	2.085	2.084	2.085	2.085	2.086	2.085	2.081	2.081
	0.10		0.05		0.00		0.04		0.00	

[1]Weight (g) before reaction, [2]weight (g) after reaction, [3]percentage of weight loss

surface of the tip of SKH51 was covered by a light brown compound. Under SEM/EDS analysis, the light brown compound revealed some chemical elements dominated by iron oxide (Fe and O) as shown in Figure 3a. The presence of Fe and O indicated the occurrence of corrosion on the surface of the tip of tool materials. Corrosion occurred on certain parts of the surface of the tip as indicated by high peaks of O profile in Figure 3b.

The SKH51 tool materials had larger percentage of weight loss compared with tungsten carbide for all wood species. This was due to the wide variation in metal components of the SKH51. Iron, especially, in the SKH51 was susceptible to corrosion caused by reactive chemical compounds of wood extractive rather than tungsten carbide and cobalt in the tungsten carbide (Table 2). This fact could also relate to the phenomenon that the microstructure of the tungsten carbide tools, which consists mainly of face-centered cubic matrix, is more stable and more resistant to chemical reaction than hardened steel tools, which consists mainly of ferrite matrix (Davis 1998, Pipple et al. 1999).

Mechanical wearing of tool bits

Mechanical wearing was characterised by the amount of wear on the clearance face of the cutting edge of the tool bits. Wear behaviour on the clearance face of the bits is presented in Figure 4 and wear pattern of the bits, in Figure 5. The progress of wear on the clearance face can be described as a linear function. Regression coefficients obtained from the linear functions in Figure 4 determined the rate of the clearance wear (μm km^{-1}) of SKH51 and K10 bits and the results are summarised in Table 7.

Mersawa and oil palm woods worn the SKH51 and K10 bits faster compared with the rest of the samples (Figure 4), hence the largest rate of wear of the bits tested (Table 7). This was due to the higher content of silica in these two woods. The hardness of silica is high, i.e. about 1200 HV.

The SEM/EDS analysis indicated the presence of silica compound in the tested woods (Figure 6). Mersawa had the highest silica compound followed by oil palm and white meranti. The EDS analysis on the radial section along 150 μm of wood samples showed that the silica was distributed in different profiles among the mersawa, oil palm and white meranti (Figure 6f). Irregular peak levels on each profiles indicated that silica was present in certain places in the woods. The occurrence of silica in mersawa, oil palm and white meranti at the captured length of 150 μm indicated that the cutting edge of the bits would intermittently cut the silica when the woods were machined at 0.1 mm feed per revolution. The more uniform occurrence of silica in mersawa wood would cause the cutting edge of the bits to be dull faster compared with oil palm and white meranti.

Although ulin and damar laut had almost the same silica content, they were different in densities. Higher wear rate of the SKH51 and K10 bits in cutting ulin compared with damar laut could be caused by the higher density of the former (Table 1). The clearance wear and wear rate of the SKH51 bit were twice greater than those of the K10 tungsten carbide bit when

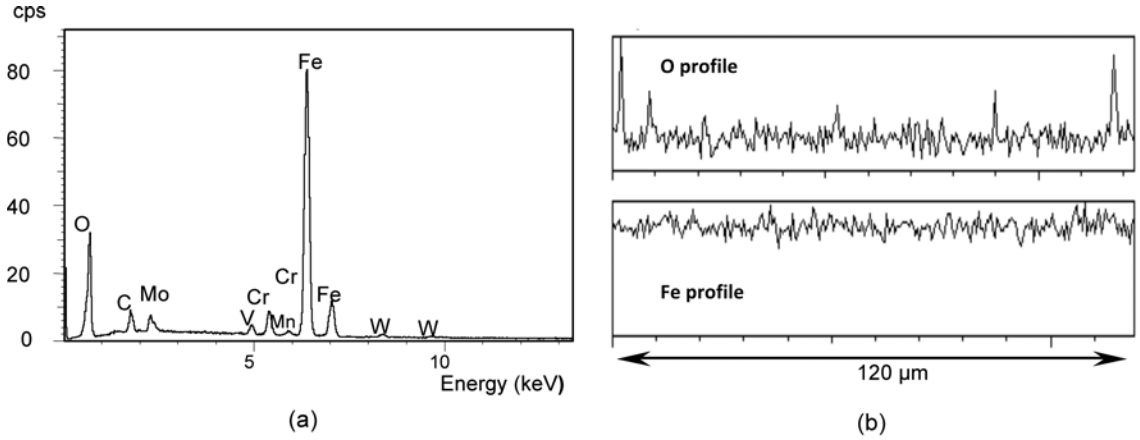


Figure 3 SEM/EDS analysis showing (a) corrosion indication with the presence of Fe and O on the surface of the SKH51 tool material, and (b) the Fe and O profiles after reaction with the mersawa extract (see Table 2 for names of elements)

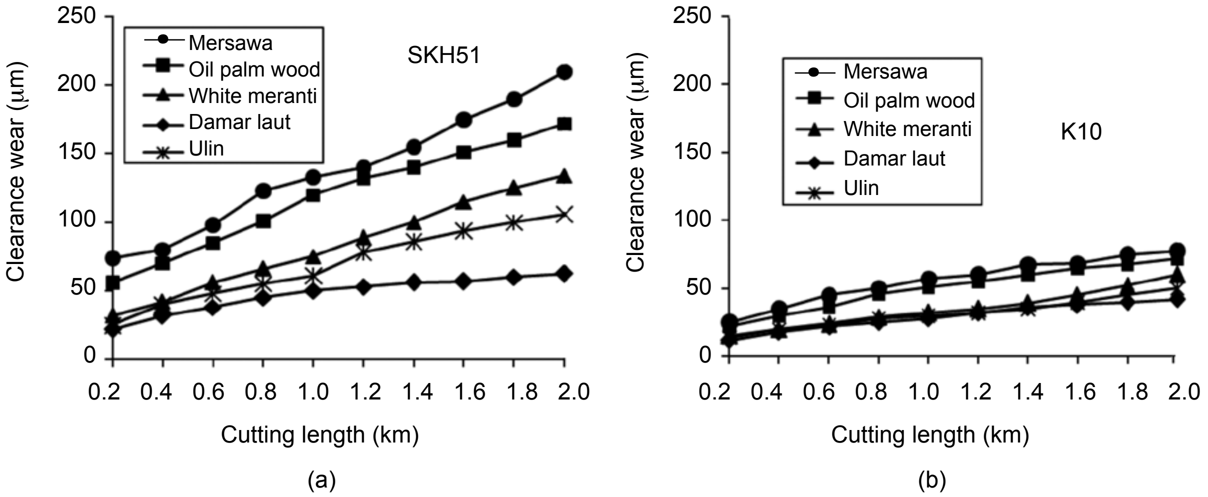


Figure 4 Wear behaviours of (a) SKH51 and (b) K10 bits with cutting length in routing some tropical woods

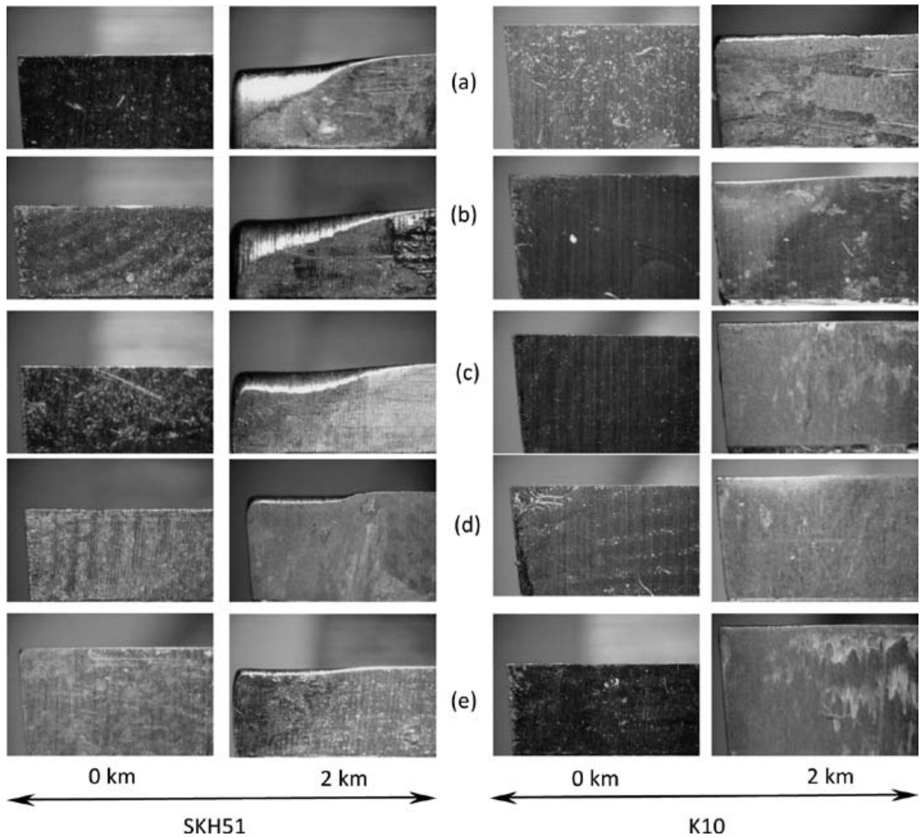


Figure 5 Wear patterns of the SKH51 high speed steel and K10 carbide before and after 2 km cutting length for (a) mersawa, (b) oil palm, (c) white meranti, (d) ulin and (e) damar laut

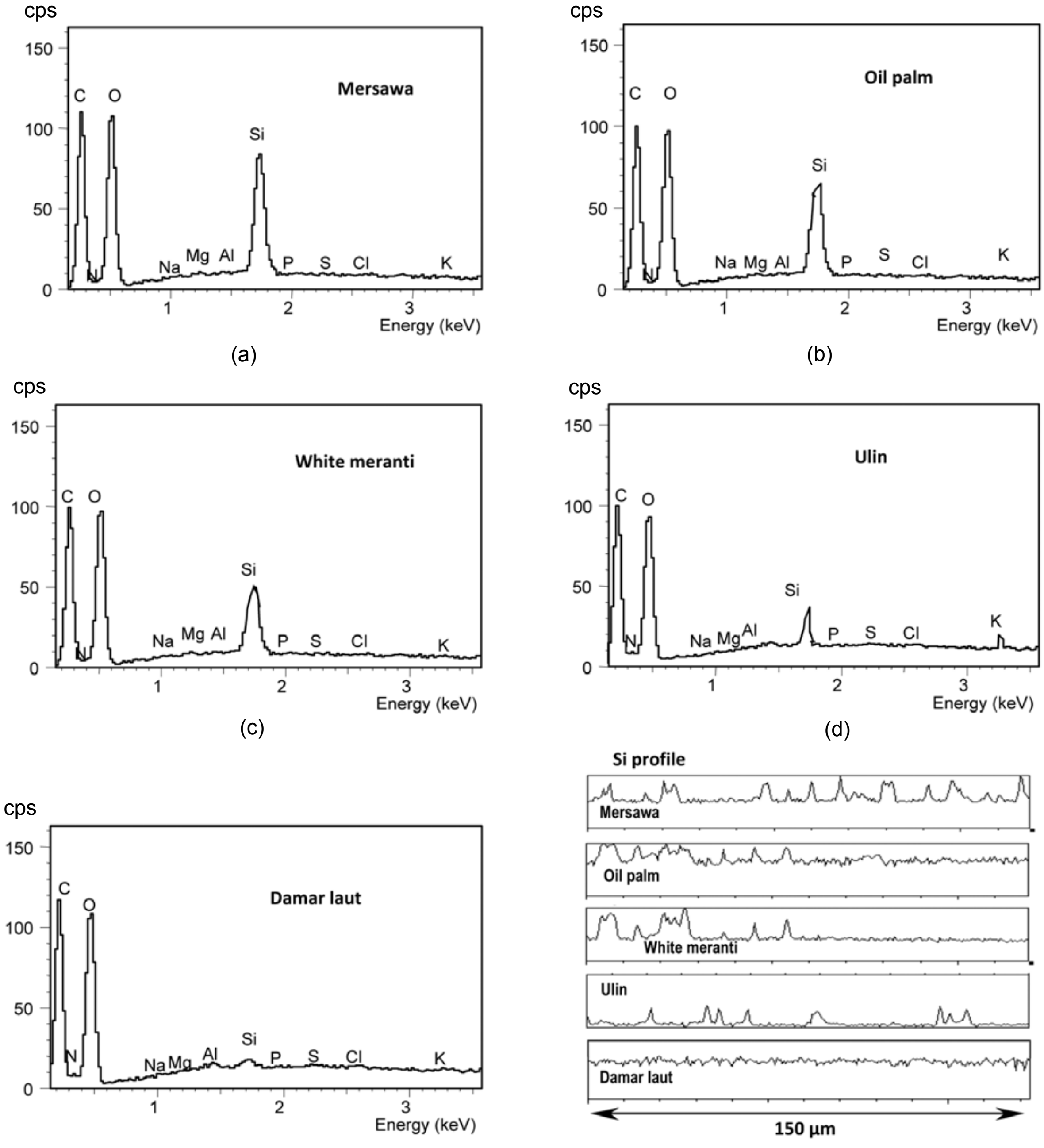
Table 7 Rate of clearance wear (µm km^{-1}) of the router bits for different wood species[1]

Bits	Wood species				
	Mersawa	Oil palm	White meranti	Damar laut	Ulin
SKH51	75.8	64.6	57.8	20.9	35.1
K10	27.9	27.4	23.2	16.4	18.4

[1] According to the linear function in Figure 4

cutting ulin and damar laut (Figure 4, Table 7). Clearance wear of both SKH51 and K10 increased linearly with increasing silica content (Figure 7). However, the relationship of clearance wear rate with the increase in silica content was quite different. With a lower hardness (Table 3), SKH51 had higher regression coefficient, which indicated a more rapid clearance wear compared with K10.

Wear patterns of the SKH51 bits were the same for all wood species studied (Figure 5). From a previous study (Darmawan et al. 2001) and because the samples were in air-dried condition and were routed at low cutting speed, we concluded that the wear of the bits was primarily caused by mechanical abrasion. However, there was a slight difference in clearance wear pattern between the K10 tungsten carbide and SKH51 high speed steel. The cutting edge of K10 tungsten carbide was more corrugated especially when cutting mersawa (Figure 8a). SEM micrograph (Figure 8b) revealed that the



(a) (b) (c) (d) (e) (f)

Figure 6 Scanning electron microscope/energy dispersive spectroscopy (SEM/EDS) profiling of the elements on the radial section of woods samples

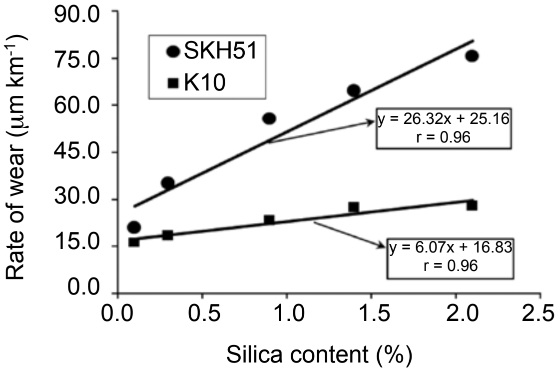


Figure 7 Relationship between rate of clearance wear and silica content for SKH51 and K10 bits

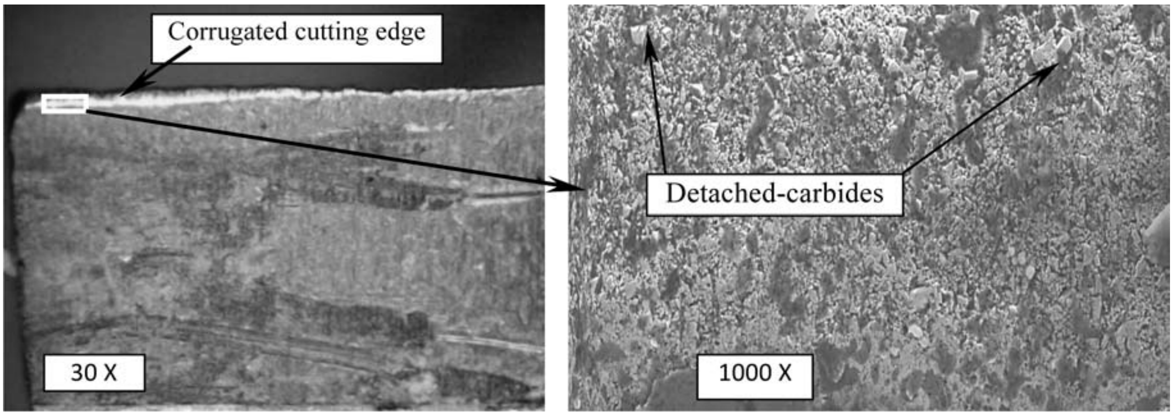


Figure 8 (a) Worn cutting edge and (b) SEM micrograph of the worn edge of K10 tungsten carbide in cutting mersawa at the final cutting length

corrugated edge was caused by lower toughness of the K10 tungsten carbide compared with SKH51, which led to the retraction of carbide grain from the fraction.

CONCLUSIONS

From the findings of this experiment, it could be summarised that wood extractive was important in the chemical wearing of tool materials. Among the wood species studied, mersawa caused the largest percentage of weight loss of tool materials due to corrosion.

Wood silica content and distribution were important in determining the mechanical wearing of the cutting tool. Mersawa and oil palm, wood with silica content of more than 1%, wore the tool bits faster compared with the rest of the woods.

SKH51 high speed steel tool material had lower resistance in chemical wearing by the wood extractive and in mechanical wearing by the silica.

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