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Reduction of dustiness in sawing wood by universal circular saw

Smanjenje emisije drvne prašine tijekom piljenja drva univerzalnom kružnom pilom

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ABSTRACT • *The aim of this paper is a comparison of particle size distribution of sawdust in longitudinal sawing of wood by the universal circular saw when using two saw blades with different types of teeth.*
Experiments were carried out by use of a universal circular saw, at the cutting speed of $v = 50\ m{\cdot}s^{-1}$ *and feed speed of* $v_f = 16\ m{\cdot}min^{-1}$. *A universal saw blade with triangular asymmetric spring setting teeth K1 was used as a tool, as well as a saw blade with tipped swaged teeth K2. Specimens were used of spruce, beech and meranti wood with moisture content from 8 to 10%, species otherwise typical of the production of Euro windows. Granulometric analysis of produced sawdust was carried out by a sieve machine Fritch, with the set of sieves whose mesh gauge were as follows 1.0, 0.5, 0.355, 0.1, 0.05 and the bottom. Each specimen was meshed for 15 minutes and three specimens were meshed for each variant.*
The results show that larger chips were produced with the use of the saw blade K2 – the proportion of 1mm mesh, where the difference in using these two types of blades was up to 25% - meranti. From the viewpoint of airborne particles, it should be emphasised that with all three species of wood, the production of particles smaller than 100 μm (0.05 and bottom mesh) was twice lower when sawing was carried out with the saw blade K2 than with the saw blade K1.
Even though the share of fine fraction was not considerable in the obtained samples, it can be stated that these amounts are also hazardous for the work environment and therefore attention should be drawn to the results of these experimental measurements, as it is possible to affect the proportion of fine fraction smaller than 100 μm by an adequate choice of tool.

Key words: *wood dust, sawing, various type of saw blade, granularity*

SAŽETAK • *Cilj je provedenih istraživanja usporedba raspodjele veličina čestica usitnjenog materijala nastaloga longitudinalnim propiljivanjem drva kružnom pilom s dva lista različitog tipa zubi.*
Istraživanje je provedeno na univerzalnoj kružnoj pili pri brzini rezanja $v = 50\ m{\cdot}s^{-1}$ *i posmičnoj brzini* $v_f = 16\ m{\cdot}min^{-1}$. *Korišteni su listovi pile s asimetričnim trobridnim razvraćenim zubima K1 i sa stlačenim zubima K2. Odabrani su uzorci relativne vlažnosti od 8 do 10 % od smrekovine, bukovine i merantija, drvnog materijala tipičnog za proizvodnju europrozora. Granulometrijska analiza uzoraka provedena je na tresilici proizvođača Fritch i sitima veličina (stranice kvadratnih otvora) 1,0; 0,5: 0,355; 0,1; 0,05 sa dnom. Svaki uzorak prosijavan je 15 minuta, uz tri ponavljanja.*

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Rezultati pokazuju da pri piljenju listom pile K2 nastaju krupnije čestice te da je nastalo 25 % više čestica merantija krupnijih od 1 mm nego pri piljenju listom pile K1. Za sve tri ispitivane vrste drva značajno je da nastane dvostruko manje čestica sitnijih od 100 μm, tzv. lebdećih čestica (sito 0,05 s dnom) piljenjem pilom K2 negoli pilom K1. Iako dobiveni uzorci nisu sadržavali znatniji udio sitnih lebdećih čestica, zbog njihovoga štetnog utjecaja na zdravlje radnika, nužno je skrenuti pozornost na to da se odgovarajućim izborom alata može smanjiti udio drvnih čestica sitnijih od 100 μm .

Ključne riječi*: drvna prašina, vrste listova pile, granulometrijski sastav piljevine*

1 INTRODUCTION
1. UVOD

At the present time, pursuant to the Law 330/1996 Coll., as amended, Safety and Health Protection at Work Act, considerable importance is given to the employer's care for his employees, their work environment and consequently also the employer's care for the environment. Not only classic injury or occupational disease are thought as health impairing, but in a broader sense, also circumstances, such as peace at work, work without stress, disturbance, and satisfactory working conditions. Hard working conditions are characteristic of wood processing industry, especially with regard to microclimatic conditions (cold, heat), noise stress, and also dustiness of some operations. Efforts to improve the present state are welcome and very important for employees who try to make their time spent at work under full stress less depressing and exhausting. At present, there are a lot of companies that can be ranked very low in terms of their care for the working conditions and employees.

Dust is one of the factors with negative effects on work environment. When assessing work and workplaces according to physiological and psychical responses of organisms to working conditions, dust was ranked among predominant factors with specific effects (Annex 1 to Directives No. 13/1986 of the official publication MZSR), as due to its physical, chemical and biological character it can cause occupational disease, industrial poisoning or other health effects at work.

A large amount of dry wood waste is generated in manufacturing and technological processes related to wood processing in furniture companies. Fine dust is also frequently produced in surface finishing operations carried out by sanding and polishing. Due to their low weight, dust particles have a tendency to swirl, which results in bad safety and health conditions in the working environment. Moreover, possible explosibility of wood dust in mixture with air should also be taken into account and accordingly certain ways of facility protection should be taken into consideration with the aim of increasing work safety. From this viewpoint dust air pollution represents one of the major safety issues for enterprises.

Horák (1996) defines dust as particles mostly produced mechanically in technical practice – by grinding, cracking, and abrasion within the range from 1 to 500 μm. In terms of transport technique, dust is defined as the part of loose substance with particles ranging between 1 and 75 μm, (Dzurenda, 2000). From the standpoint of fire safety (Mračková, 2001) finer dust reacts more vigorously than coarser one. Predominant dimension is 40 μm. According to the Standard STN 26 00 70 the particles of wood sanding dust range between the fractions of fine particles (0.5–3.5 mm) and very fine particles (0.07–0.4 mm). The particles smaller than 100 μm are defined as particles floating in the air and hence they are considered as the most hazardous for the work environment (Kos and Beljo Lučić, 2004 a,b; Hemmilä and Gottlőber, 2003).

Wood dust is a factor that cannot be completely eliminated from technological processes. However, by gaining knowledge on fundamental relations, its amount can be limited or reduced, or if this is not possible, other suitable solutions can be chosen – to cover dust producers and to entrap the dust as near as possible to the place of its production, to prevent raising of return dust (regular cleaning of the space from deposited dust), to isolate dirt work, to use a suitable ventilation system or to provide individual protection of employees - personal protection equipment at work.

From this point of view, focus is placed on all kinds of work aimed at exploring the characteristics of wood saw dust and dust. Beljo Lučić et al. (2005) explore in their paper granularity and bulk density of wood dust produced by the most frequently used machines in wood processing industry. Kopecký and Pernica (2004) tried to assess the detrimental effect of wood dust upon human organism, Očkajová and Beljaková (2004a) observed granularity and bulk characteristics – bulk density, bulk angle and tilt angle of wood sanding dust, Očkajová and Beljaková (2004b) compared granulometric composition and characteristics of sanding dust produced by hand belt sander, disk sander and orbital sander. Očkajová and Dzurenda (2002) presented in their paper the dimensions of the smallest and biggest particles of wood sanding dust. Rogozinski and Dolny (2004) focused their research on influence of moisture content on bulk densities of dust from sanding of alder wood.

The aim of this paper was to compare an amount of dust fraction produced in longitudinal wood sawing with the universal circular saw by using two different designs of saw blades by means of granulometric analysis showing percentage rate of particular fractions of sawdust trapped on sieves.

2 THEORETICAL BACKGROUND
2. TEORIJSKE OSNOVE

Kinematical parameters such as average chip thickness, cutting speed, direction of feed and tool wear affect the amount of produced dust as well as its dimensions. Based on comprehensive research, all measures leading to increasing the average chip thickness reduce the amount of produced dust (Gottlőber and Hemmilä, 2003). Kinematical model of longitudinal cutting with circular saw is shown in Figure 1.

The thickness of chips is changeable in rotating motion, and it changes from 0 up to the maximum value.

Definitions of chip dimensions:

- thickness is a vertical distance between two adjacent motions of cutting edge which depends on feed per tooth;
- length is usually given by travel of cutting edge through work piece;
- width, is identical in free cutting with the width of work piece, when cutting in a kerf the chip width is given by width of the kerf, if this is reached by one cutting edge (Lisičan, 1988).

The chip shape also depends on the type of saw blade setting of saw teeth, because with swage tooth setting each tooth cuts the full width of saw kerf and in case of spring set teeth each tooth cuts half the width of saw kerf, Figure 2.

Average chip thickness:

$$h = \frac{u_z \cdot e}{l}\text{, mm} \qquad (1)$$

h – average chip thickness (*srednja debljina strugotine*), mm
u_z – feed per toooth (*posmak po zubu*), mm
e – cutting height (*visina piljenja*), mm
l – length of chip (*duljina strugotine*), mm.

Length of chip (cutting edge path):

$$l = \frac{\pi \cdot D \cdot \psi}{360}\text{, mm} \qquad (2)$$

D – tool diameter (*promjer alata*), mm
ψ – contact angle of teeth and cutting material (*kut zahvata*), °.

Contact angle of teeth with cut material:

$$\psi = \arccos\frac{e+a}{R} - \arccos\frac{a}{R}, \ \psi = \psi_2 - \psi_1 \qquad (3)$$

a – distance of the saw blade centre from table surface (*udaljenost osi alata od radnog stola*), mm

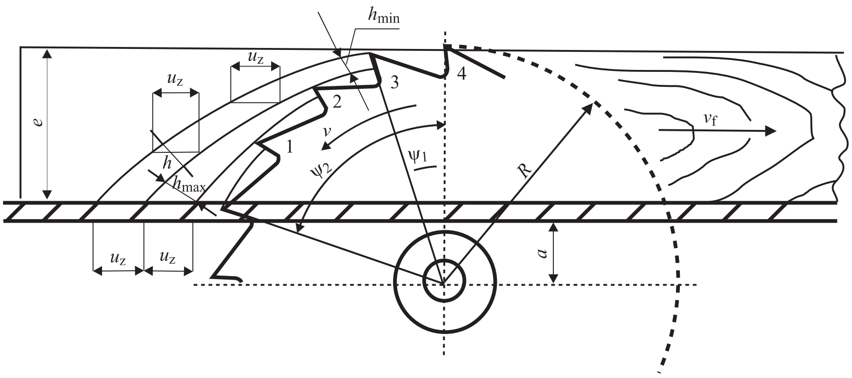

Figure 1 Kinematical model of cutting with circular saw
v – cutting speed, v_f – feeding speed, u_z – feed per tooth, R – saw blade radius, e – cutting height, a – distance of saw blade centre from table surface, $h_{min,max}$ – minimal and maximal chip thickness, h – average chip thickness, ψ_1 – central angle at the beginning of tooth cut, ψ_2 – central angle at the end of tooth cut
Slika 1. Kinematički model rezanja kružnom pilom
v – brzina rezanja, v_f – posmična brzina, u_z – pomak po zubu, R – polumjer lista pile, e – visina rezanja, a – udaljenost središta lista pile od površine radnog stola, $h_{min,max}$ – najmanja i najveća debljina strugotine, h – srednja debljina strugotine, ψ_1 – početni kut rezanja, ψ_2 – završni kut rezanja

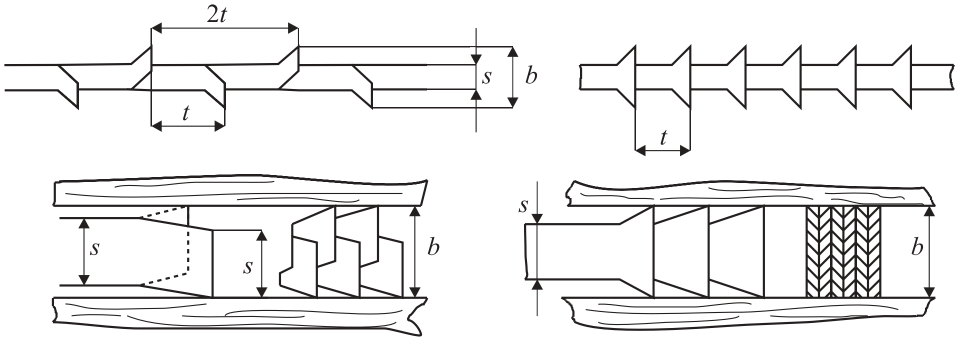

Figure 2 The shape of chip with two types of teeth setting a) spring setting, b) swage setting
b – saw kerf, s – saw gauge, t – pitch
Slika 2. Oblik strugotine za dva različita lista pile: a) razvraćeni zubi, b) stlačeni zubi
b – širina propiljka, s – debljina lista pile, t – korak zuba

R – saw blade radius (*polumjer alata*), mm
ψ_1 – central angle at the beginning of tooth cut (*kut na početku zahvata*), °
ψ_2 – central angle at the end of tooth cut (*kut na kraju zahvata*), °.

Feed per tooth:

$$u_z = \frac{v_f}{n \cdot z} \qquad (4)$$

v_f – feed speed (*posmična brzina*), mm·min^{-1}
n – spindle revolution (*frekvrencija vrtnje alata*), min^{-1}
z – number of teeth (*broj zubi*).

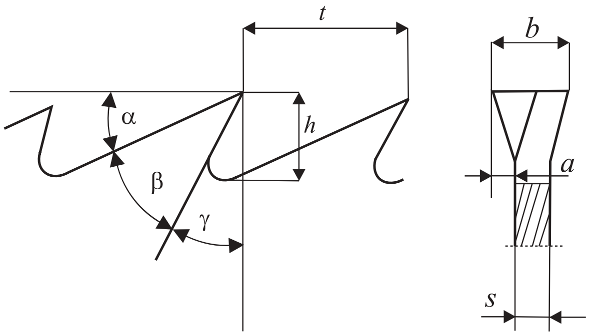

Figure 3 Saw blade with triangular asymmetric spring setting teeth K1
α – clearance angle, β – wedge angle, γ – rake angle, h – height of tooth, t – pitch, a - set, b – saw kerf, s – saw gauge
Slika 3. List pile s trobridnim asimetrično razvraćenim zubima K1
α – leđni kut, β – kut oštrice, γ – prsni kut, h_z – visina zuba, t – korak zuba, a- razvraka, b – širina propiljka, s – debljina lista pile

3 MATERIAL AND METHODS
3. MATERIJAL I METODE

Machine - universal circular saw of the following parameters: cutting speed v – 50 m·s^{-1}, spindle revolution – 3750 min^{-1} (free power), nominal output – 3000 W.

Feeding device (pressing feeding carriage) FA type – 1, motor revolution – 1400/2800 min^{-1}, feeding speed v_f - 16 m·min^{-1}.

Tool – universal saw blade with triangular asymmetric spring set teeth K1 (Fig. 3) and saw blade with tipped swaged teeth, low kickback, chip breakers and optimal chip clearance K2 (Fig. 4). Parameters of two various kinds of saw blades are shown in Tables 1 and 2.

Workpiece – wood specimens used for production of euro windows - spruce, beech and meranti were prepared for experimental purposes.

Granulometric analysis – mesh analysis was used for the assessment of experimental work and thus granulometric analysis was made of produced sawdust.

Mesh analysis was carried out by automatic vibration mesh machine Fritsch, with the set of checking meshes of sieve mesh gauges: 1.0; 0.5; 0.355; 0.1; 0.05

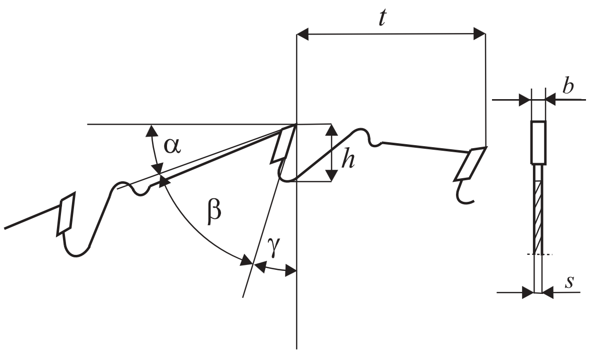

Figure 4 Saw blade with tipped swage setting teeth K2
α – clearance angle, β – wedge angle, γ – rake angle, h – height of tooth, t – pitch, b – saw kerf, s – saw gauge, t - pitch
Slika 4. List pile sa stlačenim zubima K2
α – leđni kut, β – kut oštrice, γ – prsni kut, h_z – visina zuba, t – korak zuba, b – širina propiljka, s – debljina lista pile

Table 1 Parameters of saw blade K1
Tablica 1. Obilježja lista pile K1

saw blade diameter *promjer lista pile*	**pitch of teeth** *korak zuba*	**number of teeth** *broj zubi*	**characteristic of tool geometry** *obilježja geometrije alata*			**calculated average chip thickness** *izračunana srednja debljina strugotine*
D, mm	t, mm	z	α,°	β, °	γ, °	h, mm
285	22	40	21	37	32	0,045

Table 2 Parameters of saw blade K2
Tablica 2. Obilježja lista pile K2

saw blade diameter *promjer lista pile*	**pitch of teeth** *korak zuba*	**number of teeth** *broj zubi*	**characteristic of tool geometry** *obilježja geometrije alata*			**calculated average chip thickness** *izračunana srednja debljina strugotine*
D, mm	t, mm	z	α,°	β, °	γ, °	h, mm
300	52	18	12	56	22	0,105

Table 3 Measurement results
Tablica 3. Rezultati mjerenja

Particle size number *oznaka frakcije*	**Particle size dimension** *veličina čestice frakcije, mm*	**The share of the fraction, %** – *udjel pojedinih frakcija*, %					
		Saw blade – *list pile* K1			**Saw blade** – *list pile* **K2**		
		Beech wood *bukovina*	**Meranti** *meranti*	**Spruce wood** *smrekovina*	**Beech wood** *bukovina*	**Meranti** *meranti*	**Spruce wood** *smrekovina*
0,05	< 0,05	0,28	0,31	0,06	0,45	0,07	0,01
0,1	0,05 – 0,1	2,51	3,67	1,39	1,63	1,77	1,35
0,355	0,1 – 0,355	21,24	18,34	13,64	11,56	8,21	9,71
0,5	0,355 – 0,5	9,62	12,03	10,25	6,22	5,28	5,97
1	0,5 – 1	18,28	24,41	21,88	14,91	18,23	13,97
P1	>1	48,07	41,25	52,8	65,26	66,45	69,02

mm and the bottom, according to STN 15 3105 (STN ISO 3310-1). The amount of specimen (aproximately 50 g) was removed to the upper mesh of the mesh machine. The time of meshing was 15 min. Proportions of particular sieve residues were determined by means of digital laboratory scales Bosch with weighing accuracy to the nearest 0.001 g and weight proportions from specific sieves were calculated as percentage. Measurements were carried out at the average sawdust moisture ranging between 8 and 10 %. The above procedure was repeated 3 times for each measured specimen.

4 RESULTS AND DISCUSSION
4. REZULTATI I DISKUSIJA

On the basis of calculation of average chip thickness (Table 1, 2) it can be stated that the average chip thickness produced by tipped saw blade K2 is more than twice higher than the average chip thickness produced by the universal saw blade K1, which is in fact caused by different feed rate per tooth and different number of teeth, 18 with K2 and 40 with K1.

The results of experimental measurements are given in Table 3 and recorded in graphs, which show granulometric analysis of sawdust produced in longitudinal sawing of wood (spruce, beech, meranti) by the universal circular saw depending on the type of the used saw blade, (Landiga, 2005).

The results show that the change of saw blade has a remarkable effect on granulometric analysis of sawdust, which can be observed in Figures 5, 6 and 7. On the basis of granulometric analysis of sawdust produced by saw blade K2, it can be concluded that remarkably more fractions are formed with the size exceeding 1 mm than by the universal saw blade K1, which correlates with the calculated average chip thickness as well as with the statement of Hämille and Gottlieber (2003) who claimed that by increasing the chip thickness the proportion of dust falls down. As for wood species meranti this difference is up to 25 %. Central fractions - sieves of 0.5 mm, 0.355 mm and 0.1 mm, are on the other hand more represented when using the universal saw blade K1. At the same time these differences are also caused by a different way of chip cutting-off

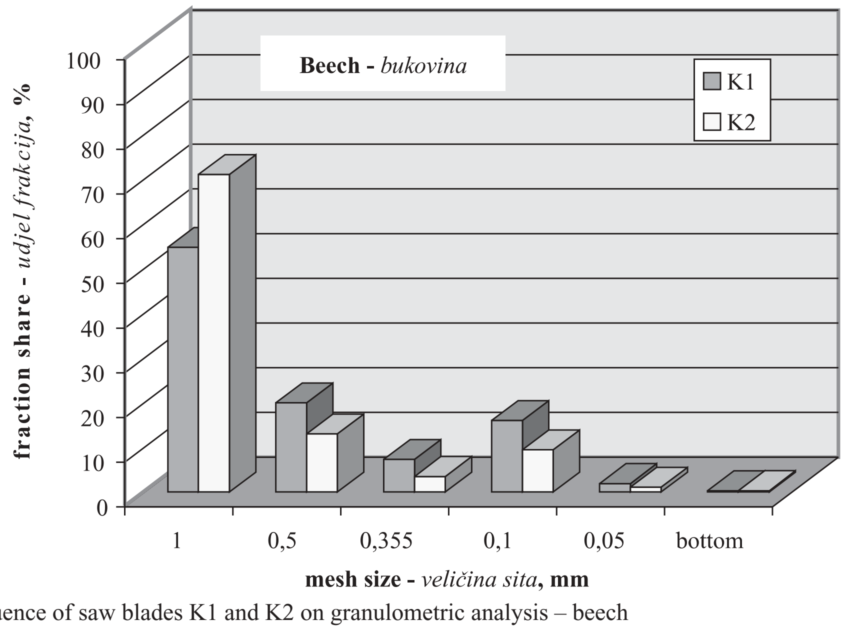

Figure 5 The influence of saw blades K1 and K2 on granulometric analysis – beech
Slika 5. Utjecaj listova pile K1 i K2 na granulometrijski sastav bukove piljevine

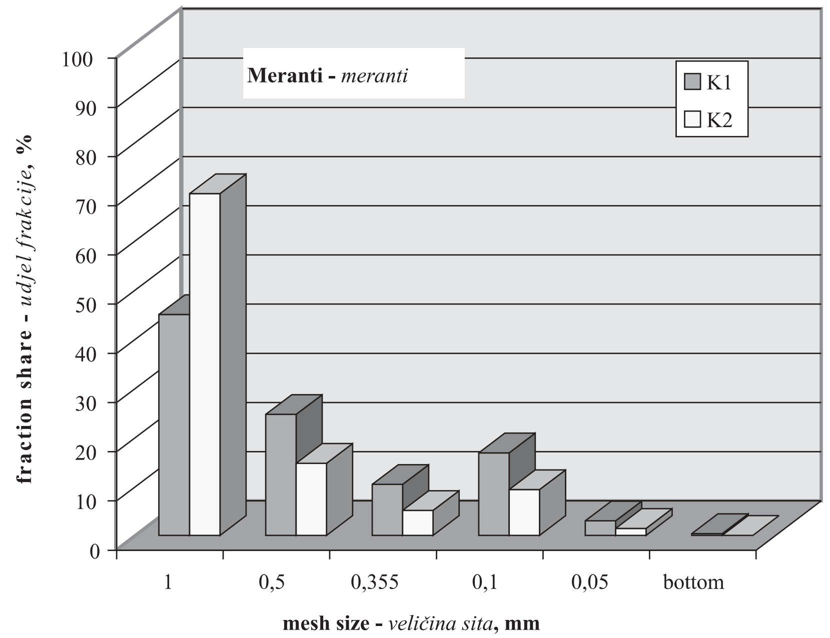

Figure 6 The influence of saw blades K1 and K2 on granulometric analysis – meranti
Slika 6. Utjecaj listova pile K1 i K2 na granulometrijski sastav piljevine merantija

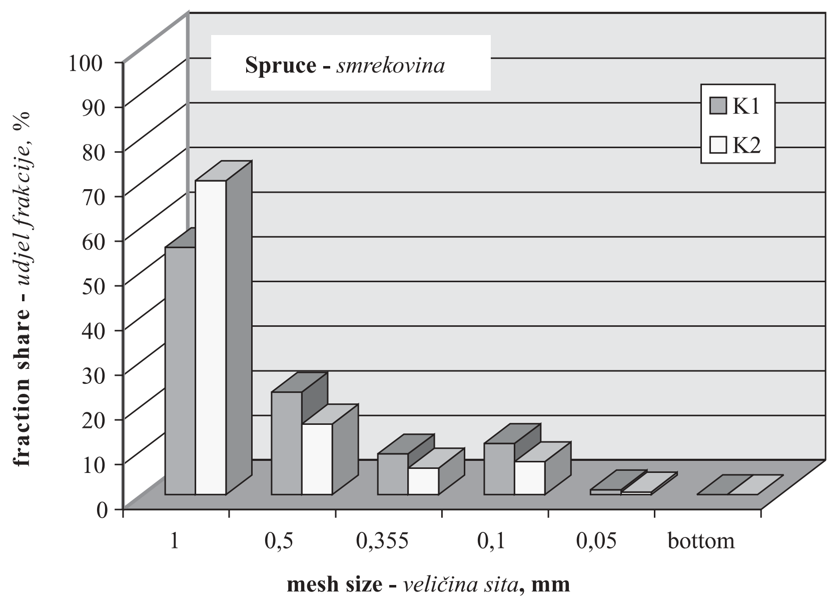

Figure 7 The influence of saw blades K1 and K2 on granulometric analysis – spruce
Slika 7. Utjecaj listova pile K1 i K2 na granulometrijski sastav smrekove piljevine

(teeth setting). The cutting edge of the saw blade K2 is as big as the width of forming the kerf, while the width of the kerf of the universal saw blade K1 is bigger than the cutting edge and therefore the formation of chips is more complicated regarding the shape, and these chips are more frequently broken. In their research Palmqvist and Gustafsson (1999) obtained the impact factor of rake angle that shows the tendency of dustiness decrease with the decrease of rake angle. The results of the present research confirmed their research results (rake angle of circular saw K1 is 32° and of circular saw K2 it is 22 °).

It is interesting that in the process of sawing, fine fraction was also recorded – wood dust (particles smaller than 100 μm) – 0.05 mm and bottom sieve, whose value ranges from 1.1 % with beech up to 3.32 % with meranti. When using the saw blade K2, values of fine fraction are half the values obtained when using the universal saw blade K1, which corresponds to the results obtained with bigger fractions. Even though the percentage of fine fraction is not high, it can be stated that even these amounts are hazardous for the work environment and hence a attention should be drawn to the results of these experimental measurements, as the proportion of fine fraction below 100 μm can be considerably affected by an adequate choice of tool for the same technological operation.

Cumulative distribution of particle size fractions for the analysed species of wood is shown graphically in Figure 8. It is obvious that in the process of sawing

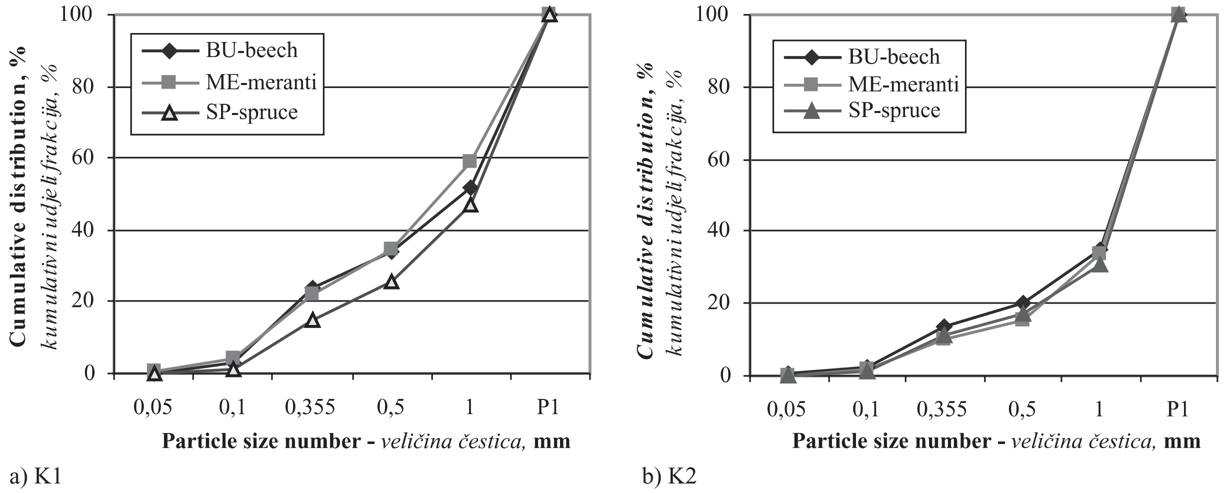

Figure 8 Cumulative distributions of particle size fractions for different wood species and two types of saw blades
Slika 8. Dijagram kumulativnih raspodjela veličina čestica piljevine za različite vrste drva i dva tipa lista pile

by use of universal saw blade K1 more fine fraction of particles is recorded than when using saw blade K2. It seems that species of wood have more influence on particle size distribution when sawing by use of saw blade K1 than K2 and more fine fractions of wood dust are recorded when sawing beech and meranti than spruce wood.

Many authors obtained the results by granulometric method (Očkajová i Beljaková, 2004a) or electromagnetic detection (Palmqvist and Gustafsson, 1999), and they have shown that processing of hardwood generated more fine particles (smaller than 0.1 mm) than processing of softwood.

5 CONCLUSION
5. ZAKLJUČAK

The realization of this experiment confirmed the presumption that the choice of tool not only affects the quality of final product, but also the way of forming chips – its granulometric analysis, thus indirectly affecting the quality of the work environment. We have compared the results of granulometric analysis of sawdust produced in the process of sawing by the universal circular saw while using the universal saw blade with triangular asymmetric spring set teeth K1 and saw blade with tipped swaged anti-kickback teeth, with chip breaker and optimal chip clearance K2.

The results show that bigger chips were formed with the use of saw blade K2 – the proportion on 1 mm sieve, where the difference in using these two types of saw blades was up to 25 %. From the viewpoint of dustiness – fractions smaller than 100 μm – 0.05 and bottom sieve, approximately half dust was produced with the use of saw blade K2 than with the use of saw blade K1.

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18. *** STN 26 0070: Klasifikácia a označovanie sypkých hmôt dopravovaných na dopravných zariadeniach.
19. *** STN ISO 3310-1: Súbor sít na laboratórne účely.
20. *** Zákon Národnej rady Slovenskej republiky č. 330/1996 Z. z. o bezpečnosti a ochrane zdravia pri práci, ako vyplýva zo zmien a doplnení vykonaných zákonom č. 95/2000 Z. z. a zákonom č. 158/2001 Z. z.

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