Dust Creation in CNC Drilling of Wood Composites

Tomasz Rogoziński,[a,*] Jacek Wilkowski,[b] Jarosław Górski,[b] Paweł Czarniak,[b] Piotr Podziewski,[b] and Karol Szymanowski [b]

This paper presents the particle-size distribution of dust created by the drilling of selected wood composites, which was carried out using a CNC machine. The particle-size distribution was studied through two methods. Two analyses were performed: the sieve analysis of samples from the whole mass of collected dust and the laser diffraction analysis of the finest fraction isolated by sieving. The results presented general information about the particle-size distribution of the dust, as well as detailed information on the content of the finest particles. This information revealed that the particles might pose a potential risk to the health of workers employed in the woodworking industry. This potential risk is due to the possibility of their dispersion in the atmosphere surrounding the workplace and their size, which allows them to be respirable. The relationship between the fineness of the dust and the type of wood composite was also tested. Most ultrafine particles are formed during the drilling of fibreboards and are especially produced in traditional wet technology.

Keywords: CNC woodworking machine; Drilling; Particle-size distribution; Wood composites; Wood dust

Contact information: a: Poznan University of Life Sciences, Department of Furniture Design, Wojska Polskiego Str. 28, 60-637 Poznan, Poland; b: Warsaw University of Life Sciences – SGGW, Department of Mechanical Processing of Wood, Nowoursynowska Str. 159, 02-776 Warsaw, Poland;
** Corresponding author: trogoz@up.poznan.pl*

INTRODUCTION

One of the main health problems experienced by workers employed in the wood and wood materials industries is exposure to air polluted with wood dust, which can be inhaled. Basic sources of air dustiness in the woodworking industry are technological operations associated with the formation of chips. The quantity, dimension, and shape of formed chips are very changeable and depend on many factors. The most important factors are the type of worked material, processing technology, and machining parameters. The content percentage of the dust particles out of the whole mass of chips strongly depends on these factors. This dependence also applies to the smallest particles (inhalable particles), which, when dispersed in air, pose the greatest risk to the health of workers (Kauppinen *et al*. 2006; Rautio *et al*. 2007; Dutkiewicz and Prażmo 2008; Beljo-Lučić *et al*. 2011).

Sanding is the method of wood processing that influences the increase in wood dust concentration the most in the working environment. During sanding, the waste is solely in the form of dust. The quantity of dust created during sanding depends on the kind of wood being sanded, along with the direction and speed of the processing (Samolej and Barcík 2006; Očkajová *et al*. 2010, 2014). Depending on the type of sander and the shape and size of its dust creation zone, there may be serious problems concerning the effective discharge of dust through an exhaust installation during certain sanding positions. High dust emission occurs especially where sanding operations are performed manually (Scheeper *et al*. 1995; Detering *et al*. 2000).

The machine type and method of processing influence increases in the dust concentration in the air (Kos *et al*. 2004). The waste creation zone of various machines, which should be covered by the operation of an exhaust device, may vary depending on the type of tool and the shape of the work piece. Removal of dust is difficult when the working zone is large and when the tool moves during processing at relatively large distances. This situation occurs in most CNC machines used in the woodworking industry (Varga *et al*. 2006). The dispersion of chips in different directions in the space of the treatment zone is very unfavorable in this respect. When the movement direction of the chips created during machining does not coincide with that of the air suction created by an extraction system, many of the chips are still not removed and can become dispersed in the air surrounding the machine. This takes place during drilling when the whole tool goes deep into the work piece. For this reason, there are problems with the direct removal of chips from working tools. The dispersion of chips in all directions also occurs due to the high-speed rotation of those tools.

The type of worked material is another factor that influences the amount of dust created, thus influencing the exposure of wood industry workers to the harmful effects of air dustiness. The processing of wood composites causes the creation of significant amounts of small dust particles (Palmqvist and Gustafsson 1999; Chung *et al*. 2000; Fujimoto *et al*. 2011). This is due to the fact that composites are made of wood that has previously been parted. So, machining by cutting tools is, in this case, the secondary fragmentation of the wood matter.

Preventive measures to reduce dust concentration in the air at workplaces should include the evaluation of technologies and materials with regards to the creation of dust. The aim of this study was to determine the particle-size distribution of dust generated during the drilling of wood composites, as well as to determine the fraction of the smallest particles, which are potentially respirable.

EXPERIMENTAL

Selection of Wood Composites

Wood composites can be categorized into three groups depending on the fragmentation degree of the wood from which they are made. The first group contains layered materials made most often of veneers, but also blockboards with cores of wood slats. The second group contains composites made of chips or wood particles, and the third group contains composites made of defibrated wood. Several different composites with different properties and technical purposes were selected from each of these groups to be sampled. These were market-type composites without defined raw material specifications. The selected wood composites are presented in Table 1. The letters are assigned to each type of composite in order to simplify the descriptions in the figures depicting the results.

Table 1. Wood Composites Selected to Tests

Type of Wood Composite		Density (kg/m^3)	Thickness (mm)	Assigned Letter
Layered boards	Compreg	1340	20	A
	Transformer plywood Elkon	990	20	B
	Plywood	660	18	C
	Exterior plywood with phenol film	730	12	D
	Blockboard	590	18	E
Made of chips	Chipboard	740	18	F
	Laminated chipboard	670	18	G
	Multifunctional panel	730	18	H
	Oriented strand board (OSB)	595	18	I
Made of fibres	Medium density fibreboard (MDF)	750	16	J
	Laminated MDF	760	16	K
	High density fibreboard (HDF)	860	3	L
	One-side lacquered HDF	800	3	M
	Standard hardboard	950	5	N
	Porous fibreboard	235	12	O

Experimental Machining

The main part of the study was carried out using a Busellato Jet-130 (Italy), which is a standard CNC machine designed for the timber industry. It was equipped with a vertical spindle with a motor power of 7.5 kW and an adjustable rotational speed (1000 to 18000 rev/min). The worktable machine consisted of 6 adjustable beams with suckers for mounting work pieces. The experimental drilling was performed at the speed of 6000 rev/min and the feed per revolution was 0.15 mm/rev. The cutting parameters established for the experiment were based on the recommendations of the tool producer (Leitz GmbH & Co. KG – Germany). The tool used for drilling was a single point drill bit that was brazed with polycrystalline diamond and had a diameter of 10 mm. The geometric parameters of the drill bit include a clearance angle of 7.5º, an edge angle of 75º, and a rake angle of 7.5º.

The machining was carried out with the chip extraction installation turned off. This decision was made due to the expected ineffectiveness of the extraction mechanism. Therefore, the working zone was surrounded in a possibly tight manner by insulation foil, which prevented the escape of dust outside the zone. The drilling was carried out to achieve approximately 1000 g of dust. After the completion of drilling, there was an hour delay that allowed the dust to settle. Finally, the entire zone was carefully cleaned in order to collect the dust and prepare the area for further machining of the samples of the next wood composite.

Particle-size Analysis

Waste from drilling wood composites is characterized by significant dimensional variability. For this reason, the general determination of particle-size distribution and the content of the smallest dimensioned particles in the total mass of created dust require complementary use of different analytical methods.

First, the dust created during drilling was subjected to the sieve analysis using an electromagnetic sieve machine (AS 200 Digit) (Retsch, Germany) equipped with a set of sieves with aperture sizes of 1000, 500, 250, 125, 63, and 32 μm. The sieves were arranged in such a way that the sieve with the largest aperture size was placed on the top, and the sieve with the smallest aperture size was placed on the bottom of the set. The bottom collector was placed below it. The fraction gathered in the collector was used for further studies to determine the smallest particles content. The average of three measurements was accepted as a result. The results of the sieve analysis allowed only the overall evaluation of the particle-size of the examined dust. This method cannot determine the content of the smallest particles, which, when dispersed in the air, can enter the human respiratory tract.

The content of such particles, including particles less than 10 μm, was determined by the laser diffraction method using a Laser Particle Sizer Analysette 22 MicroTec plus (Fritsch, Germany), which has a measuring range of 0.8 to 2000 μm. Dust collected in the bottom collector, which was below the sieve with the aperture size of 32 μm, was preserved for this purpose. The obtained results were recalculated with MaScontrol software (Fritsch, Germany) to generate the particle-size distribution curves of the test samples.

The dimension of the particles, taking into account the description of the results of the analysis, is equivalent to diameter x. This means that the particles with irregular shape corresponded to spheres with the same physical properties. The graphs obtained in this way present the cumulative particle-size distribution curves, which is represented by $Q_r(x)$ in Eq. 1, where each point shows the total amount of dust contained in the range from $x_{min.}$ to x. Each point also shows the density of the particle distribution, which is represented by $q_r(x)$, in that range. This density is the first derivative of $Q_r(x)$, with respect to x. Thus, the value of $q_r(x)$ is a fraction of the total amount of dust particles contained in the range from x to $x + dx$. Equation 1 was used to find the density of the particle distribution ($q_r(x)$) and is displayed below (MaScontrol 2009).

$$q_r(x) = \frac{dQ_r(x)}{dx} \quad (1)$$

The particle-size distributions generated by the MaScontrol software refer to the volume of the particles (r = 3). Since all of the tested dusts originated from materials with constant densities, it can be assumed that the volume fractions are the same as the mass fractions in the individual dimensional ranges. There is some inaccuracy of this method of measuring and computing of a particle-size distribution especially in the range of the smallest particles due to their irregular shape. The length of wood dust particles is predominantly larger than the other dimensions. For this reason the Laser Particle Sizer sees them as larger than they would be measured by other methods.

Based on the data from the measurements and the particle size distributions obtained from the sieving, the mass fractions of the dusts in the ranges of 0.08 to 1 μm, 1 to 2.5 μm, and 2.5 to 10 μm were calculated. These fractions were taken into account in further calculations to determine the amount of particles in each of these size ranges out of the whole mass of waste created during drilling. Since these fractions were related to the dust isolated during the sieve analysis in the bottom collector, the product of the fractions and the proportion of these particles resulting from sieve analysis were assumed.

RESULTS AND DISCUSSION

Table 2 shows the results of the analysis of particle-size distribution obtained by the sieving method. The influence of the type of wood composite on the particle-size of the dust created during drilling was recognized immediately. For all layered composites, the content of the largest particles with dimensions greater than 1 mm was more than 25%, and for comperg alone, it was over 60%. There was a negligible quantity of ultrafine particles that passed through the sieve with the aperture size of 32 μm.

Table 2. Particle-Size Distribution of Dust Obtained by Sieve Analysis

		Particle size (mm)						
		>1.0	0.5-1.0	0.25-0.5	0.125-0.25	0.063-0.125	0.032-0.063	<0.032
		Mass Fraction (%)						
Type of wood composite	A	60.87	19.45	11.09	5.50	2.05	0.67	0.36
	B	42.66	16.72	21.76	14.29	4.03	0.29	0.25
	C	27.32	18.40	27.58	17.78	7.07	1.35	0.52
	D	41.61	15.33	23.84	14.30	4.01	0.52	0.39
	E	42.86	20.97	21.46	10.27	3.24	0.87	0.33
	F	5.80	23.00	34.11	22.40	9.29	4.58	0.82
	G	8.57	25.53	33.72	20.59	8.57	2.37	0.64
	H	10.60	27.81	29.65	18.99	8.38	3.70	0.86
	I	20.26	29.60	29.23	14.38	5.02	1.24	0.27
	J	0.13	2.15	15.97	26.47	28.75	23.66	2.87
	K	0.22	3.47	17.51	24.59	22.55	30.77	0.89
	L	0.91	5.58	21.26	26.21	20.14	24.49	1.40
	M	1.34	3.31	17.34	26.22	24.67	23.96	3.17
	N	3.11	18.40	26.90	21.02	15.64	12.04	2.88
	O	4.95	5.86	20.72	36.94	13.51	14.41	3.60

These percentages changed together with the increase in the fragmentation degree of the wood used in the production of the composites. There was a considerably smaller amount of the largest particles for composites made of chips (between 6 and 20%) as compared to composites A, B, C, D, and E. For example, OSB, which is made of significantly larger chips than other composites, had the highest value (20.26%) for the largest particles for composites made of chips.

The drilling of fiberboard made of defibrated wood is, in this comparison, a source of a relatively large amount of ultrafine dust particles. The most significant differences can be seen for the fractions isolated on the sieves with aperture sizes of 32 and 63 μm. There was an observed multiple increase in the amount of this dust in relation to other wood composites used in this experiment.

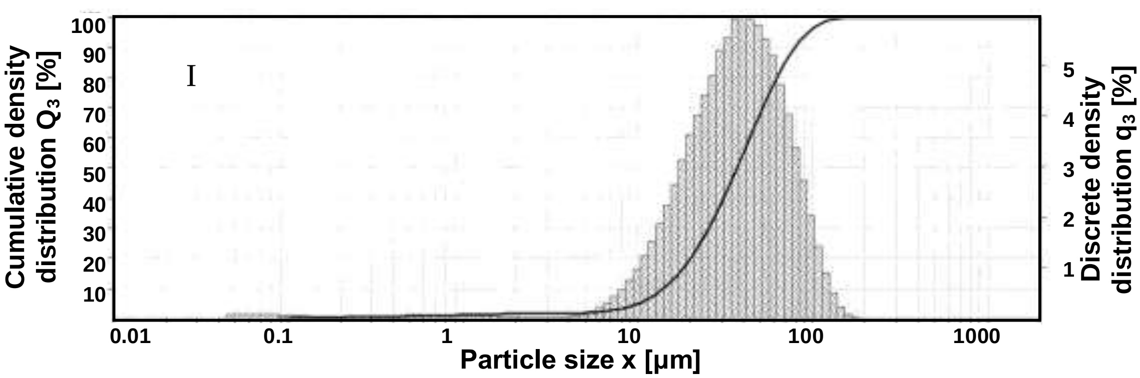

Fig. 1. Particle-size distribution obtained by laser analysis

Fig. 2. Sample analysis using the Laser Particle Sizer Analysette 22 MicroTec plus

Figure 1 shows a typical histogram of the particle-size distribution obtained from the analysis done using the Laser Particle Sizer Analysette 22 MicroTec plus (Fig. 2). Because this analysis involved the same fractions of dust passing through the sieve with the aperture size of 32 μm with respect to the waste from working of all wood composites included in the study, their histograms and curves of distributions did not visually differ much. The amounts of dust contained in the selected ranges calculated on the basis of these distributions were much more important. Therefore, it was decided not to include all the graphs in this paper, but rather use the results of the laser analysis directly in order to calculate the content percentages of the particles in these ranges out of the whole mass of dust. The results of this calculation are shown in Figs. 3, 4, and 5.

The fact that the average particle size reached up to about 60 μm and exceeded the aperture size through which the particle passed was noteworthy. This is due to at least two reasons. Firstly, the non-spherical (longitudinal) shape of the particles allowed the particles, whose length was much greater than their transverse dimensions, to pass through the sieve with an aperture size smaller than the particles' length. On the other hand, the shape of these particles may have caused the laser particle sizer to recognize them as being larger than they actually were. This is because their size was determined by only one dimension.

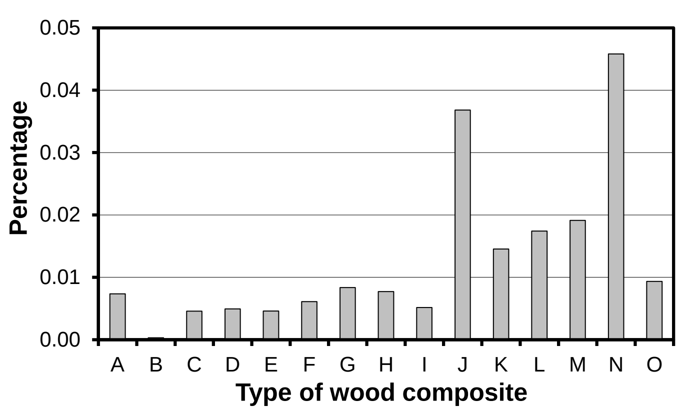

Fig. 3. Content percentages of dust particles with a size smaller than 1 μm in the dust created during the drilling of wood composites

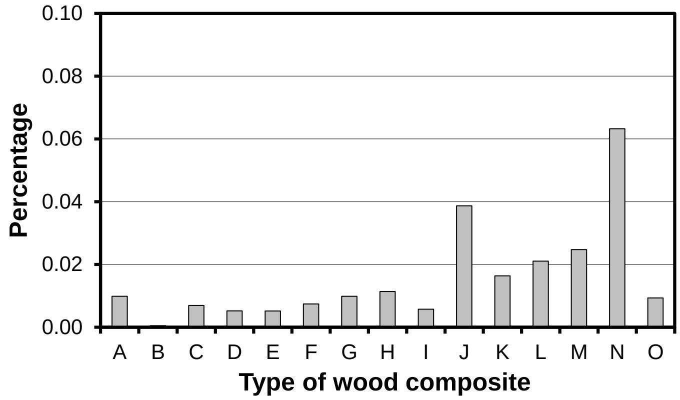

Fig. 4. Content percentages of dust particles with a size of 1 to 2.5 μm in the dust created during the drilling of wood composites

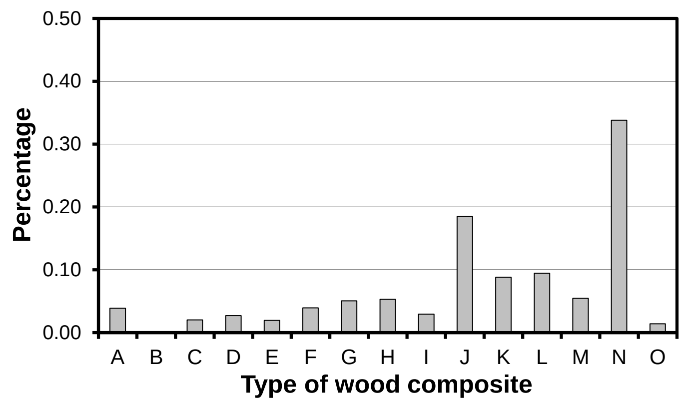

Fig. 5. Content percentages of dust particles with a size of 2.5 to 10 μm in the dust created during the drilling of wood composites

Figures 3, 4, and 5 illustrate the content percentages of particles with the dimensions of 0.08 to 1 μm, 1 to 2.5 μm, and 2.5 to 10 μm out of the whole mass of dust calculated on the basis of the results of the sieve and laser analyses. The fractions of the particles within the range below 1 μm were different for all the tested wood composites; there was a negligible value for Elkon (B), while the value for fiberboards was quite significant. In the case of MDF, the content percentage (for 0.08 to 1 μm) was more than 0.035%, and for hardboard, it was more than 0.045%. It seems that these mass fractions are very small, but it must be remembered that they relate to very fine particles.

The content percentages of particles with the dimensions of 1 to 2.5 μm and 2.5 to 10 μm were similar to those found in the case of the smallest particles (0.08 to 1 μm). The total mass content of the dust was greater for obvious reasons. In the case of hardboard, it achieved 0.065% and 0.34%, respectively, in those two ranges, and its percentages were much greater than for all the other dusts' percentages. Generally, it can be stated that the working of fiberboards by this method results in the creation of a much larger amount of fine dust particles than for the other types of composites. Subsequently, in this respect, composites made of chips should be mentioned, and then finally laminates, where the dust contained the smallest amount of the finest particles. Other machining methods of fiberboards are also a source of large amounts of fine dust. Rogoziński and Očkajová (2013) have found using the same methods (sieving and laser analysis) that the contents of dust particles smaller than 10 μm from the milling of MDF was more than 1%. While on the other hand, the machining of solid wood can also result in the creation of fine dust. This was confirmed by the study of Wieruszewski and Rogoziński (2013), who have found the contents of particles smaller than 10 µm on the level of 0.1 % in the dust from milling the self-locking longitudinal joints in pine wood.

CONCLUSIONS

1. Despite the small mass fractions of the finest particles in the dusts created from the drilling of wood composites, one needs to be aware that this type of processing is often the cause of the increased level of dustiness in the surrounding air due to the tool geometry, as well as the conditions of its operation.
2. The reason for this is the fact that there was no possibility of effective exhausting of the dust particles. They were dispersed in the air during their creation in CNC machining, especially when the tool moved often over considerably large distances in many directions. In addition, the penetration of the tool in the work piece caused the dust created during machining to not be instantly exposed to the operation of the air stream of the extraction mechanism. As a result, a serious risk was posed since the air was polluted by ultrafine particles even though the finest dust had minimal mass.
3. The results confirm the possibility of this risk. It was shown that the chips created by the drilling of wood composites contained the particles which, when dispersed in the air, could enter the unciliated parts of human respiratory tract.
4. The use of wood composites that have a considerable content of the finest particles (which are potentially respirable) in the dust created from drilling should be avoided.

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REFERENCES CITED

Beljo-Lučić, R., Čavlović. A. O., and Jug, M. (2011). “Definitions and relation of airborne wood dust fractions,” *Woodworking Techniques: Proceedings of the 4th International Scientific Conference*, Czech University of Life Sciences, Prague, 25-32.

Chung, K. Y. K., Cuthbert, R. J., Revell, G. S., Wassel, S. G., and Summers, N. (2000). “A study on dust emission, particle size distribution and formaldehyde concentration during machining of medium density fibreboard,” *Ann. Occup. Hyg.* 44(6), 455-466. DOI: 10.1093/annhyg/44.6.455

Detering, B., Neuschaefer-Rube, J., Poppe, M., Woeste, W., Wüstefeld, B., and Wolf, J. (2000). “Dust-intensive manual wood working,” *Gefahr. R. L.* 60(11), 445-452.

Dutkiewicz, J., and Prażmo, Z. (2008). “Occupational biohazards in wood industry,” *Zdr Publ.* 118, 138-444.

Fujimoto, K., Takano, T., and Okumura, S. (2011). “Difference in mass concentration of airborne dust during circular sawing of five wood-based materials,” *J. Wood Sci.* 57(2), 149-154. DOI: 10.1007/s10086-010-1145-y

Kauppinen, T., Vincent, R., Liukkonen, T., Grzebyk, M., Kauppinen, A., Welling, I., Arezes, P., Black, N., Bochmann, F., Campelo, F., *et al*. (2006). “Occupational exposure to inhalable wood dust in the member states of the European Union,” *Ann. Occup. Hyg.* 50(6), 549-561. DOI: 10.1093/annhyg/mel013

Kos, A., Beljo-Lučić, R., Šega, K., and Rapp, A. O. (2004). “Influence of woodworking machine cutting parameters on the surrounding air dustiness,” *Holz Roh- Werkst.* 62(3), 169-176. DOI: 10.1007/s00107-004-0473-2

MaScontrol (2009). “Milling and sizing control software for laser particle sizers and mills,” from Fritsch GmbH Manual. Fritsch GmbH, Idar-Oberstein, Gremany

Očkajová, A., Beljaková, A., and Siklienka, M. (2010). “Morphology of dust particles from the sanding process of the chosen tree species,” *Wood Res.* 55(2), 89-98.

Očkajová, A., Stebila, J., Rybakowski, M., Rogoziński, T., and L’uptáková, J. (2014). “The granularity of dust particles when sanding wood and wood-based materials,” *Adv. Mater. Res.* 1001, 432-437. DOI: 10.4028/www.scientific.net/AMR.1001.432

Palmqvist, J., and Gustafsson, S.-I., (1999). “Emission of dust in planing and milling of wood,” *Holz Roh- Werkst.* 57(3), 164-170. DOI: 10.1007/s001070050035

Rautio, S., Hynynen, P., Welling, I., Hemmilä, P., Usenius, A., and Närhi, P. (2007). “Modelling of airborne dust emissions in CNC MDF milling,” *Holz Roh- Werkst.* 65(5), 335-341. DOI: 10.1007/s00107-007-0179-3

Rogoziński, T., and Očkajová, A. (2013) “Comparison of two methods for granularity determination of wood dust particles,” *Ann. WULS – SGGW, For. and Wood Technol.* 81, 197-202.

Samolej, A., and Barcík, Š. (2006). “Influence of specific pressure on cutting power and wood removal by disc sander,” *Drvna Ind.* 57(1), 5-11.

Scheeper, B., Kromhout, H., and Boleij, J. S. M. (1995). “Wood-dust exposure during wood-working processes,” *Ann. Occup. Hyg.* 39(2), 141-154. DOI: 0.1093/annhyg/39.2.141

Varga, M., Csanady, E., Nemeth, G., and Nemeth, S. (2006). “Aerodynamic assessment of the extraction attachment of CNC processing machinery,” *Wood Res.* 51(2), 49-62.

Wieruszewski, M., and Rogoziński, T. (2013). “Dust creation in milling the self-locking longitudinal joints in pine wood,” *Intercatherda* 29(4), 80-84.

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