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SURFACE MODIFICATIONS OF WOOD DUE TO MACHINING PROCESSES

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The surface modifications and subsurface damages induced by machining processes of wood like planing, circular sawing, abrasive planing and laser-machining are described using light and electron microscopic methods.

Mechanical separation of wood is mostly done by machining processes, leading to the production of surfaces of variable quality, depending on several factors of both the workpiece and working machine. While it is known that there occurs a certain amount of destruction of the surface due to the separating chips, the wood surface characterization has not been that extensive. On the other hand, it is a very important criterion to know the quality of wood surface produced to evaluate and understand subsequent operations such as finishing, gluing etc. [1].

Only a few papers deal with the substructure of damages produced by the machining of wood; in this connection the effects of moisture content as well as the influence of knife planing and abrasive planing have been studied [10, 11]. There is also increased interest in recent years in surface quality with reference to window joints [2].

The present study is concerned with the effect of moisture content and sharpness of knives and blades on the wood of beech and spruce produced by planing, circular sawing and abrasive planing. In addition the laser-machining as a new technology for cutting wood is considered.

MATERIAL AND METHODS

The mechanical machining was performed on beech and spruce woods. For laser-machining birch-plywood, particleboard, white oak and pinewood were used.

Planing was performed on a Panhans machine, Type 250/4, using both sharp and dull knives at a feed speed of 10 m/min and 6000 r.p.m.

Circular saw used was also a Panhans Type 604; conditions of sawing were: 4000 r.p.m. and feed speed of 7 m/min. The tooth form UW Type (2021) with 48 teeth was selected with both short (5 mm) and long (40 mm) blade projections. Abrasive sanding was conducted using a contact abrasive machine with abrasive belts of two grit sizes, Nos. 40 and 180; the feed speed was adjusted to 10 m/min. Laser-cutting was effected by a CO_2-laser with an output of 500 W; the gas used was nitrogen. The surfaces produced by the different techniques were analysed using mostly scanning electron microscopy, after coating the samples with gold. In addition light microscopy of cut surfaces was also employed to check the results.

RESULTS AND DISCUSSION

PLANING

Beech (air-dry) sharp knives (Figs. 1,2). Most of the vessel walls have been cut cleanly, suggesting a sharp state of the knives used. Numerous short fibrous bundles sticking out of the surface have been cut short. The lumina of cells exposed are devoid of any wall fragments. Crushing and densification of cells is hardly present.

Beech (air-dry) dull knives (Fig. 3). The surface evinces a closed, densified character, without any fuzziness. Both the blocked and non-blocked lumina appear densified, leading to a great subsurface damage in the form of bent cells and flat-rilled surface.

Beech (sap-green) sharp knives (Fig. 4). The fine structure analysis of the surface reveals only a few fuzzy areas and no fragments in the vessel lumina. There appears to be a glue-effect of the isolated wood fragments, lying still attached to the surface, not becoming blown off during the processing. The cut margins are very smooth, and no compression areas are visible.

Beech (sap-green) dull knives (Fig. 5). In contrast to the sharp knife planing there occur frequently extensive areas of fuzzy grain with numerous isolated cell fragments distributed all over the surface.

Spruce (air-dry) sharp knives (Figs. 6, 7). As can be readily seen the most obvious difference to the beechwood is the behaviour of early- and latewood zones. The earlywood is open with a fuzzy grain. The short cells are mostly appressed to the surface; the long raised cells were severed and lifted up during the first rotation of the knives and pressed against the surface; subsequently they become slightly raised, leaving impressions on the surface. The latewood possesses no fuzziness and appears densified. Fig. 6 shows partially an uneven surface of earlywood and short fibre wall projections in latewood. The cut is on the whole neat and smooth.

Spruce(air-dry) dull knives (Fig. 8). This resembles the surface produced by sharp knives; here also the latewood is slightly densified. Fuzziness on the other hand is a characteristic feature for both early- and latewood zones. The wavy surfaces of planed wood are a result of several rotating knives [3]. With the increasing dullness of the knives the radius of cutting circle becomes greater, contributing to an increase in pressure of the tissue towards the knives [cf. 4]. The tissue gets densified, deformed and finally severed, without being cut short.

CIRCULAR SAWING/SHARP BLADES (48 teeth, ϕ 300 mm)

Beech (air-dry) short blade projection (Figs. 9, 10). The scratches of the saw teeth on the surface in Fig. 9 demonstrate that the wood has been sawn. The number and size of such knife marks indicate the extension of the saw beyond the workpiece and its oscillatory behaviour. The cells have mostly been cut clean by the new sharp saw. Only a few fuzzy areas are visible near to the vessels, located immediately on the surface as well as just beneath the surface (Fig. 10). The severed fibre bundles project from the surface, showing no specific orientation. They mostly stand out and are not appressed to the surface. The open vessel lumina contain wall fragments from the neighbourhood. The surface reveals on the whole an open character.

Beech(air-dry) long blade projection (Figs. 11, 12). The surface produced is much smoother; the sporadically present frayed fibres get appressed to the surface. The number of open vessels are greatly reduced in contrast to the cutting with a short blade projection. In the sample examined every third notch of the saw teeth goes deeper into the wood, indicating a high oscillation of the saw blade, resulting from a great cutting force due to long blade projection. This is further enhanced by the fuzziness, the wall fragments being closely appressed to the surface; this yields a closed character for the surface.

Beech (sap-green) short blade projection (Fig. 13). The surface appears open-porous and smooth, with almost all the cells cut clean. Only a few of the severed cell fragments are transported further and come to lie on the surface. The wood rays and fibres are discernible as distinct cell types. No cell wall fragments are seen appressed to the surface. Due to the high elasticity of the moist cell walls, they have been cut clean without much fragmentation and tearing.

CIRCULAR SAWING/DULL BLADES

The cutting of wood using dull circular saws and manual feed causes a blockage at short intervals. This results in the blade running past the same part of the wood repeatedly, producing a high frictional heat. This situation yields a dark colouration of the wood surface, due to local plasticization effects of the cells. The furrows produced on the surface in the direction of cutting are partly caused by the wood particles adhering to the flanks of the blade.

Beech (air-dry) short blade projection (Fig. 14). The cut surface exhibits a closed and blocked-up structure with the severed fragments of walls appressed closely to the surface. In addition a plasticization of the cell walls has occurred, leading to a compact and closed surface without many openings.

Beech (air-dry) long blade projection (Fig. 15). The surface is more open with exposed lumina than in the former case. Characteristic for the lumina is their filling with wall debris severed during cutting. Marks produced by the saw teeth are partly visible, which have crushed the wood in the direction of rotation of the saw. In total the use of a dull saw blade appears to lead to an increase in the depth of roughness with increasing blade projection.

Beech (sap-green) short blade projection (Fig. 16). The most characteristic feature is a fuzzy surface, with cell walls sputting out of the surface, especially near the vessels. The open lumina contain only very little wall debris. Light microscopy also reveals that even with a dull knife a rather acceptable clean cut is obtainable with sap-green wood.

The knife marks seen on the surface of circular saw-cut woods reflect a lateral deviation of the saw blades. The long blade projection leads to an increase in the depth of roughness. Pahlitzsch and Friebe [8] related this to the enlarged fibre cutting angle, the tissue becoming separated perpendicularly. The cutting force increases with increasing sharpness angle and blade projection, yielding an increased depth of roughness. Koch [5] also confirms that the chips produced are shorter when the blade projection is short. A dull circular blade saw can severe, shear and cut. The difficulty experienced by the instrument in the penetration into the workpiece results in densification and tissue degradation. The high temperature rise (up to 160°C) leads to a thermal degradation of wood, the degradation products getting attached to the saw and contributing to a temperature increase [6].

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Fig. 1. Beechwood(air-dry) sharp knives/planing
Rys. 1. Drewno bukowe, powietrzno suche, struganie, ostre narzędzie

Fig. 2. Beechwood (air-dry) sharp knives/planing
Rys. 2. Drewno bukowe, powietrzno suche, struganie, ostre narzędzie

Fig. 3. Beechwood (air-dry) dull knives/planing
Rys. 3. Drewno bukowe, powietrzno suche, struganie, tępe narzędzie

Fig. 4. Beechwood (sap-green) sharp knives/planing
Rys. 4. Drewno bukowe, świeże, struganie, ostre narzędzie

Fig. 5. Beechwood (sap-green) dull knives/planing
Rys. 5. Drewno bukowe, świeże, struganie, tępe narzędzie

Fig. 6. Sprucewood (air-dry) sharp knives/planing EW — earlywood, LW — latewood
Rys. 6. Drewno świerkowe, powietrzno suche, struganie, ostre narzędzie; EW — drewno wczesne, LW — drewno późne

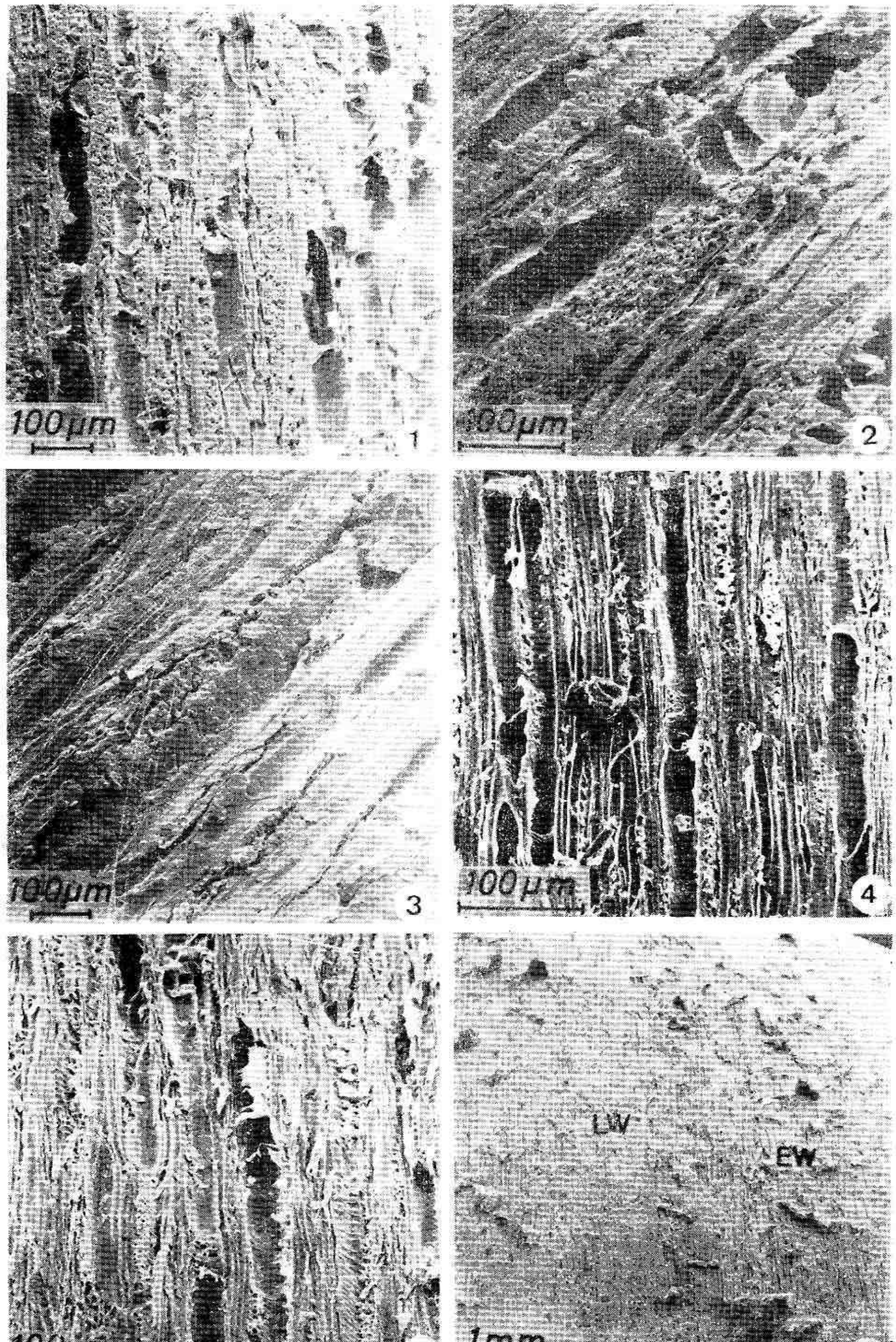

100µm
1
100µm
2
100µm
3
100 µm
4
100µm
5
LW
EW
1mm
6

Fig. 7. Sprucewood (air-dry) sharp knives/planing

Rys. 7. Drewno świerkowe, powietrzno suche, struganie, ostre narzędzie

Fig. 8. Sprucewood (air-dry) dull knives/planing; EW — earlywood, LW — latewood

Rys. 8. Drewno świerkowe, powietrzno suche, struganie, tępe narzędzie; EW — drewno wczesne, LW — drewno późne

Fig. 9. Beechwood (air-dry) sharp blade (short blade projection) circular sawing

Rys. 9. Drewno bukowe, powietrzno suche, cięcie piłą tarczową, ostre narzędzie, mała wysokość rzazu

Fig. 10. Beechwood (air-dry) sharp blade (short blade projection) circular sawing

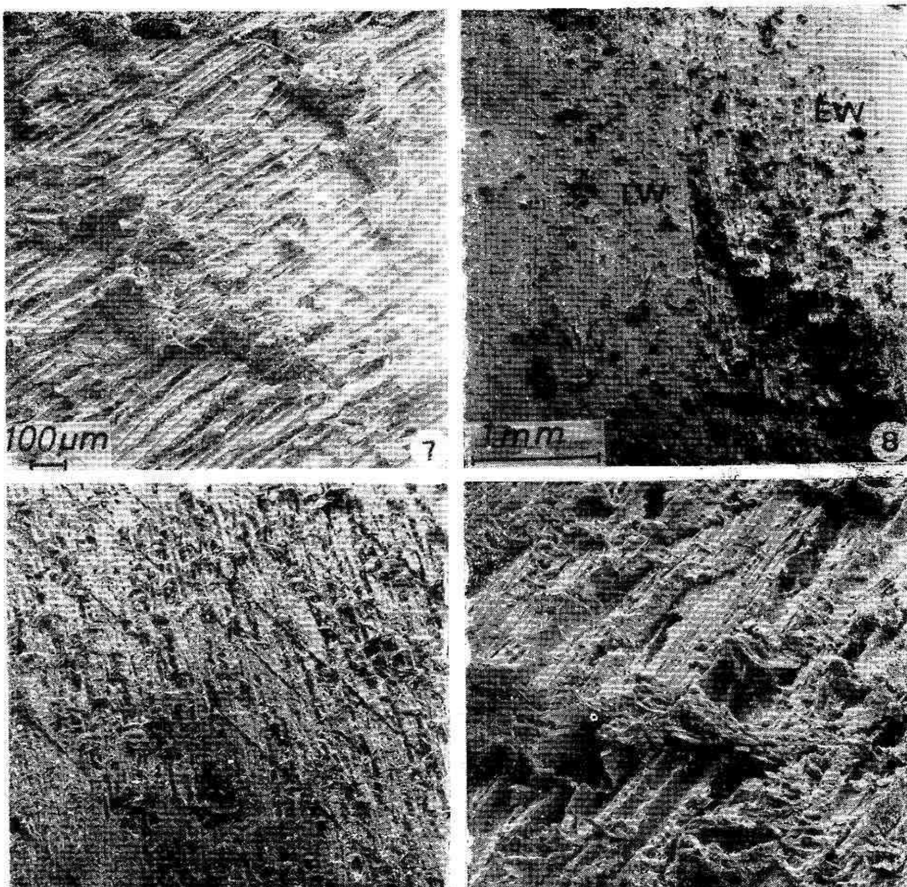
Rys. 10. Drewno bukowe, powietrzno suche, cięcie piłą tarczową, ostre narzędzie, mała wysokość rzazu

Fig. 11. Beechwood (air-dry) sharp blade (long blade projection) circular sawing

Rys. 11. Drewno bukowe, powietrzno suche, cięcie piłą tarczową, ostre narzędzie, duża wysokość rzazu

Fig. 12. Beechwood (air-dry) sharp blade (long blade projection) circular sawing

Rys. 12. Drewno bukowe, powietrzno suche, cięcie piłą tarczową, ostre narzędzie, duża wysokość rzazu



100µm
7
1mm
EW
LW
8
1mm
9
100µm
10
1mm
11
100µm
12

Fig. 13. Beechwood (sap-green) sharp blade (short blade projection) circular sawing

Rys. 13. Drewno bukowe, świeże, cięcie piłą tarczową, ostre narzędzie, mała wysokość rzazu

Fig. 14. Beechwood (air-dry) dull blade (short blade projection) circular sawing

Rys. 14. Drewno bukowe, powietrzno suche, cięcie piłą tarczową, tępe narzędzie, mała wysokość rzazu

Fig. 15. Beechwood (air-dry) dull blade (long blade projection) circular sawing

Rys. 15. Brewno bukowe, powietrzno suche, cięcie piłą tarczową, tępe narzędzie, duża wysokość rzazu

Fig. 16. Beechwood (sap-green) dull blade (short blade projection) circular sawing

Rys. 16. Drewno bukowe, świeże, cięcie piłą tarczową, tępe narzędzie, mała wysokość rzazu

Fig. 17. Beechwood (air-dry) new belt grit size 40/abrasive planing

Rys. 17. Drewno bukowe, powietrzno suche, szlifowanie, nowa taśma, ziarnistość 40

Fig. 18. Beechwood (air-dry) new belt grit size 40/abrasive planing

Rys. 18. Drewno bukowe, powietrzno suche, szlifowanie, nowa taśma, ziarnistość 40

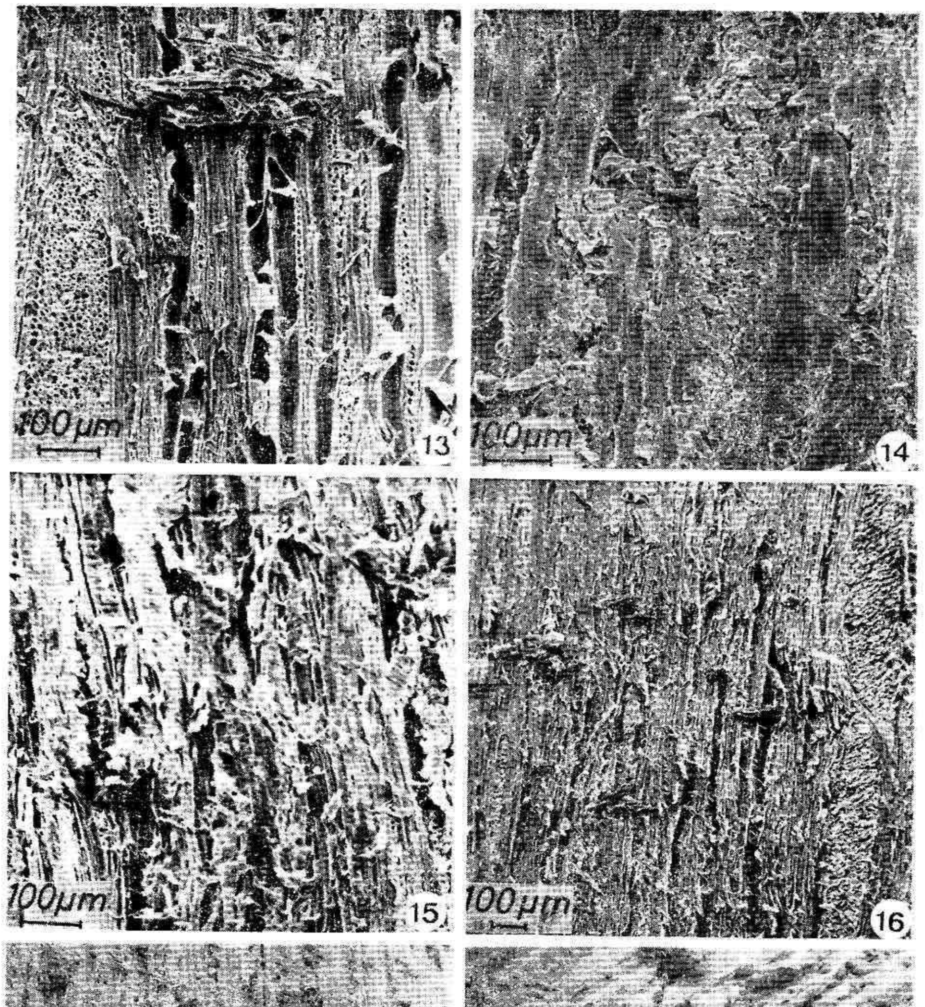

100 µm
13
100 µm
14
100 µm
15
100 µm
16
1 mm
17
100 µm
18

Fig. 19. Beechwood (air-dry) new belt grit size 180/abrasive planing

Rys. 19. Drewno bukowe, powietrzno suche, szlifowanie, nowa taśma, ziarnistość 180

Fig. 20. Beechwood (air-dry) dull belt grit size 40/abrasive planing

Rys. 20. Drewno bukowe, powietrzno suche, szlifowanie, zużyta taśma, ziarnistość 40

Fig. 21. Fibres with holes in the fibre walls (arrows) of birch plywood (laser-machined)

Rys. 21. Sklejka brzozowa cięta laserem. Strzałki wskazują otwory w ścianach naczyń

Fig. 22. Cross-cut oak wood char surface with coagulated mass of degraded wall material. (laser-machined)

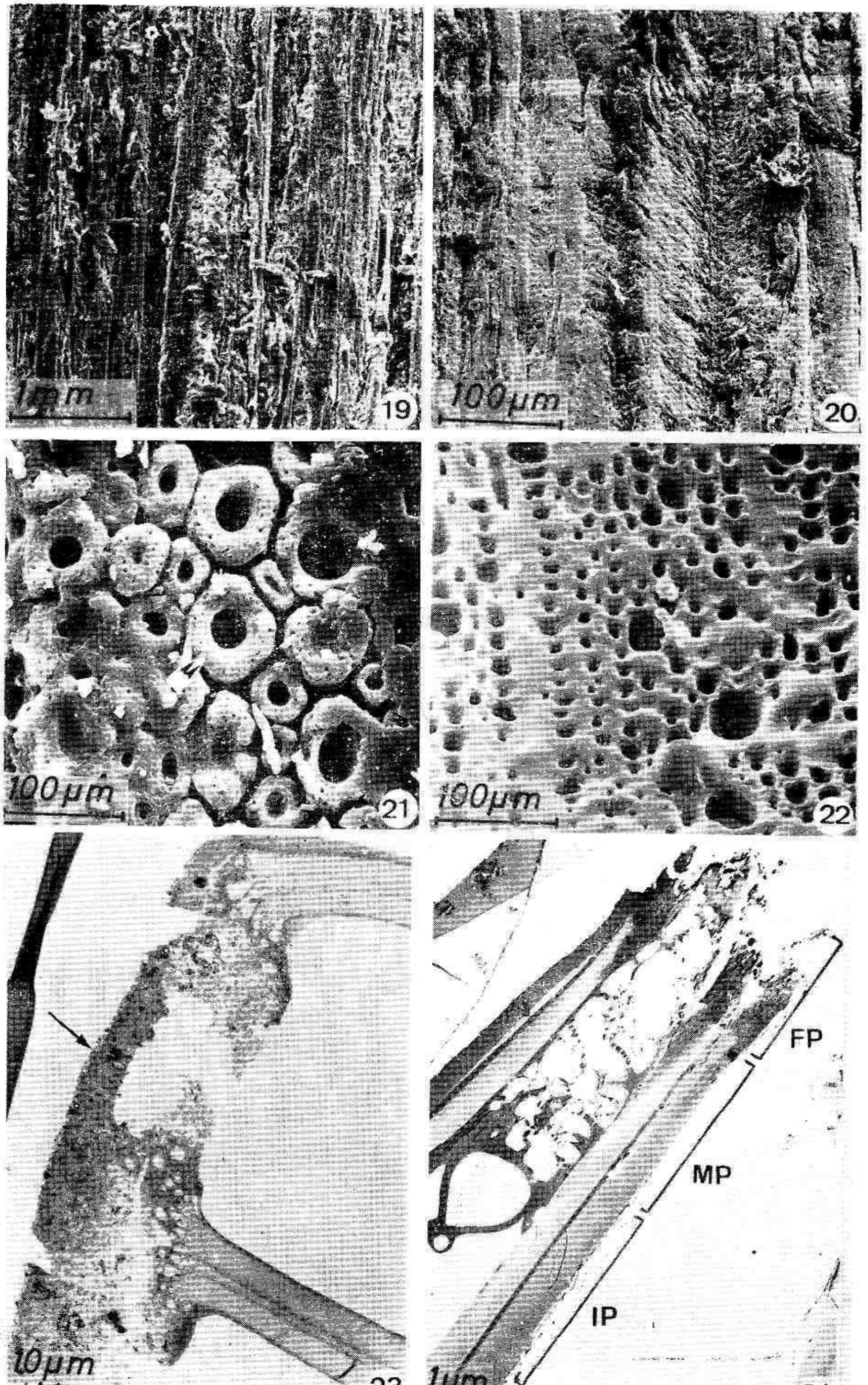
Rys. 22. Zwęglona powierzchnia poprzecznego przekroju drewna dębowego ciętego laserem. Widać skoagulowaną masę materiału ścian naczyń

Fig. 23. Ends of two tracheids in the final pyrolysis zone fused together (arrow) (laser-machining)

Rys. 23. Stopione końce dwóch tracheid (strzałka) w końcowej strefie pirolizy (cięcie laserem)

Fig. 24. Final pyrolysis zone (FP), middle pyrolysis zone (MP) and initial pyrolysis zone (IP) in pinewood (laser-machined).

Rys. 24. Końcowa (FP), środkowa (MP) i początkowa (IP) strefa pirolizy w drewnie sosnowym ciętym laserem



1mm
19
100µm
20
100µm
21
100µm
22
10µm
23
FP
MP
IP
1µm
24

ABRASIVE PLANING

Abrasive planing or sanding using grits of different sizes is directed towards the reduction of the rough surface of a previously machined workpiece to a relatively smooth flat surface and is characterized by a low cutting width and low penetration of the individual grits. Further, scratches on the surface are quite frequent when using dull abrasive belts. The presence of numerous fissures, densification and wall compressions in the fibre direction is also characteristic. These are caused by the grits running perpendicular to the fibre direction but in the surface plane. They are further related to the slightly conical form of the grits and the non-parallel alignment of the fibre direction and abrasive belt running.

Beech (air-dry) new belt/grit No. 40 (Figs. 17, 18). The general appearance is an irregular surface, with little fuzziness and partly debris-filled lumina. The lumen-filling is a result of the grit pushing in its front the severed particles and the next grit either pushing it aside (leading to the formation of wedges) or pushing to the front to the already present aggregation of similar particles; they get closely appressed to the surface through the continuous rotation of the abrasive belt, so that on such sanded surfaces hardly any open lumina are found. One can also observe compression marks and densification.

Beech (air-dry) new belt grit No. 180 (Fig. 19). Use of fine grits such as No. 180 produces a smooth surface, which is even and closed with only a few severed cells lying around. Occasionally distinct impressions of a grinding profile of a single grit are also visible. When grits pass by hard cells they cannot penetrate deeper into the tissue, leading to numerous fissures of the wall due to the pressure exercised by the grit.

Beech (air-dry) dull abrasive belt/grit No. 40 (Fig. 20). The use of dull abrasive belts results in a very rough extensively densified surface, the lumina containing masses of debris of severed walls. It becomes apparent the belt has become partly worn out, the grits leaving more or less circular impressions on the deformed wood surface.

Abrasive planing yields a surface with numerous long, narrow notches. Use of dull abrasive belts exhibits well-defined grit traces, the surface appearing highly densified. The abrasive traces are more or less pressure notches. As a result of the high friction between the belt nad the workpiece there result areas of high plasticization [7]. The natural inhomogeneous structure of the wood is destroyed and becomes substituted by a homogeneous, abrasive-furrowed structure, giving a smooth appearance.

LASER MACHINING

The laser machining of materials is a new technology which has been gaining practical application in the wood industry for special purposes during the past few years. The general advantages of such a separation of wood are well known: small kerf, ability of cutting forms, reduced noise, clean cut, absence of tool wear, absence of residues, computer control etc. The assessment of the smooth surface produced was performed using microscopical methods [9]. Due to the thermopyrolytic effect of laser rays the cut wood surface appears mostly black and smooth. The characteristic appearance of the cut surfaces shows the depression caused by a removal of the middle lamella as well as a variable formation of holes in the wall (Fig. 21), depending upon the intensity of temperature development, which ranges in general round about 700°C. In other cases molten wall areas of neighbouring cells get fused together, leading to a glassy surface, which again is a result of varying temperatures (Fig. 22). Woods with high specific gravity necessarily reduces the feed speed, resulting in the development of high temperatures and subsequently of degradation products.

The fine structural changes in the surface layers of the wood have been followed in pinewood. The molten black surfaces contain masses of amorphous cell wall degradation products with partly fibrillar materials (Fig. 23). The degradation products lead to a filling of the open lumina of adjacent cells. Beneath the burnt zone the cell walls exhibit a loosening of wall structure, the middle lamella getting mostly affected and partly pyrolyzed. In the secondary wall layers there occur areas lacking wall substances, suggesting their removal through pyrolysis. In this zone the walls are also beset with microfissures running along the fibre axis (Fig. 24). Next to this zone deeper in the wood the walls appear intact, though partly with exposed fibrillar structures. Thus the laser-cut surface exhibits three distinct zones of differing wall degradation patterns (Fig. 24): a) The final pyrolysis zone (Char zone) contains a glassy mass of amorphous wall material at the very surface. b) The medium pyrolysis zone is a zone beneath the surface containing middle lamella removal and partial pyrolysis of secondary wall layers with microfissure formation c) The initial pyrolysis zone contains mostly intact wall structures, but with the exposure of fibrillar structures due to the removal of some matrix substances. In the samples analysed the pyrolytic degradation due to laser machining is not extensive; it reaches only a depth of 25 - 50 μm due to the physical properties of laser rays and depending upon various machine and workpiece parameters.

SUMMARY

The surface modifications and subsurface damages induced by machining processes of wood like planing, circular sawing, abrasive planing and laser-machining are described using light and electron microscopic methods. The

surface damages are clearly revealed by disturbance-free observations of the variously machined woods; characteristic patterns for the surface quality depending upon the sharpness of the working instruments as well as the wood characters are shown. On the whole this type of analysis of wood surfaces is essential to an evaluation of the surfaces produced in order to manipulate further operations like preservative and coating treatments, gluing etc.

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MODYFIKACJA POWIERZCHNI DREWNA WYWOŁANA JEGO OBRÓBKĄ MASZYNOWĄ

Streszczenie

Badano zmiany powierzchni i uszkodzenia podpowierzchniowe wywołane maszynową obróbką drewna — struganiem, cięciem piłą tarczową, szlifowaniem i cięciem laserem na podstawie zdjęć mikroskopowych i mikroskopii elektronowej. Ujawniono uszkodzenia powierzchni drewna obrabianego w różny sposób. Pokazano charakterystyczne zmiany powierzchni zależne od jakości narzędzia skrawającego i stanu drewna. Tego rodzaju analiza powierzchni drewna jest istotna dla oceny powierzchni przed dalszymi operacjami, takimi jak — stosowanie środków ochrony drewna, wykańczanie powierzchni, klejenie itp.

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