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INFLUENCE OF BIRCH WOOD DENSITY AND POLYSTYRENE CONTENT ON THE COMPOSITE PROPERTIES

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Birch wood (*Betula verucosa*) from 24 year old trees was used to produce a wood-polymer composite with application of styrene. Special consideration was paid to the wood density of obtained birch-wood-polystyrene composite. Thermal polymerization with the use of set of initiators and catalysts was used in the process. Quality of obtained composite was evaluated by means of measurement following properties: density, dimensional stability, absorbability, hardness, static bending strength at two moisture content levels.

GENESIS OF THE PROBLEM AND SCOPE OF THE WORK

For the puropse of improvement of wood of fast growing trees speaks out the fact that this wood is characterized by low strength properties which to the great extent are limiting its use in practice [3, 4, 9, 15, 18, 19]. The last years have had shown without doubt that there is renaisance of building on the base of wood materials. Wood – as the creation of biospherae – borne from solar energy and with use of carbon dioxide and production of oxygen, this material of high structure organisation among many advantages has a lot of inborn defects. The most essential advantage of this raw material is that it is regenerated by nature, while the defect that has, low durability against external factors.

In conection with that wood in service outdoor needs protection against biotical and abiotical corrosion. Till to this time used classic methods are based on its impregnation or covering surface with protective coatings. The used chemicals for impregnation are basically toxic for environement and human health. Efficiency of those preservatives is limited due to their leaching and evaporation from wood. On the other surface coatings on the surface of wood are disturbed in result of moisture deformations of wood, and their effectiveness sometimes drops to zero. The further deficiencies of wood is its low strength when loaded across the grain and low dimmensional stability during service in changeable climatic conditions. The mentioned defects to the great extent are limiting possibility of its use in many fields of economy. The basic advantage of wood is its high strength along the grain and excellent structure. Long lasting investigations have had shown, that elimination of inborn defectes of wood and improvement even its peak properties can be achieved above all by creation of new material composites based on association of wood as phytopolymer with synthetic polymers.

The way of creation of new material composits is based on introduction to the untouched wood structure, the lowest chemical molecules in form of monomers, which in turn undergo are polymerized inside of wood [6]. In the process of polimerization of monomers in wood takes place constant chemical and physical bonding between wood substance and synthetic polymer, and partial filling with polymer of free voids in wood [7, 13]. The effect of mentioned treatement is not only improvement of properties, but also strengthening with wood fibers of the used plastic and in better way than with the synthetic fibers [10]. The aim of presented investigations is to found effects of density of birch wood and polystyrene content on the chosen properties of created composite.

Intermediate scope of investigations is an attempt to workout principles of improvement of known and newly invented properties of choosen species of fast growning species in aim to improve of its quality.

The practical aim of investigations is an attempt of technical valorization of wood and adoption of its properties to the needs of economy life in the light of constantly increasing demands concerning quality and reliability of expected structure and products, compatible with environement protection needs.

SELECTION OF MATERIAL

WOOD SPECIES

It was based on the fact, that birch wood is representing fast growing species, is characterized with high susceptibility for impregnation with liquids, and simultaneously due to its properties has limited use in practice [3, 19]. It is to be added, that the birch tree has small demands in respected to soil and is easy in breeding.

KIND OF MONOMER AND INITIATORS IN COURSE OF INVESTIGATIONS

Till to this time carried out research concerning modification of wood have shown, that with the use of thermal – calalytic polymerization most suitable is styrene, which is characterized by relatively high temperature of boiling (147°C) [7]. Accordingly to the worked out original technology of wood--polymer composite production up to initiation of styrene polymerization

procces were adapted siluaneously three kinds of initiatingsubstances, namely:
- benzoil peroxide (NB),
- cumene hydrochloride (WNK),
- metapinane hydrochloride (TR).

Mentioned kinds of polymerization initiators, in respect to 100 weight parts of styrene in following quantities:
- 0.6 w.p. benzoil peroxide,
- 0.3 w.p. cumene hydrochloride,
- 0.3 w.p. metapinene hydrochloride.

In aim of obtaining of polymer with linked structure was used as the linking substance capable to double-linking in form of N-methylometacrylamide (N-NMA) in quantity 0.5 w.p. for 100 w.p. of styrene [12].

KIND OF HEATING MEDIUM

The heating medium plays basic role in course of production of wood-polymer composite, therefore very important is the selection of it, to ensure proper thermal treatement of the wood impregnated with styrene with added initiating and linking substances.

Accordingly to our invention concerning methods of polymerization of monomers in wood, the thermal treatment is to be carried on in liquid environement [6]. On the begining of wood treatement process, liquid plays the role of heating medium conveying heat to the wood containing styrene, and due to that takes place initiation of polymerization process of styrene, accompanied by heat emission (egzothermal reaction).

Liberated heat in course of polymerization causes rampt increase of temperature inside wood. In this period liquid used for treatement takes out the heat playing the role of cooling medium. In this way it prevents overheating of beeing in course of creation composite to the to high temperature inside of wood, which after overreaching 160°C could damage structure of produced composite [10]. Above all the application of liquid has in aim to isolate of impregnated with styrene wood against the oxygen access found in air, which has the inhibiting action on the process of styrene polymerization.

The conducted by us research have shown, that for the thermal treatement the most suitable is saturated water solution of sodium nitrate ($NaNO_3$), which increases water boiling temperature up to about 110 ± 5°C.

METHOD OF EXPERIMENTS CONDUCTING

METHOD OF WOOD PREPARATION

The common birch wood was used, harvested in Forest District Zielonka, Forestry Potasze. Trees were felled from previously arable sails. The age of trees was about 24 years. From harvested boles, squares were made, 50 ×

× 3 mm, from three zones of crossection area of bole, namely peripheral, intermediate and pith zone. From particular squares samples were cut out measuring in length 150 mm which on the way of conditioning were led to moisture content 12±2%.

METHOD OF STYRENE PREPARTION

To the stabilized styrene, produced by Oświęcimskie Zakłady Chemiczne factory on 100 weight parts at first 3 initiators of polymerization in quantity 1.2 w.p. on 100 parts of styrene. After 15 minutes of homogenization of styrene with initiators with the use of mechanic stirrer, to the solution linking agent was added N-metyhlmetacrylamide (N-MMA) in quantity 0,5 w.p. for 100 w.p. of styrene, was added, and for further 15 minutes solution for wood impregnation, was stirred.

METHOD OF IMPREGNATION

Wood samples measuring 30 × 50 × 170 mm with moisture content 12±2% were placed in autoclave, from which in next 30 minutes air was evacuated with the aid of vacuum pump. When air evacuated from wood it was impregnated with styrene with addition of initiators and linking agent. After one-hour immersion of samples in impregnation liquid they were taken out and degree of impregnation expressed in weight, was stated.

METHOD OF THERMAL TREATMENT

In aim to observe the course of process of styrene polymerization in wood, prior to the thermal processing in every sample in half of its width and length for the depth of 15 mm the thermocouple iron-constantan was placed, and then previously impregnated with styrene samples were put to the sodium nitrate water solution with temperature 90°C. C in autoclave. After placing samples liquid was warmed during 60 minutes up to the temperature 110±5°C. Further during 120 minutes thermal treatment was conducted at the temperature 110±5°C After 180 minutes thermal processing was finished, samples of composite were taken out from liquid. After cooling down samples to the environement temperature, density of wood-polystyren composite was measured. During thermal processing, temperature inside samples was measured and recorded by means of thermocouples and compensating recorder type MKV; speed of recording paper was 40 mm for hour with recording frequency 10 seconds.

CRITERIONS OF EVALUATION

METHOD OF EVALUATION OF THE COURSE OF POLYMERIZATION OF STYRENE IN WOOD

The evaluation of polymerization process of styrene in wood in dependence upon density was executed by the measurement of temperature inside of arising composite wood-polystyrene in the period of thermal processing. On the basis of observation of temperature changes inside composite, could be stated begining of polymerization initiation, maximum temperature and time of treatment, indispensable for occurenze of temperature peak.

METHOD OF EVALUATION OF QUALITY OF PRODUCED COMPOSITE

As the criterion of quality evaluation of produced composite were taken: density, dimmensional stability, absorbability, hardness, static bending strength at moisure content 8±2% and in maximum saturation in water. Dimensional stability of wood-polystyrene composite was determined on the basis of measurement of its moisture borne deformations in form of swelling during soaking in water with temperature 20±2°C. Swelling was determined on the samples 50 × 50 × 100 mm (the last dimmension along the grain) characterized by annual rings parallel to one of side edges. Quite dry samples were placed in container with water of temperature 20±2°C. Distance between upper surface of sample and the water level was always 15 mm. Swelling was measured in tangential and radial directions in times 1, 3, 6, 24, 72, 120, 180 and 240 hours.

Parallel to swelling measurement on the same sample absorbability was determined by measurement on the same sample absorbability was determined by measurement sample mass, with accuray 0.1 g.

Static bending strength was measured with the use of apparatus for measurent of plastics, named Dynstat the samples 3 × 10 × 15 mm. The loading force direction was corresponding with parallel direction in wood.

Samples at the moment of tests have moisture 8±2% or state of maximum saturation with water. Hardness of wood-polymer composite was determined with Brinell's method in parallel and perpendicular directions in respect to the grains. In course of determinations of hardness, ball measuring 10 mm was used, and the force 1250 N was aplied when testing wood-polymer composite, and 500 N for the wood. Measurement of dents was made with the measuring magnifier with the accuracy up to 0.05 mm.

RESULTS OF EXPERIMENTS AND THEIR ANALYSIS

EFFECTS OF BIRCH WOOD DENSITY UPON THE DEGREE OF IMPREGATION WITH STYRENE AND POLYMERIZATION COURSE

The effect of birch wood density upon degree of impregation with styrene and on wood-polymer composite density is presented in Table 1.

From the data presented in table 1 results, that as it was to be foreseen, that together with decrease of birch wood density increase degree of saturation with styrene. Density of producer composite birch wood-polystyrene increases with degree of styrene content. But this density depends upon wood density, not

Table 1

Effect of birch wood quality upon degree of impregnation with styrene and density of composite wood-polystyrene

Wpływ jakości drewna brzozy na stopień nasycenia styrenem i gęstość kompozytu drewno-polistyren

Wood density Gęstość drewna	Degree of impregnation with styrene Stopień nasycenia styrenem	Density of wood-polystyrene composite Gęstość kompozytu drewno-polistyrenu	
kg/m^3	%	kg/m^3	%
610±10	66	958	157
570±10	72	938	163
520±10	86	905	174

form quantity by of introducad styrene. Increase of composite density in respect to the wood density from which it was made is as higher the higher density has had wood.

Effect of birch wood density and styrene content in wood upon temperature course inside produced composite is shown on the Fig. 1.

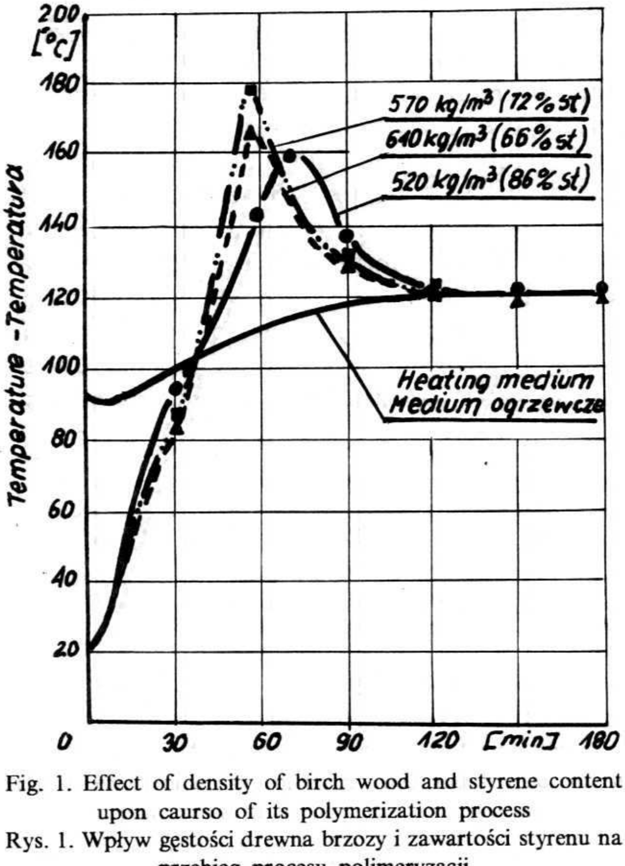

Fig. 1. Effect of density of birch wood and styrene content upon caurso of its polymerization process

Rys. 1. Wpływ gęstości drewna brzozy i zawartości styrenu na przebieg procesu polimeryzacji

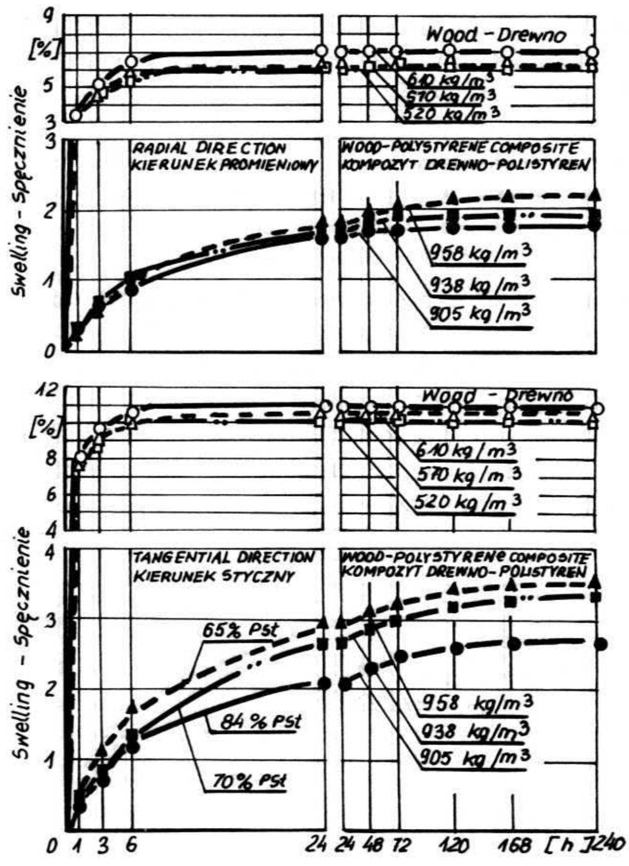

Fig. 2. Effect of composite density birch wood-polystyrene on its swelling during soaking in water in temp. 20±2°C
Rys. 2. Wpływ gęstości kompozytu drewno brzozowe-polistyren na pącznienie w wodzie o temp. 20±2°C

From the curves presented on the Fig. 2 i results, that at the initial period of thermal treatement, increases temperature of wood impregated with styrene independently from its density. In wood with density increase of styrene content due emission of heat during its polymerization rises temperature inside wood. The lowest temperature inside of produced composite occured in samples with lower density despite of highest styrene content. This certifies that in this case took place faster absorption of heat by surrounding liquid. After occurence of maximum temperature inside composite beeing in production, due to the cooling down, takes place drop of temperature till to equalization with temperature of surrounding medium used for thermal treatement. The curves presenting temperature of styrene in wood polymerization process could be divided in to three periods:

– first period of temperature increase during which takes place neutralization of inhibitors contained in styrene and in wood, and activation of initiating substances;

– second period of fast temperature increase, beeing the effect of polymerization of styrene inside wood;

– third period pertains lowering of temperature, what certifies finishing of polymerization proces.

EFFECT OF BIRCH WOOD DENSITY UPON DIMENSIONAL STABILITY AND ABSORPTION OF WOOD-POLYSTYRENE COMPOSITE

Dimmensional stability birch wood-polystyrene composite in dependence upon density and polystyrene content is shown on the Fig. 2.

From the curves presenting dynamics of swelling of the birch wood-polystyrene composite in dependence upon wood density and polystyrene content results that the smallest was the density of birch wood and greater in polystyrene content, the highest it showed dimmensional stability. From that

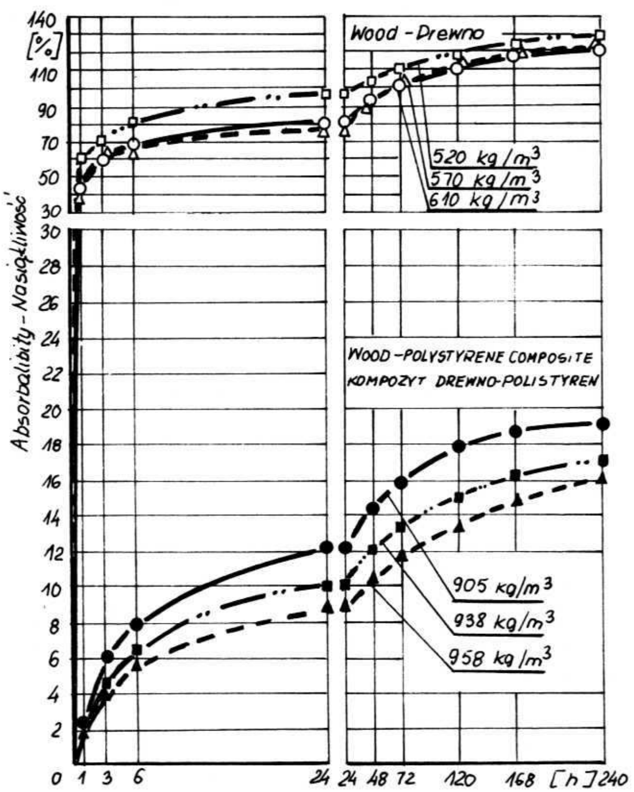

Fig. 3. Effect of density of birch wood-polystyrene composite on its absorbability during soaking in water in temp. 20±2°C
Rys. 3. Wpływ gęstości kompozytu drewno brzozowe-polistyren na nasiąkliwość podczas moczenia w wodzie o temp. 20±2°C

results without doubts, that the dimmensional stability of wood-polystyrene composite deciding role has polystyrene content in composite.

From that practical conclusion can be drawn that for production of wood-polystyrene composite with extermly high dimmensional stability birch wood of small density is to be used. It can be explained by the fact that, in the wood of lower density the task of grafting of polystyrene to wood substance, what decreases its suitability for dimmenssional changes.

Effect of birch wood density on the absorbability of produced wood-polymer composite is shown on the Fig. 3. From this drawing results, that the absorbability of birch wood-polystyrene composite is very small and not over 20%, and is 6 times smaller from wood absorbability. Absorbability of wood-polystyrene composite depends upon its density namely composite with higher density is characterized by lower absorbability.

EFFECT OF DENSITY OF BIRCH WOOD ON THE STATIC-BENDING STRENGHT OF WOOD-POLYMER COMPOSITE

Effect of density of birch wood upon strength of wood-polystyrene composite is presented in Table 2. From the data tabulated in Table 2 results, that static bending strength of birch wood-polystyrene composite at moisure content 8±2% inreases ca twice, and in maximum wet state three times in respect to wood static bending strength. However absolute strength birch wood-polystyrene composite is much higher, the higher was density of used

Table 2

Effect of birch wood density on the static bending strength of composite wood-polystyrene
Wpływ gęstości drewna brzozy na wytrzymałość na zginanie statyczne kompozytu drewno-polistyren

Wood density Gęstość drewna	Denstiy of wood-polystyrene composite Gęstość kompozytu drewno-polistyren	Composite mositure content at testing Wilgotność kompozytu w chwili badania							
		8±2%				maximum-maksymalna			
		M		±δ	υ	M		±δ	υ
kg/m³		MPa	%	MPa	%	MPa	%	MPa	%
610	958	172	207	7.9	4.6	140	358	7.0	5.0
570	938	147	201	7.2	4.9	125	347	6.1	4.9
520	905	137	190	4.5	3.3	110	333	7.6	6.9

wood for its production. This certifies the that introduction to the birch wood of low density greater styrene quantity, could not ensure production of composite with properties corresponding with properties of composite produced from birch wood with higher density and with smaller styrene quantity.

It is to be stresed, that tested composites in maximum saturation water, are characterized by thrice higher static bending strength than wood. This observation allows to formulate assumption, that this fact is caused by constant joining polystyrene with phytopolymer, namely wood. That decreases quantity of higroscopic water inside cell-walls, could cause their swelling and in the same decrease of wood strength.

The certification of this assumption could be the photographs made with the use of scanning microscope, presenting structure of crossection of birch wood and birch wood-polystyrene composite Fig. 4 – 6. On the Fig. 4 there is shown natural birch wood. There can be seen a lot of tracheids without any obstacles, vessels are not seen. On the Fig. 5 we can see that the librofom tracheids are to the great extent filled with polystyrene, which closely adheres to the walls. Above is a part of the vessel. Previously made experiments have had shown that about 35% of introduced to wood polystyrene, has the features of polymer closely bound with components of wood substance, in that also with its carbohydrate part [11, 13]. On the Fig. 6 can be seen a bit of crossection of birch wood composite, there are two tracheids one filled and one void.

EFFECT OF BIRCH WOOD DENSITY ON THE HARDNESS OF WOOD-POLYMER COMPOSITE

Effect of birch wood density on the hardnes of wood polymer composite is presented in Table 3. From the figures presented in above table results that, it is not be stated without doubt the effect of the birch wood density on the composite hardness. In this case pores of wood were filled with polystyrene, which to the great extent decided about composite hardness. In the wood with lower density polystyrene content was higher, and from that we observe distinct increase of hardness of composite produced from wood of lower density. It is be stressed that distinct increase of hardness of wood-polystyrene

Table 3

Effect of birch wood density upon the composite wood-polystyrene hardners at moisture content $8 \pm 2\%$

Wpływ gęstości drewna brzozy na twardość kompozytu drewno-polistyren przy wilgotności $8 \pm 2\%$

Wood density Gęstość drewna	Density of wood-polystyrene composite Gęstość kompozytu drewno-polistyren	Direction of measurement Kierunek pomiaru					
		tangential styczny		radial promieniowy		longitudinal wzdłużny	
kg/m³		MPa	%	MPa	%	MPa	%
610	958	101,0	451	96,0	384	150,0	269
570	938	96,1	488	86,6	364	148,5	260
520	905	82,6	470	87,0	353	123,5	265

composite across the grain, in which direction most often are loaded structures and wood products made of wood. In course of measurement of the width of annual rings, in central part of stem crossection were observed changes of colour, covering on the stem level height; 1.3 m – 12 annual rings, 5.0 m – 10 annual rings.

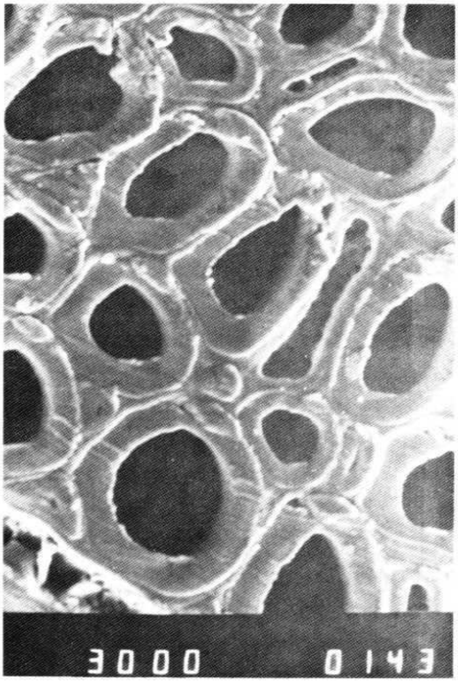

Fig. 4

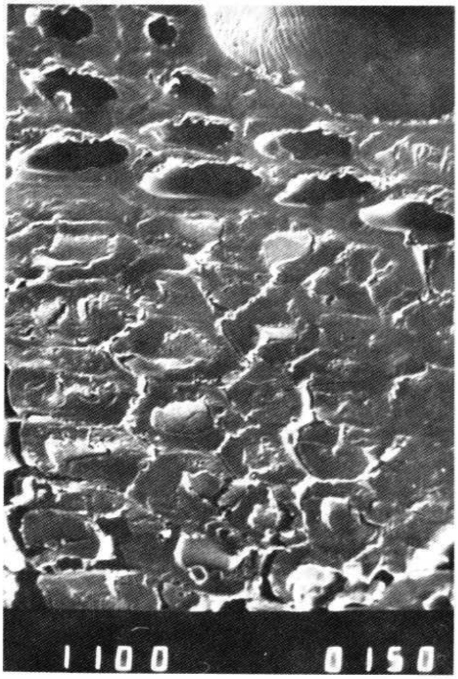

Fig. 5

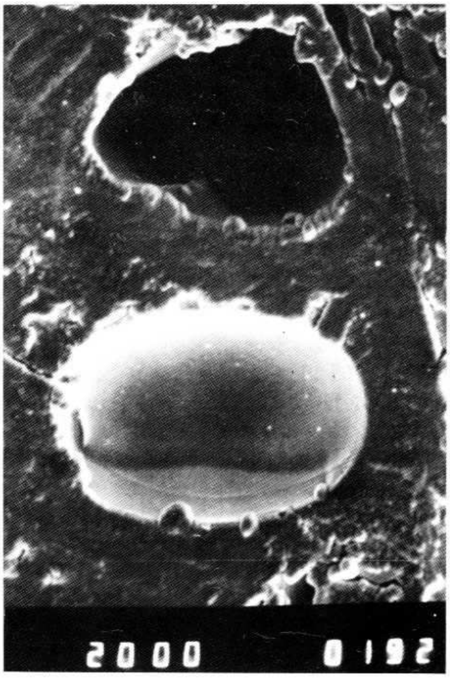

Fig. 6

Fig. 4. Natural birch-wood used in experiments (cross-section-magnification 3000 ×)
Ryc. 4. Naturalne drewno brzozy użyte w doświadczeniach (powiększenie przekroju poprzecznego 3000 ×)

Fig. 5. General view of cross-section of birch-wood-polystyrene composite. Above is part of the vessel cross-section. Tracheids are filled with polystyrene (magnification 1100 ×)
Ryc. 5. Ogólny widok przekroju poprzecznego kompozytu drewno brzozowe-polistyren. Powyżej znajduje się część przekroju poprzecznego członu naczynia. Cewki są wypełnione polistyrenem (powiększenie 1100 ×)

Fig. 6. Cross-section of birch-wood-polystyrene composite. There are two tracheids which are filled completely with polistyrene, in the second polystyrene only on the cell-wall (magnification 2000 ×)
Ryc. 6. Przekrój poprzeczny kompozytu drewno brzozowe-polistyren. Są tutaj dwie cewki, które są wypełnione całkowicie polistyrenem, w drugiej polistyren znajduje się jedynie na ścianie komórkowej (powiększenie 2000 ×)

CONCLUSIONS

On the basis of analysis results can be drawn following coclusions:
1. The styrene polymerization process in birch wood is as much slower, the lower the density has the wood used for composite production. In wood with close densities increase of styrene content, increases temperature of the inside beeing in production composite.
2. Dimmensional stability of birch wood-polystyrene composite increases with the drop of density and with the increase of polystyrene in wood.
3. With the decrease of wood density increases in wood polystyrene content and simultanteously decreases absorbability of produced composite.
4. Static bending strength of composite expressed in absolute values decreases together with wood density decrease despite of the higher in it content of polystyrene.
5. Composite made of birch wood of lower density, containing more polystyrene is characterized by higher increase of hardness in comparison with hardness of composite from wood of high density.
6. Birch wood independently to its density and place of sampling on the stem of tree is in full suitable for the production of composites on the styrene base.

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WPŁYW GĘSTOŚCI DREWNA BRZOZY I ZAWARTOŚCI POLISTYRENU NA WŁAŚCIWOŚCIACH WYTWORZONEGO KOMPOZYTU

Streszczenie

Do badań zastosowano drewno brzozy (*Betula verucosa*) pozyskane z 24-letniej plantacji na gruntach porolnych. Wyróżniono trzy grupy gęstości drewna, a mianowicie 520, 570 i 610 kg/m^3, z których wyrobiono graniaki o przekroju 30 × 50 × 150 mm. Graniaki te po ewakuacji powietrza z drewna, nasyconego styrenem z dodatkiem 3 inicjatorów polimeryzacji w ilości 1,2 cz.w. w stosunku do 100 cz.w. styrenu. Jako środek sieciujący zastosowano N-metylolometaktrylamid w ilości 0,5 cz.w. na 100 cz.w. styrenu. Polimeryzację styrenu zawartego wewnątrz drewna przeprowadzono według sposobu opracowanego w Katedrze. Przeprowadzone badania wykazały, że stabilność wymiarowa kompozytu drewno brzozowe-polistyren wzrasta ze spadkiem gęstości drewna i wzrostem zawartości w nim polistyrenu. Zawartość polistyrenu w kompozycie zmniejsza jego nasiąkliwość. Wytrzymałość na zginanie statyczne kompozytu, wyrażona w wartościach bezwzględnych, obniża się ze spadkiem gęstości drewna, pomimo większej zawartości w nim polistyrenu. Kompozyt wykonany z drewna brzozy o mniejszej gęstości zawierający więcej polistyrenu charakteryzował się większym przyrostem twardości w odniesieniu do twardości drewna, z którego został wytworzony. Drewno brzozy, bez względu na miejsce pozyskania w strzale, jest w pełni przydatne do produkcji kompozytów drewno-polistyren.

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