FOLIA FORESTALIA POLONICA
Seria B, zeszyt 25, 1994

EFFECTS OF THE DENSITY OF *COCOS NUCIFERA* L. WOOD ON THE QUALITY OF PRODUCED WOOD-POLYSTYRENE COMPOSITE

Maciej Ławniczak

Department of Hygrothermal Treatment
and Wood Modification
Agricultural University in Poznań

The object of studies was to find possibility of valorization of *Cocos nucifera* wood, especially from the zones of wood with low density. Four wood density zones were distinguished 320, 370, 410 and 480 kg/m^3.

The valorization of cocos palm wood was conducted on the way of creation wood-polystyrene material composite. On the base of research results analysis, it has been found that the properties of *Cocos nucifera* wood from the zones characterized by low density, could be considerably improved even in respect to the properties of wood with high density sampled from the outside zone.

The tests have shown, that the cocos palm wood is suitable for production of composite, and properties of wood from inside zones are characterised by the low quality, what limits its practical suitability, could be valorized above properties of wood from external zone characterized by high density and good quality.

1. GENESIS AND SCOPE OF THE WORK

Cocos palm wood *Cocos nucifera* L., is one of important palm species growing in tropical zone, most abundant in Asia and Pacific zone.

The deficiency of cocos palm wood is very diversified in its density. It is known, that wood properties are very differentiated in respect to density. The zone of wood with the highest density and relatively good properties covers only ca 20% of general stem volume.

In aim to create conditions for increase and equalize density of palm wood on the whole crossection of stem, it was taken as appropriate to start research aiming to valorize palm wood, especially of the lowered density by chemical valorization.

The practical aim of studies were attempts to create conditions to greater use palm wood by increase uniformity of palm wood and equalization of its strength properties in particular zones of stem. Intermediate scope of work was to decrease affinity of palm wood to water, that is increase of its hydrophobic properties and durability upon biotic and abiotic factors action, as well as improvement of suscebility on machining.

2. METHODS AND WAYS OF RESEARCH

2.1. WOOD MATERIAL SAMPLING

2.1.1. POSSIBILITIES OF UTILIZATION COCOS PALM WOOD

Cocos palm, due to the its numerous occurence in tropical zone is real "Multi-Purpouse-Tree" providing people and agricultural industry series of products:

- foodstuffs: oils and fats, cocos milk for drinking and boiling, vegetables (milioner's salad) from delicate meristem of growth apex, drinks from fermented juice,
- fodder for cattle: from oil cake,
- fibers: for strings, lines, sacks, mats, rugs,
- fuel material: from dried stems and leaves,
- charcoal: from nut shells; and activated carbon,
- building material: for walls and roofing from leaves and stem wood.

The zones of cocos palm stem utilization are shown on the Fig. 1.

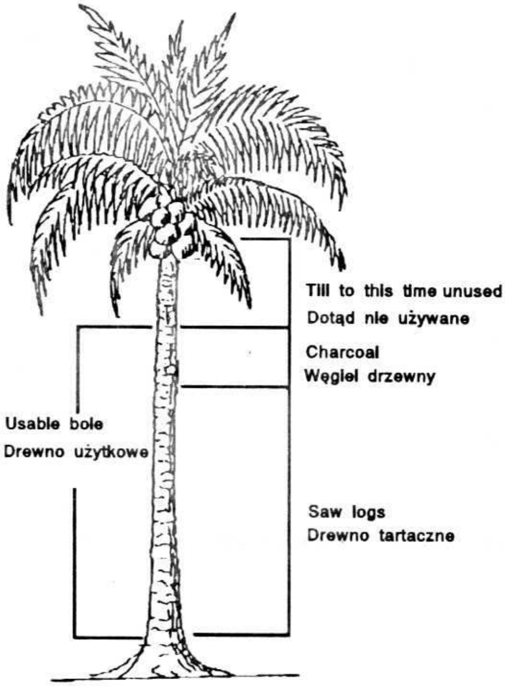


Fig. 1. Zones of utilization of cocos palm bole acc. to A. Frühwald, R.D. Peek, M. Schulze [1]

Ryc. 1. Sposób wykorzystania poszczególnych stref drewna palmy według A. Frühwalda, R. D. Peeka i M. Schulze [1]

2.1.2. STEM CHARACTERISTIES

The palm belongs to the Monocotyledones. Hers stem differs from many points of view of broad leaved and coniferous trees. Palm does not have cambium, hers meristematic tissue is positioned in the growth apex in leaves crown. The secondary growth into thickness tooks place only by the growth of dimmensions of existing cells. Therefore palms have not annual growth rings, and rays, have not branches and knots and sapwood and heartwood. The tissue of cocos palm consists of vascular bundles surrounded with parenchymatic tissue. Each vascular bundle has floem, xylem and parenchymatic cells, which are surrounded with sclerenchymatic cells containing silicat (silicate). Number of vascular bundles increases in direction from inside to outside.

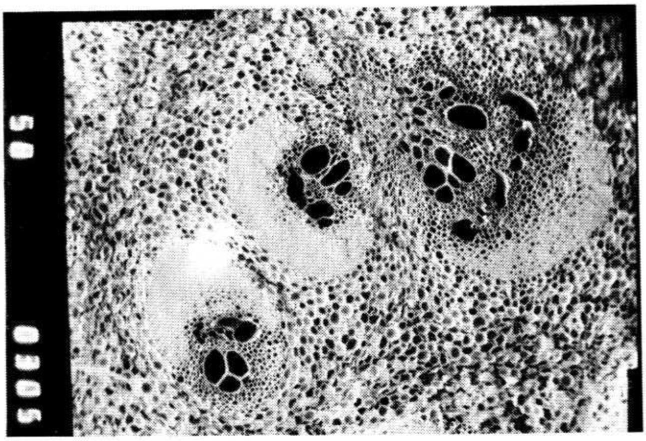


Fig. 2. Colateral Vascular bundles in wood from central of stem (Phot. by D. Chovanec, TU Zvolen)

Ryc. 2. Wiązka naczyniowa centralnej części pnia (Fot. D. Chovanec, TU Zvolen)

Structure of typical vascular bundle of central stem zone presents Fig. 2. In the middle of the stem occurs small quantity of vascular bundles in great distances between them. Distances between particular vascular bundles decrease with the periphery of stem. Crossection has characteristic brown points on the yellow-brownish pattern, what presents photograph. Central cylinder is surrounded with ca 10 mm thick bark, difficult to remove. The rays and annual growth rings are absent, therefore radial and tangential direction are difficult to distinguish. Wood on the cross-section has the reddish-yellow colour with irregular black-brown oblong stripes of various length. Those are vascular bundles. Often they are diagonally cut laying from the bases of old leaves.

2.1.3. WOOD PROPERTIES

The essence of properties of cocos palm wood is ununiformity of displacement properties on the crossection of stem and on its height.

Density and mechanical properties are decreasing from outside to inside and together with height of the stem.

Density changes between 100 kg/m³ and 900 kg/m³.

This differentiation is presented on the Fig. 3.

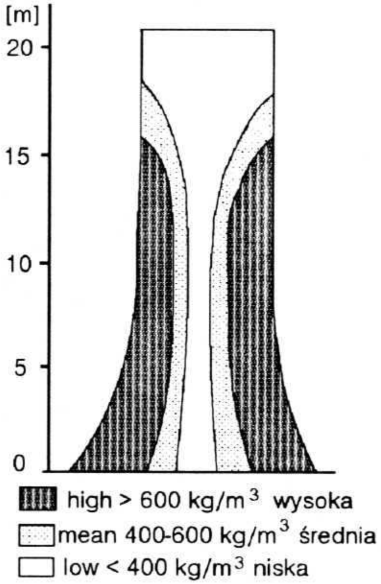


Fig. 3. Diferentiation of wood density of cocos palm wood acc. to A. Frühwald, R. D. Peek, M. Schulze

Ryc. 3. Zróżnicowanie gęstości drewna palmy kokosowej według A. Frühwalda, R. D. Peeka i M. Schulze

There are distinguished three density ranges:

- 400 kg/m³. Wood of lower density collected from the stem inside is suitable for ineteriors lining walls and covering panels.
- 400 - 600 kg/m³ – wood of medium density collected from intermediate zone between inside zone. It is suitable for elements of not loaded structures and furniture.
- 600 kg/m³ wood of high density, collected from lower, outside part of stem. It is suitable for the structures, furniture, pallets.

Accordingly to the density are displaced on crossection of stem mechanical properties.

2.1.4. DURABILITY AND TILL TO THIS TIME PRESERVATION OF WOOD

Wood, especially of lower density is atacked by fungi and insects, and could not be taken as durable. Therefore, imediately after cut it has to be processed, and after sawing protected by means of preservatives in aim to avoid the drop of value during drying. The wood assigned for structures needs long term preservation. Wood of cocos palm can be impregnated under pressure.

For the long term in tropical conditions suitable are CCA salts (chromium, copper, arsenic) but as the tests shown, they are unfriendly for environment.

2.2. METHOD OF PREPARATION OF WOOD FOR THE TESTS

The material for the tests has been obtained from University in Hamburg. It has been delivered in form of squares, from which directly were cut small samples of dimmensions $35 \times 35 \times 170$ mm. During cutting samples tested material has been divided into twin samples: first was assigned for impregnation, the second in natural state has been used as controls.

After cutting samples they have been divided into following density groups:

I – 320 ± 20 kg/m^3,
II – 370 ± 15 kg/m^3,
III – 410 ± 15 kg/m^3,
IV – 480 ± 15 kg/m^3.

The moisture content of samples was $10 \pm 2\%$.

2.3. CHOICE OF MODIFYING SUBSTANCE AND METHOD OF ITS INTRODUCTION INTO WOOD

Till to this time gathered practice and investigations concerning obtaining woodpolimer composites are showing, that the most suitable for wood modification are: winyl monomers, mainly styrene and methyl- metacrylate. It has been decided to select styrene as the impregnation chemical due to the low price and higher boiling temperature.

The impregnating substance has been prepared by mixing styrene with initiators and adding after that the linking agent. The whole mixture has been stirred to complete homogenization of additives and styrene. Styrene with added initiators and linking agent has benn introduced to wood by means of vacuum-pressure method.

2.4. METHOD OF POLYMERIZATION OF STYRENE IN COCOS PALM WOOD

The impregnated wood is placed in the heating medium, the said medium has the task of delivery of needed amount of heat to initiate the polymerization process. The introduced heat causes of introduced with styrene to disintegrate wood initiators into the free radicals. Their task is neutralization of inhibitors and initiation agents conducting polymerization reaction of impregnating chemical. The second role of medium is to accept excess of heat arising during polymerization, which is strongly exothermic – 15.4 kcal/mol of styrene. Polymerization of styrene inside of palm wood, complying with elaborated by us original technology has been carried on with the use of water with addition of salt increasing boiling temperature. The time of procesing in temperature from 90 - 110°C was 60 minutes, and in temperature 115±5°C by further 120 minutes. The joint time of processing was 180 minutes.

2.5. CRITERIA OF QUALITY EVALUATION OF PRODUCED PALMWOOD COMPOSITE

As the criteria of quality evaluation were adopted:
- swelling and absorbability in water,
- static bending strength at moisture content 8±2% and in state of maximum soaking in water,
- Brinell's hardness in air dry state.

3. RESULTS OF EXPERIMENTS AND THEIR ANALYSIS

Effect of cocos palm wood density on the polystyrene content and density of produced composite palm wood-polystyrene is presented by figures listed in Table 1.

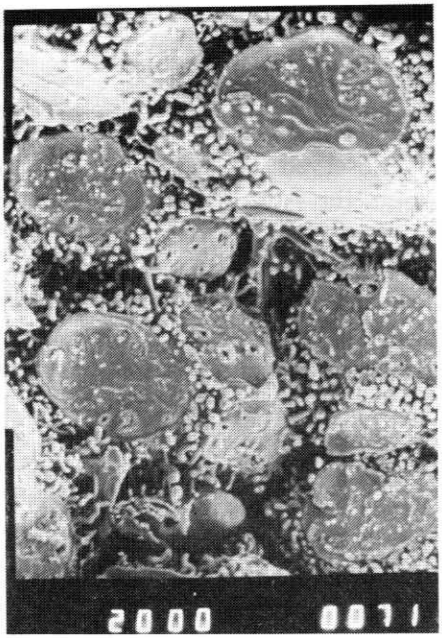
Table 1

Effect of palm wood density upon the polystyrene content and composite density
Wpływ gęstości drewna palmy na zawartość polistyrenu i gęstość kompozytu

Density group Grupa gęstości	Wood density Gęstość drewna	Polystyrene content Zawartość polistyrenu	Composite density Gęstość kompozytu	
	kg/m³	%	kg/m³	in % of wood density w % gęstości drewna
I	320	148	720	225
II	380	85	680	180
III	410	73	640	156
IV	490	67	780	159

From figures presented in table 1 results, as it was to be foreseen, that together with the decrease of cocos palm wood density increases polystyrene content in produced composite, and in the same its density.

Polystyrene content in cocos palm wood is dependent upon degree of its impregnation with styrene Fig. 4.



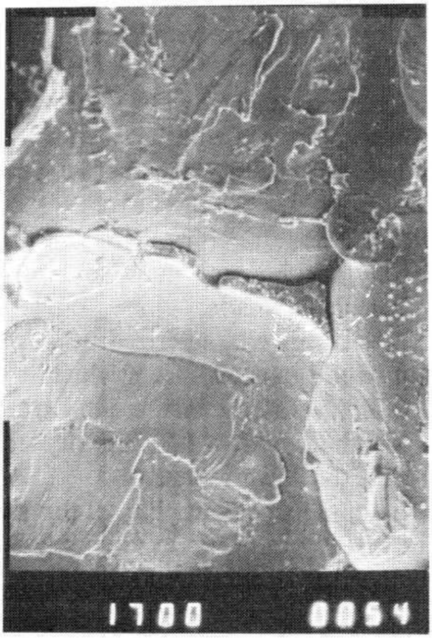


Fig. 4. Cocos palm wood cells partially filled with polystyrene and partially empty
Ryc. 4. Komórki drewna palmy kokosowej częściowo puste i częściowo wypełnione polistyrenem

Fig. 5. Presence of polystyrene between split parenchymatic cells
Ryc. 5. Obecność polistyrenu między rozdzielonymi komórkami miękiszu

Fig. 6. Polystyrene on the surface of parenchymatic cells walls
Ryc. 6. Polistyren na powierzchni ścian komórek miękiszu

(Photos by D. Chovanec, TU Zvolen)

The lower polystyrene content in wood of higher density is caused by the more frequent occurence of parenchymatic cells with completely of partially lignified cell walls, which undoubtely limited penetration of styrene into cells Fig. 5, 6. In cocos palm wood of higher density can be observed greater number of thickwalled grains with small light what limits their impregnability with styrene.

The greatest growth of density, in relation to wood density was characteristic for composite produced from wood with lower density. Produced composite was characterized by lower differentiation of density than wood density, from which it was produced. However introduction to the cocos palm wood of lower density, greater quantity of styrene does not ensure obtaining the composite with close density, independently to the wood density from which it has been produced.

Effect of density of cocos palm wood upon composite static bending strength are presented figures in Table 2. From figures tabulated in the Table 2 results that static bending strength of composite cocos palm wood-polystyrene is dependent upon strength of wood from which it was made, and from content of polystyrene in it.

Static bending strength at moisture content $8 \pm 2\%$ is dependent upon its density with the exception of composite produced from the wood of lowest density and containing above twice of polystyrene. Analysing results of studies obtained for composite tested on the static bending strength in state of maximum soaking in water, it can be observed effect of polystyrene content in composite upon its strength, namely increase of polystyrene content in composite effects favourably on its strength. Effect palm wood density upon hardness of produced composite are presenting figures in Table 3.

From this table results, that produced composite from cocos palm wood allows to obtain composite with close hardness despite to density of used wood for its production. Particularly hardness of composite increases across the grain in respect to wood.

In general, it can be stated, that about hardness of composite cocos palm-wood polystyrene decides composite polystyrene content in it, and in less degree hardness of wood from which it has been made.

Produced composite from cocos palm wood was characterized by 2 to 3.5 times higher hardness across the grain from wood hardness from which it was made. Presence of polystyrene has much lower effect in the increase of hardness parallel to the grains, namely from 39% for the wood of high density up to 105% in respect to hardness of wood with the lowest density.

Effect of cocos palm-wood density on the dimensional stability of produced from it composite is on the Fig. 7.

From the curves on the Dwg. 7 results that the dynamics of swelling of the produced composite is much more slower, than the speed of swelling of cocos wood, from which composite was made. Increase of dimensions of composite samples, caused by moisture deformations is so slower the lower was the

Table 2

Effect of cocos palm wood density and polystyrene content upon composite during static bending strength at moisture content $8 \pm 2\%$ and in state of maximum soaking with water

Wpływ gęstości drewna palmy kokosowej i zawartości polistyrenu na wytrzymałość kompozytu podczas zginania statycznego przy wilgotności $8 \pm 2\%$ i w stanie maksymalnego nasycenia wodą

Density group Grupa gęstości	Density Gęstość		Polystyrene content Zawartość polistyrenu	Moisture content during testing Wigotność drewna w chwili badania													
				$8 \pm 2\%$							Maximun moisture content Wilgotność maksymalna						
	Wood Drewno	Composite Kompozyt		Wood Drewno			Composite Kompozyt				Wood Drewno			Composite Kompozyt			
				x	$\pm\sigma$	v	x	$\pm\sigma$	v	in % of wood w % drewna	x	$\pm\sigma$	v	x	$\pm\sigma$	v	in % of wood w % drewna
	kg/m³		%	MPa		%	MPa		%		MPa		%	MPa		%	
I	320	720	149	16,9	3,3	19,5	38,2	5,9	15,4	226	7,9	1,0	12,7	28,2	4,3	15,2	357
II	380	650	85	28,4	3,9	13,7	51,8	5,5	10,6	182	16,9	0,7	4,1	32,7	1,0	3,1	193
III	410	640	73	31,3	3,6	11,5	54,0	6,1	11,3	172	19,6	0,7	3,6	37,4	0,6	1,6	191
IV	490	780	67	35,5	4,2	11,8	85,9	7,3	8,5	242	27,2	0,7	2,6	51,4	0,9	1,8	189

Table 3

Effect of cocos palm wood density and polystyrene content upon composite hardness measured across and along the grains acc. Brinell's method
Wpływ gęstości drewna palmy kokosowej i zawartości polistyrenu na twardość kompozytu w kierunku wzdłuż i w poprzek włókien określoną metodą Brinella

Density group Grupa gęstości	Density Gęstość		Polystyrene content Zawartość polistyrenu	Direction of measurement Kierunek pomiaru					
				Across the grain W poprzek włókien			Along the grain Wzdłuż włókien		
	Wood Drewno	Composite Kompozyt		Wood Drewno	Composite Kompozyt	in % of wood w % drewna	Wood Drewno	Composite Kompozyt	in % of wood w % drewna
	kg/m³		%	MPa			MPa		
I	320	720	149	10,7	37,8	353	40,1	82,4	205
II	380	650	85	11,8	35,0	297	44,5	75,0	169
III	410	640	73	14,8	31,9	216	52,4	81,9	156
IV	490	780	67	16,9	34,8	206	62,4	86,8	139

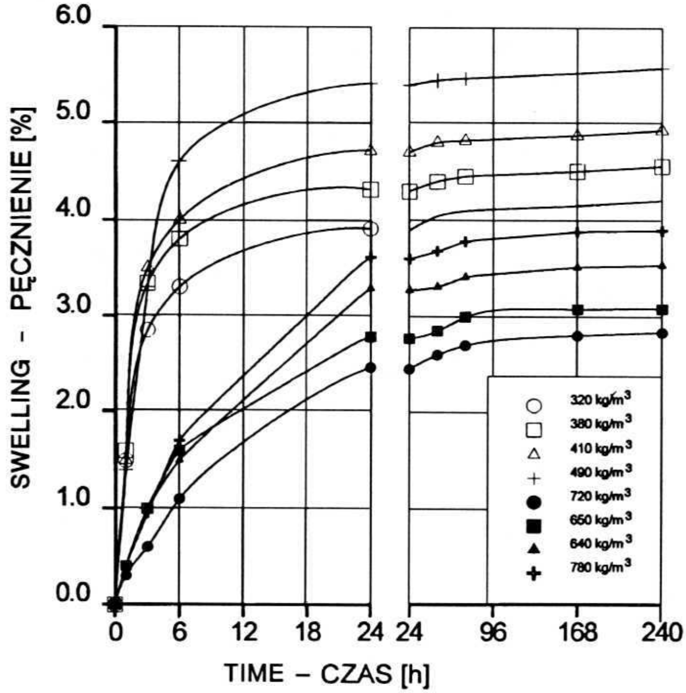


Fig. 7. Effect of wood density and polystyrene content upon swelling of composite made of cocos palm wood – polystyrene during soaking in water in temperature $20 \pm 2°C$

Ryc. 7. Wpływ gęstości drewna i zawartości polistyrenu na pęcznienie kompozytu drewno palmy kokosowej – polistyren podczas moczenia w wodzie o temperaturze $20 \pm 2°C$.

density of wood from which composite was made. Increase of dimensional stability of composite is informing on the permanent binding of polystyrene with wood substance and blocking of hydrophilic groups OH. It is worth of mentioning the fact, that the styrene is nonpolar liquid during wood impregnation, at moisture content $12 \pm 3\%$ enters also to the cell walls and did not cause changes of wood samples. Due to particular character of anatomical structure of cocos palm wood, dimensional stability has been tested only in one anatomical direction, namely across the grains.

4. CONCLUSIONS

On the base of carried out analysis of experiments could be drawn following conclusions:

1. Density of cocos palm wood in essential way influences its impregnability. Together with the drop of density increases polystyrene content in produced composite, which decides upon its density.

2. On the static bending strength of composite made of cocos palm wood-polystyrene decides composite density and content in it of polystyrene.

During tests of composite with $8 \pm 2\%$ moisture content about it static bending strength decides above all the wood density, namely with the increase of wood mass increases its strength. But on the composite in maximum saturation with water, about its strength decides content in it of polystyrene. In this case increase of polystyrene content increases its static bending strength.

3. On the composite made of cocos palm wood-polystyrene hardness, dominating effect has polystyrene content in composite, namely: the more polystyrene in composite, the higher its density.

4. Dimensional stability of is much higher the more in it of polystyrene. Composite made from cocos palm wood with the lowest density is characterized with the lowest dimensional stability.

5. Wood sampled from inside layers and top parts of cocos palm tree can be in distinct way valorized with the use of styrene, obtaining new composite predisposed for production of many goods and structures for fulfilling social demands.

Received in April 1994

REFERENCES

1. Frühwald A., Peek R., Schulte M.: Nutzung von Kokospalmenholz. Studie im Auftrag der Deutschen Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH Eschborn, Bundesrepublik Deutschland und des Badan Pengkajian dan Penerapan Teknologi, Republik Indonesien, Hamburg, Februar 1992.
2. Ławniczak M., Chovanec D., Supin M.: Information on cocos wood – polymer composite. Holz als Roh- und Werkstoff 51 (1993) 364.

WPŁYW GĘSTOŚCI DREWNA PALMY KOKOSOWEJ (*COCOS NUCIFERA* L.) NA JAKOŚĆ WYTWORZONEGO KOMPOZYTU DREWNO–POLISTYREN

Streszczenie

Celem pracy było określenie wpływu gęstości drewna palmy kokosowej (*Cocos nucifera* L.) na wybrane właściwości kompozytu drewno–polistyren.

Drewno przeznaczone do badań pochodziło z Uniwersytetu w Hamburgu. Z materiału dostarczonego w postaci graniaków o wilgotności $8 \pm 2\%$ wyrobiono dwie bliźniacze grupy próbek składające się z czterech grup gęstości podanych w tabeli 1.

Proces polimeryzacji monomeru styrenu przeprowadzono metodą termiczno-katalityczną, opracowaną w Katedrze Hydrotermicznej Obróbki i Modyfikacji Drewna AR w Poznaniu. W wyniku polimeryzacji styrenu w drewnie palmy kokosowej uzyskano kompozyt stanowiący materiał do dalszych badań.

Przyjętymi kryteriami oceny jakości wytworzonego kompozytu były: nasiąkliwość i pęcznienie w wodzie, wytrzymałość na zginanie statyczne przy wilgotności $8 \pm 2\%$ i w stanie maksymalnego nasycenia wodą oraz twardość wg Brinella.

Na podstawie przeprowadzonych doświadczeń i ich analizy można stwierdzić, że drewno palmy kokosowej, zwłaszcza o niższej gęstości, jest przydatne do modyfikacji. W wyniku badań stwierdzono, że gęstość drewna palmy kokosowej ma wpływ na ilość wprowadzonego do niego styrenu. Nie ma natomiast wpływu na gęstość uzyskanego z niego lignomeru.

Im wyższą zawartością polistyrenu odznaczało się drewno, tym pęcznienie i nasiąkliwość w wodzie kompozytu były mniejsze. Zawartość polistyrenu nie wpływała natomiast na wytrzymałość kompozytu na zginanie statyczne przy wilgotności $8 \pm 2\%$. Stwierdzono, że wzrost gęstości drewna palmy kokosowej powodował wzrost wytrzymałości kompozytu, a o wytrzymałości na zginanie statyczne w stanie maksymalnego nasycenia wodą decydowała zawartość polistyrenu w kompozycie. Wraz ze wzrostem zawartości polistyrenu zwiększała się również twardość kompozytu.

Na podstawie wyników badań można stwierdzić, iż drewno palmy kokosowej o niższej gęstości nadaje się do modyfikacji styrenem. Drewno to, pochodzące ze środkowych stref pnia, nie mające dotąd szerszego zastosowania może być poddane waloryzacji na drodze tworzenia kompozytu drewno–polimer, w celu poprawy jego gęstości i poszerzenia możliwości jego wykorzystania w praktyce.

Study made in the range of research N° F.1292.91.01. financed by Scientific Research Committee of Poland.

Authors adress:
Prof. dr hab. Maciej Ławniczak
Agricultural University
Wojska Polskiego 38/42
PL 60-637 Poznań