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Modified wood (lignomer) - - a promising material for shipbuilding

SUMMARY

Test results of the modified wood (lignomer) are presented with a view to its future application in shipbuilding industry. Influence of modification process of the wood on its strength, water absorbability, impact and fire resistance properties is highlighted.

INTRODUCTION

In recent years many composite structural materials, such as reinforced plastics or modified natural materials, are applied in machine industry. Their common feature is ageing mechanical properties as well as mechanical anisotropy in general.

Therefore, if the materials are intended to be applied for structural elements, knowledge of both their instantenous and time-dependent physical-mechanical properties is necessary.

In result of polymerization of the natural wood a new material is obtained of a higher strength and much lower anisotropy than those of the initial material. Wood-polystyrene composites are proved to be applicable wherever non-magnetic properties, high strength connected with lightweight and elasticity as well as easiness of machining and joining the elements, high damping and insulating properties in respect to noise, vibration and temperature, are required at moderate cost.

Wooden structural materials are suitable for the construction of small floating units. As far as the naval vessels (e.g. mine hunters, fast torpedo crafts) are concerned, the wooden units are still built (repaired or converted) by French, German and US shipyards [4,9,12,14]. Wood, the ideal structural material for mine hunters and patrol boats has been used since the invention of these ship types [9]. Also, non-magnetic properties of the wooden hulls improve operation of the electronic equipment installed onboard the ships.

Moreover, I and II- class wood materials from oak, beech, and pine trees are used in shipbuilding industry for ship outfit and production processes. Wood is used for ship accomodation outfitting, deck and hold planking, fenders for ships, shipyard quays and docks. In shipyards wood is also used for the dock keelblocks and keelblock pads which are wearable and have to be replaced periodically.

Chemically modified wood - lignomer

Valorization of wood properties can be effected by forming wood-polymer composite materials (called lignomers) [11]. Fast growing wood species : pine, birch, poplar, aspen and alder are used as the initial material [3]. The applied synthetic polymer not only eliminates inherent deficiences of wood but also improves its properties. The tests [10] confirmed that wood-polystyrene composites based on the above specified initial wood materials are suitable for the applications where stable dimensions and invariable shapes as well as machining precision are required.

Natural wood is an anisotropic material. The thermo-chemically treated wood exhibits lower anisotropy than the natural one. Different methods can be used to lower anisotropy of natural wood and obtain higher strength of the modified wood in the directions not complying with fibre direction [7,10].

The lignomer exhibits high increase of hardness especially in the tangent and radial directions in which hardness of the natural wood is very low (see Fig.1 acc.[10]).

The tests of lignomer fire resistance by means of Trux-Harisson's method [10] demonstrated that the lignomer can be assessed as a material of good fire resistance. For instance the flame temperature during burning the alder lignomer treated with AP-1 agent reached 300°C only, but when burning the alder wood it exceeded 800°C. Fire propagation speed over surface of the lignomer treated with AP-1 agent is about two times lower than that over the natural wood surface [10].

Some other mechanical properties of the lignomer are reported below mainly on the basis of the author's own investigations [5,6,7,8].

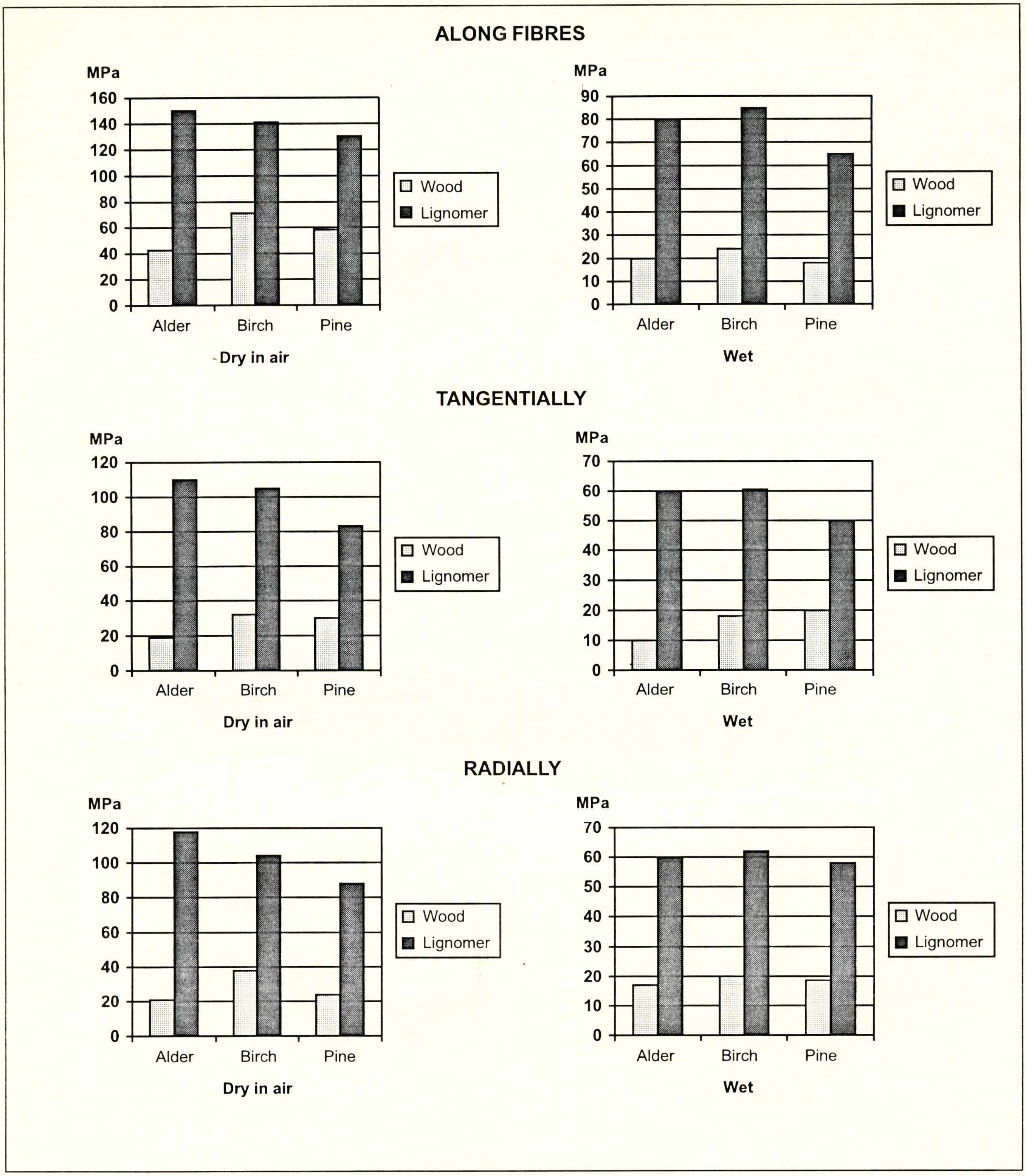

Fig. 1. Hardness of the natural and modified wood measured by using Brinell's method [10]

RESULTS OF RESEARCH ON SOME MECHANICAL PROPERTIES OF THE LIGNOMERS

Research on wood modification with a view to substitution of natural wood in shipbuilding was initiated by the Institute of Basic Problems of Machine Technology, Polish Naval Academy, Gdynia. A special test stand for saturation and polymerization of wood was built. An attempt was made to develop a wood surface saturation method to form strength (and other) properties of structural elements.

Ultimate strength

The specimens of 20 × 100 × 350 mm made of the modified pine wood tested under tensile load along fibres obtained the ultimate tensile strength R_m = 114 MPa (against to 85 MPa obtained for the natural wood).

During compression tests of the modified wood specimens of 20 × 20 × 20 mm the folowing values of the ultimate strength were obtained :

- crosswise to fibres : R_m = 115.7 MPa
- tangentially to fibres : $(R_{mt})_t$ = 41.2 MPa
- under 45° angle in respect to fibre direction in the plane a - t (see Fig.2) : $(R_m^{45})_{a-t}$= 48.5 MPa

(against to R_m= 76,7 Mpa, $(R_m)_t$= 6,5 MPa, $(R_m^{45})_{a-t}$ = 30,7 MPa obtained for the natural wood) [1].

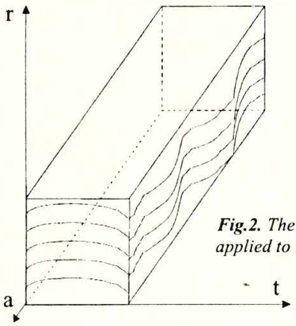

Fig.2. The co-ordinate system a, t, r applied to the ultimate strength tests

The results demonstrated that the modification increased the ultimate strength of wood and effectively lowered its anisotropy.

Tests were carried out to determine influence of methyl methacrylate (MMA) content in wood on its strength properties. The polimer content in the tested wood in function of saturation time is given in Tab.1.

Tab.1. Polymer content in pine wood in function of saturation time

Item no.	Item	Saturation time [h]			
		0.5	2.0	4.0	24.0
1	Polymer content in sap-wood [%]	35	43	48	56
2	Polymer content in heart-wood [%]	4.7	8	13.1	28

Ultimate tensile strength anisotropy of the modified pine wood is exemplified in Fig.3 separately for sap-and heart-wood, different content of monomer and saturation time periods : t = 0.5 h and 24 h.

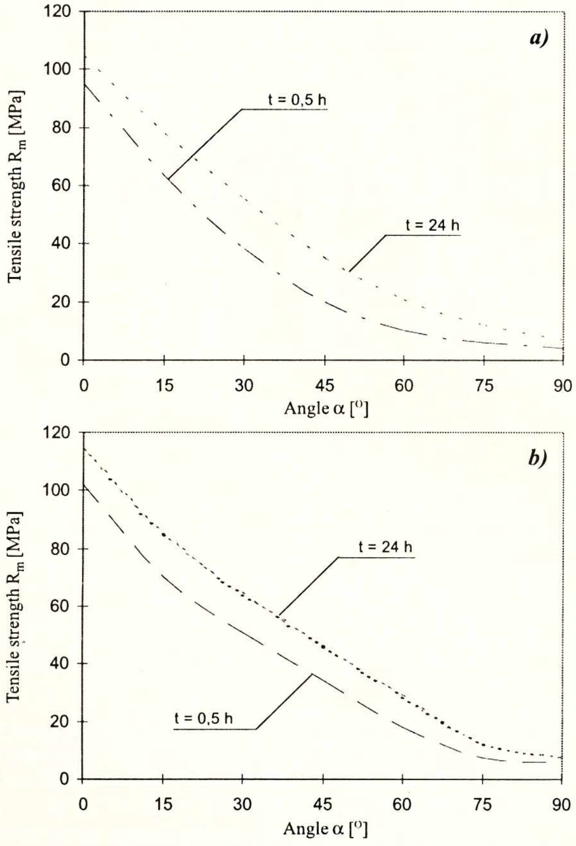

*Fig.3. The ultimate tensile strength R_m of the modified wood in function of the angle α contained between fibre and tensile load directions, at two different saturation time periods t = 0.5 h and 24 h : **a)** sap-wood specimens, **b)** heart wood specimens*

The lignomer specimens made of the alder and birch wood immersed in sea water at the depth of 3 m showed only a small drop of the ultimate tensile strength. Tests were carried out on the specimens of alder-wood lignomer with 80% polymer content (marked O3), and birch-wood lignomers of 76, 62 and 83% polymer content (marked B1,B2,B4 respectively). The specimens complying with PN-81/D-04107 standard underwent ultimate tensile strength and water absorbability tests after 10, 20, 30 and 40 days of wetting. Results of the ultimate tensile strength tests (each mean value calculated from test results of 5 specimens) are presented in Fig.4 [5].

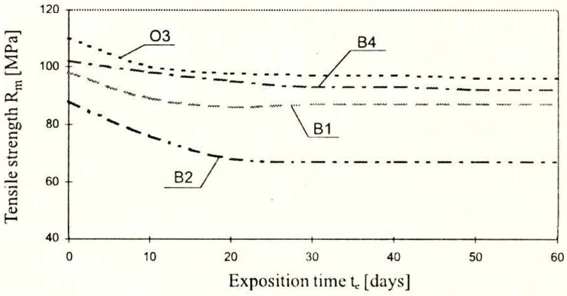

Fig.4. The ultimate tensile strength R_m of the modified wood after immersion in sea water in function of the exposition time t_e : O3 – alder-wood lignomer of 80% polymer content, B1, B2, B4 - birch-wood lignomers of 76, 62 and 83% polymer content, respectively

Water absorbability and hygroscopicity

It was demonstrated in other tests [10] that water absorbability of the modified wood materials is more than 5 times lower than that of natural wood. The author's test results of changing sea-water absorbability of the lignomers versus time are presented in Fig.5. The testing performance and specimen preparation was the same as the above described.

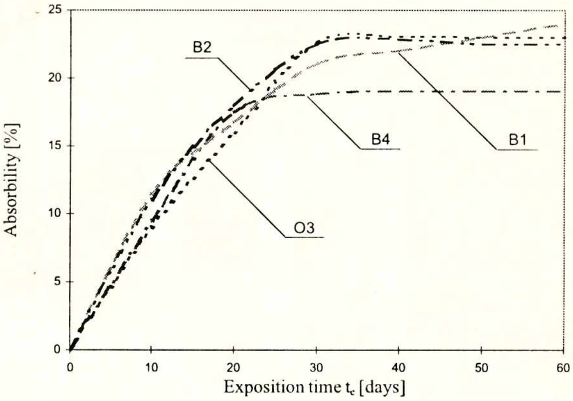

Fig.5. Sea-water absorbability of the lignomers versus the exposition time t_e : O3 – alder-wood lignomer, B1, B2, B4 – birch-wood lignomers of the diffrent polymer content values specified in the text

During the earlier tests [7] it was shown that absorbability of the lignomer after 20 days of immersion in sea water stabilized at 18÷20% level.

It was revealed from other tests [10] that hygroscopicity of the lignomers during moisturing in the air of 293 K temperature and about 94% wetness was lower by about 60% than that of the natural wood, and it stabilized within 12 to 15% range in the case of the alder-wood lignomer.

Water absorbability of the lignomer and its impact strength

Results of the impact strength tests of the polymerized pine wood after immersion in sea water, performed in low temperatures were presented in [6]. The tests were carried out on the 10 × 10 × 100 mm uniform specimens of modified pine wood after immersing them in sea water at 3 m depth, within cycles of 10, 30 and 60 days, I, II and III test cycle, and at the initial (dry condition) state, 0-test cycle.

At each of the test cycles the impact strength of the specimens at the temperatures of 293, 273, 263 and 243 K was tested. The strength was determined by applying impact of the hammer of a testing machine of 15 J energy, tangentially to the specimen fibre direction.

The diagrams of Fig.6 present the lignomer impact strength values related to the entire transverse cross-section area of the specimen, at constant temperature values in function of time, obtained from correlation equations of the specimen exposition time in sea water [6].

The tests were carried out within the annual mean air temperature range of 293÷243 K typical of the Baltic Sea area.

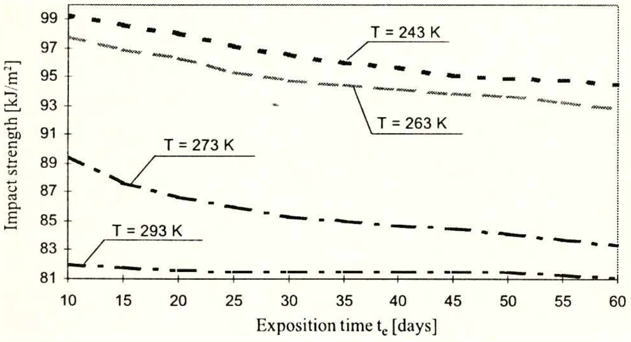

Fig.6. Lignomer impact strength in function of exposition time t_e in sea water, at constant temperature values

It can be observed from Fig.6 that the lignomer impact strength increases as the test temperature decreases, and it decreases along with increasing the water absorbability level. The highest impact strength was obtained for dry lignomer specimens tested at 243 K temperature.The lowest values were revealed by the specimens of the longest exposure to sea water and tested at the ambient temperature of 293 K.

Modulus of elasticity

The influence of the saturation time of pine wood with methyl methacrylate, both of its sap-and heart-wood parts, on values of the elasticity moduli at static bending in radial, tangent and diagonal directions, is presented in Fig.7 [7]. The tests were carried out under static bending load in compliance with PN-75/D-04123 standard on the specimens of 20 × 20 × 300 mm so cut from wood logs as to obtain specimens for determining the elasticity moduli characteristic for tangent, diagonal and radial directions (in the sense of the angles between wood fibre and load directions).

The tests revealed that the saturation process of heart-wood specimens was significantly slower and much lower saturation level was obtained than that of the sap-wood ones, in the same time period. Anisotropy of the wood strength properties decreases with growing saturation level – values of the elasticity moduli in radial and tangent directions become close to each other and significantly exceed relevant values of the natural wood, both of its sap-and heart-wood parts. Surface saturation process of the sap pine wood (started from an initial sub-pressure in the autoclave) proceeded very fast, especially during first two hours, on the contrary - the same process on the heart-wood ran slowly.

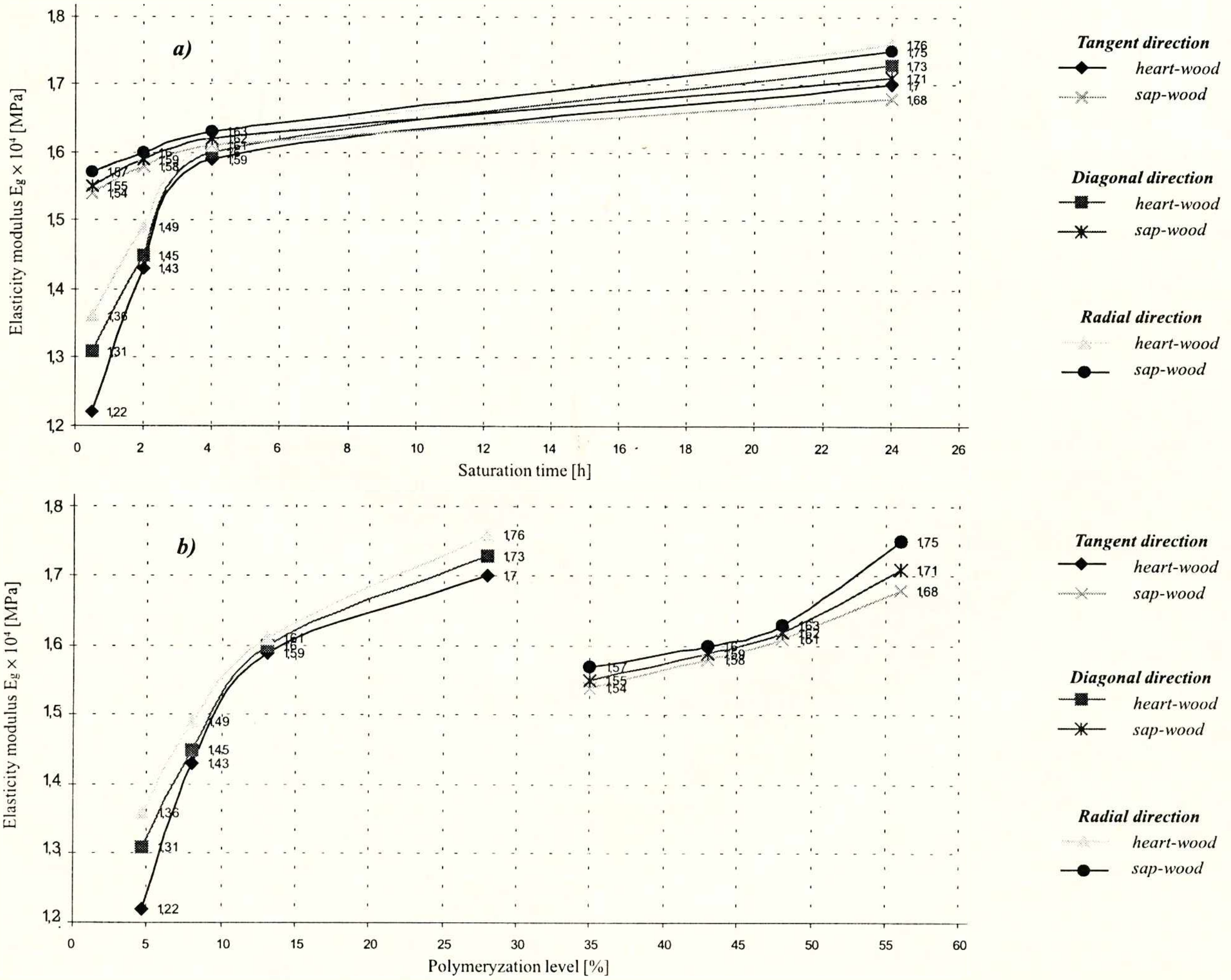

Fig.7. Elasticity moduli at static bending of the lignomer specimens (of pine wood polymerized by methyl methacrylate) in function of :
a) saturation time, b) polymerization level

***Note:** The polymerization level is defined as the weight of methyl methacrylate which remained within the wood after polymerization process, related to the initial weight of the wood and expressed in [%]*

FINAL REMARKS

- Much higher ultimate strength properties of the modified wood, its lower anisotropy and water absorbability, as well as higher impact strength justify undertaking further research on substitution of the natural wood by a modified one.

- The method of the surface wood saturation and polymerization, preliminarily investigated so far, could make it possible to form lignomer properties as well as to lower monomer consumption and production cost (up to 70%). (Materials of well-matched properties could be obtained for using to structural elements working e.g. under compressive, bending or wearing-off load).

- The promising results of the initial research on saturation and polymerization of the heart-wood indicate that continuing the research would be justified (especially that directed to forming the modified wood properties dependent on the monomer content).

Appraised by Henryk Zaradny, Assoc.Prof.,D.Sc.

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Mechanical Engineering Committee (KBM) of the Polish Academy of Sciences (PAN)
Utility Foundations Section (SPE)

E REGIONAL GROUP

Gdańsk - Gdynia - Koszalin - Olsztyn - Bydgoszcz - Elbląg

Committees of the Polish Academy of Sciences realize their statutory tasks in several sections focused on selected scientific areas. For instance, within the Mechanical Engineering Committee, acts the Utility Foundations Section, divided into Topic Teams dealing with tribology, machine diagnostics and exploitation. A concept of research regionalization by organizing the regional groups was proposed to integrate scientists connected with machine exploitation and to tighten co-operation between them and engineers. The groups are supposed to realize, each on its own territory, inter-disciplinary tasks arising in the activity area of the entire Utility Foundations Section. So far, such regional groups hawe been established in Kraków, Poznań, Wrocław, Łódź, Szczecin, and Silesia and the Baltic Coast (Pomerania) Districts.

The Pomerania Regional Group organized and headed at first by Prof. Jan Włodarski from Gdynia Maritime Academy, with Prof. Jan Czajgucki as its secretary, integrates activity of scientists from academic schools and research institutes of Gdańsk, Gdynia, Koszalin, Olsztyn, Bydgoszcz, and recently also of Elbląg.

These scientific centres are :

- Institute of Fluid - Flow Machinery, Polish Academy of Sciences, Gdańsk
- Technical University of Gdańsk
- Gdynia Maritime Academy
- Polish Naval Academy, Gdynia
- Technical University of Koszalin
- Olsztyn University of Agriculture and Technology
- University of Technology and Agriculture, Bydgoszcz
- The Higher School of Vocational Training, Elbląg.

In this way the Regional Group represents an important scientific and intellectual potential in the afore-mentioned areas of machine exploitation.

Aims of the Group are as follows :

- integration of the scientists activity
- exchange of scientific information
- development of junior scientific staff
- research co-operation with regional industrial centres.

The aims are realized mainly by means of special, seminars, alternately organized by the mentioned scientific centres, which serve well the aims and also exchange of experience gained by particular research teams. Apart from presentation of research results, such seminars offer opportunities of getting acquainted with local laboratory facilities and current research themes as well as arranging direct personal contacts which sometimes help in undertaking common research.

Helping in development of junior scientific staff is a specially important aim of the Group activities. Hence special seminars devoted to the problem were held in Olsztyn and Bydgoszcz, and so--called „Forum of Junior Scientists" was arranged at the University of Technology and Agriculture in Bydgoszcz where outstanding achievements of junior scientists from the particular centres were presented. These biennial presentations connected with critical but friendly assessment of the works made by more experienced scientists help young people in developing their qualification and preparation for gaining scientific degrees. The meetings are more and more popular among junior scientific workers.

However much organizational effort is still needed to encourage industrial circles to co-operate with the Regional Group and undertake the research themes interesting for the industry and connected with exploitation of the technical facilities. The seminars are a good opportunity of clarifying and solving such problems with benefit to both sides.