Also, the comparison study of different adhesive composition formulations, whether the study films were exposed to water or not, has shown that the best indexes of absorption capacity within the range from 3700 cm^{-1} to 2500 cm^{-1} in the regions with the presence of associated and non-associated (–OH) hydroxyl groups in the layers are referred to those specimens that are formed by PVAD-51P dispersion modified with 30% aqueous solutions of nitric acid (NHO_3) and Aluminium nitrate ($Al(NO_3)_3$). In practical terms this means it is precisely this kind of composition that is able of forming the most durable and water-resistant adhesive joints.

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Вплив води на структуру клейових плівок сформованих за допомогою композицій на основі ПВА дисперсій

Наведені результати досліджень впливу води на структуру полімерних плівок отриманих з модифікованих і немодифікованих клеїв на основі полівінілацетатної дисперсії марки ПВАД-51П. Зроблені висновки щодо можливостей використання ПВА клеїв модифікованих реактивом Фентона або кислотно-соляним комплексом в залежності від можливих умов експлуатації сформованих ними виробів.

Ключові слова:модифікуючі добавки, полівінілацетат, дисперсія, полівініловий спирт, спектрофотометр, ІЧ-спектроскопія, інтенсивність поглинання, пропускна здатність.

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OPTIMIZATION OF MOISTURE AND TEMPERATURE EFFECTS ON STRENGTH AND DURABILITY OF THERMOPLASTIC ADHESIVE WOOD JOINTS

Presented is optimization methodology, also a gradient method is proposed to estimate optimum values of atmospheric moisture and ambient temperature effects on strength and durability of thermoplastic adhesive wood joints. By means of the proposed gradient method and methodology as well as mathematical modeling stress-strain state of bonded wood joints, the optimization of atmospheric moisture and ambient temperature influence on strength and durability of thermoplastic adhesive wood joints under operating conditions has been carried out. Optimum values for atmospheric

moisture content and ambient temperature have been established for operation of thermoplastic polyvynilacetate-based adhesive wood joints.
Keywords: thermoplastic polyvynilacetate glues, glue connection, mathematical model, optimization, durability, longevity.

Thermoplastic polyvynilacetate-based adhesives are widely used for bonding wood parts in fabricating millwork and structural members, furniture items, parquet work and furniture panels as these types of adhesive have good gluing properties concerning wood and wood-based material, they form non-dense netted and elastic glue line which is environmentally safe and easier to make bonding. Wood joints obtained by means of such adhesive can take loads of D3-D4 degrees according to the European standard EN DIN 204. In Ukraine, thermoplastic polyvynilacetate-based adhesive with D3-D4 degrees of load came into use for gluing wood and wood-based material comparatively not long ago. It should be noted, however, that the level of their usage, both in Ukraine and abroad, is rapidly rising and, as of today, is equal to 25 % of the total amount of adhesives used for glueing wood and wood-based material. That is why the studies and prediction of strength and durability of thermoplastic polyvynilacetate-based adhesive wood joints are of importance today.

The author of the article has proposed mathematical models for prediction (1) strength and (2) durability of thermoplastic adhesive wood joints depending on atmospheric moisture and ambient temperature [1, 2, 3]

$$\sigma = -A^{(i)}\Delta T^{(i)} + B^{(i)}\Delta W^{(i)} \exp(-\alpha^{(i)}\tau^{(i)}); \tag{1}$$

$$\tau^{(i)} = \frac{1}{C^{(i)}} \cdot \ln\left(\frac{B^{(i)} \cdot \Delta W^{(i)}}{\sigma_{гран.} + A^{(i)} \cdot \Delta T^{(i)}}\right), \tag{2}$$

where: $\Delta T^{(i)}$ – the average ambient temperature, ^{o}C; $\Delta W^{(i)}$ – the average atmospheric moisture, %; $\sigma_{гран.\ (boundary)}$ – the boundary strength of wood joint; the parameters $A^{(i)}$, $B^{(i)}$, $C^{(i)}$ are dependent on the temperature and moisture variation.

In order to construct the mathematical model, methods of mathematical modeling heat-and-mass transfer, the results of studies on physical-and-mechanical characteristics of thermoplastic polyvynilacetate glue film were applied. Performed was modeling the process of moisture transfer in wood as a basic structural material of adhesive joints, which is dependent on cyclic effect of atmospheric moisture. Moisture content change in glued wood was mathematically described for varying and harmonic conditions of the environment, also it was established that such changes depend on the specimen geometry, thermal-and-physical properties of the wood as well as the atmospheric moisture and ambient temperature [4, 5].

The proposed model provides means of predicting strength and durability of thermoplastic adhesive wood joints taking into account the cyclic effect of atmospheric moisture and ambient temperature irrespective of the adhesive type used and trade mark of the producer and regardless of the specific temporal rate and the particular moisture-temperature environmental conditions [6, 7, 8]. Also, the prediction of strength and durability of thermoplastic adhesive wood joints by means of mathematical modeling makes it possible to identify the change in strength or durability for thermoplastic adhesive wood joints during the service time, but it does not allow for determining optimum parameter values of operational conditions of glued wood joints.

Therefore, in order to determine the optimum effect of atmospheric moisture and ambient temperature on strength and durability by means of mathematical modeling, optimization of the temperature and moisture effects on strength and durability of thermoplastic adhesive wood joints under operating conditions has been performed.

A gradient method was applied to solve the task in hand [9, 10].

It is a difficult task to perform optimization of the temperature and moisture influence on strength and durability of thermoplastic adhesive wood joints as it is difficult to describe moisture and temperature measuring of the environment in various regions.

That is why the optimization was performed according to the results of the obtained mathematical model and prolonged experimental studies.

$$\sigma_{op} = -A_1^{(i)}\Delta T^{(i)} + B_1^{(i)}\Delta W^{(i)} \exp(-C_1^{(i)}\tau^{(i)}); \quad (3)$$

where: $A_1^{(i)} = \alpha_1 \exp(-\beta_1\tau^{(i)}) + \gamma_1$; $B_1^{(i)} = \alpha_2 \exp(-\beta_2\tau^{(i)}) + \gamma_2$; $C_1^{(i)} = \alpha_3 \exp(-\beta_3\tau^{(i)}) + \gamma_3$;

The objective function $R = \sum_{k=0}^{\tau(i}\left(\sigma_{op}^{(k)} - \sigma^{(k)}\right)^2 \rightarrow \min;$ (4)

where $k = (\tau_{поч.}^{(i)} - \tau_{кін.}^{(i)})$

The following restrictions are imposed: The strength at the beginning of each $\Delta\tau^i$ – time interval is to be higher than the final one in this time interval.

$$\sigma_{op} = (\alpha_{k^*}^{(i)}, \beta_{k^*}^{(i)}, \gamma_{k^*}^{(i)} \geq \sigma^{(i)}), k^* = 1,2,3; \quad (5)$$

At each next moment, the strength is not to be higher than the set boundary strength in the previous interval $\sigma_{op} = (\alpha_{k^*}^{(i)}, \beta_{k^*}^{(i)}, \gamma_{k^*}^{(i)} \geq \sigma^{(i-1)}, k^n = 1,2,3.$ (6)

The task is solved by gradient method for the time interval $\tau_{поч.}^{(i)} \leq \tau \leq \tau_{кін.}^{(i)}$ for each i-set.

The realization of optimization task involves:

- a choice of initial parameter values of the optimization $R(\alpha_k, \beta_k, \gamma_k)$, which corresponds to the value $A_1^{(i)}, B_1^{(i)}, C_1^{(i)};$ at the initial instant $\tau^{(i)}$, obtained by the mathematical model;
- determination of components $\frac{\partial R}{\partial \alpha_k}; \frac{\partial R}{\partial \beta_k}; \frac{\partial R}{\partial \gamma_k}$ of gradient vector of function $R(\alpha_k, \beta_k, \gamma_k)$;
- computing the values $R(\alpha_k, \beta_k, \gamma_k)$ and the components of gradient vector of $R(\alpha_k, \beta_k, \gamma_k)$ for initial values;
- set parameter λ to find descending pitch to the optimum of function $R(\alpha_k, \beta_k, \gamma_k)$;
- realization of locating algorithm α_k, β_k, γ_k $R(\alpha_k, \beta_k, \gamma_k)$ in the iteration process

$$R^{(j)}(\alpha_k, \beta_k, \gamma_k) = R^{(j-1)}(\alpha_k, \beta_k, \gamma_k) + \lambda \cdot \text{grad}\, R^{(j-1)}(\alpha_k, \beta_k, \gamma_k), \quad (7)$$

where (j) is the initial number of the iteration:

- determination of components of vector $R(\alpha_k, \beta_k, \gamma_k)$ at the previous points of the iteration process.

In order to calculate partial derivatives in each j-iteration, approximation relation are employed:

$$\frac{\partial R}{\partial x_k} \approx \frac{\Delta R}{\Delta x_i} = \frac{R(x_i + \Delta x_i, y_1, \ldots y_m) - R(x_1, \ldots, x_n, y_1, \ldots y_m)}{\Delta x_i} \quad (8)$$

$$\frac{\partial R}{\partial y_k} \approx \frac{\Delta R}{\Delta y_i} = \frac{R(x_i + \Delta x_i, y_1, \ldots y_m) - R(x_1, \ldots, x_n, y_1, \ldots y_m)}{\Delta y_i} \quad (9)$$

In the gradient method, the absolute value of parameter λ is set arbitrary and is constant for all k-iterations. However, with decrease in values |λ| the accuracy of the problem solution is higher, and number k is high.

The sigh of value λ is determined by the character of the unknown extreme value of function $R(\alpha_k, \beta_k, \gamma_k)$ / To calculate max $R(\alpha_k, \beta_k, \gamma_k)$ a positive number λ is taken, while to find min $R(\alpha_k, \beta_k, \gamma_k)$ – negative number.

An expression for finding vector grad $R(\alpha_k, \beta_k, \gamma_k)$ can be written as follows

$$\frac{\partial R}{\partial \alpha_k} = 2\sum_{k=0}^{\tau(i)} (\sigma_{op}^{(k)} - \sigma^{(k)}) \exp(-\beta_1 \tau^{(i)}); \quad \frac{\partial R}{\partial \beta_k} = 2\sum_{k=0}^{\tau(i)} (\sigma_{op}^{(k)} - \sigma^{(k)})(-\tau^{(i)}) \exp(-\beta_k \tau^{(i)}); \quad \frac{\partial R}{\partial j_k} = 2\sum_{k=0}^{\tau(i)} (\sigma_{op}^{(k)} - \sigma^{(k)}).$$

Thus, the algorithm of the optimization of temperature-moisture influence on strength and durability of thermoplastic adhesive wood joints has been constructed based on gradient method.

Optimum values of atmospheric moisture content and ambient temperature, at which thermoplastic adhesive wood joints will have the highest durability, have been calculated, a diagram of the moisture content and temperature effects on thermoplastic adhesive wood joints has been constructed.

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УДК 674.028.9.004.15:519.216.3 ***Доц. Б.Я. Кшивецький, д-р техн. наук – НЛТУ України***

Оптимізація впливу вологості і температури на міцність і довговічність термопластичних клейових з'єднань деревини

Наведено методику оптимізаційної задачі та запропоновано градієнтний метод для розрахунку оптимальних показників впливу вологості та температури навколишнього середовища на міцність і довговічність термопластичних клейових з'єднань. За допомогою запропонованого методу і методики та математичного моделювання напружено-деформаційного стану з'єднань деревини, здійснено оптимізацію впливу вологості і температури навколишнього середовища на міцності та довговічність термопластичних клейових з'єднань деревини під час експлуатації. Встановлено оптимальну вологість і температуру навколишнього середовища для експлуатації термопластичних полівінілацетатних клейових з'єднань деревини.

Ключові слова: термопластичні полівінілацетатні клеї, клейове з'єднання, математична модель, оптимізація, міцність, довговічність.

UDC 674.620.168 ***Master's degree S.B. Pobereyko; assoc. prof. O.M. Petriv; prof. B.P. Pobereyko − UNFU***

DEVELOPING SOFTWARE FOR MODELLING THE STRENGTH OF BIAXIALLY STRESSED WOOD

An algorithm and the software for modelling the strength of biaxially stressed composite materials have been developed.

Keywords: algorithm, strength criterion.

Introduction. An important problem when rationalizing the selection of the criterion for the short-term strength of wood is constructing the curves of the short-term strength of biaxially stressed material according to the given strength criteria for the purpose of their verification in the particular case. Nowadays, for composite anisotropic materials, the class of which includes wood, there are more than 10 criteria of strength, namely those of R. Mises, A. K. Malmeister, K. V. Zakharov, Goldenblatt-Kopnov, E. K. Ashkenazi etc. However, the main criterion tested on wood is Ashkenazi's criterion, which does not fully reflect the strength peculiarities of materials under combined stress. According to the data in [1], this criterion adequately describes mainly the limit stress state of hardwood. It cannot be employed to define the strength of softwood.

The problem is therefore relevant. One way of solving it is analyzing the curves of strength constructed for each of the abovementioned criteria from such viewpoints: a) the strength surface in case of the combined stress state of the composite material, namely wood, in stress space should be gradual, closed, smooth and convex; b) the correlations between the strength characteristics of the composite material should satisfy the so-called Goldenblatt-Kopnov's heuristic principle according to which, if at least one constant of the material changes, the new surface of strength should be located inside or outside the initial one.

These are the crucial conditions for the verification of the existing strength criteria. If during the adaptation of some of the criteria at least one of these conditions is not satisfied, then such a criterion is unreliable and deserves no further attention.