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Improving of Adhesive Bonding Tecnology of Solid Timber for Wooden Housing Construction in Conditions of Siberian Region

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Abstract: Wooden housing construction nowadays is becoming more popular because of using a renewable source of raw material it is wood creating a favorable atmosphere indoors, having a pleasant by touch surface and what is the most important it is an eco-pure material. For construction of wooden houses in Siberia as a rule, glued solid timber is used-CLT-panels, BSP, X-lam, glued wall beam. Sufficient heat and frost resistance of glued panels are provided by adhesives of polycondensation and polymerization types: C3, D3, C4, D4 according to EN 204. Glued wooden constructions must meet the requirements of State Standard (SS) 20850-2014 "Wooden glued bearing constructions" based on the standard EN 14080:2005. According to these standards the following adhesives are approved for using: Resorcinol Formaldehyde (RF), Melamine-Urea-Formaldehyde (MUF, MF); Polyurethane (PUR), Emulsion of Polymer-Isocyanate (EPI). In accordance with the current Russian standards polyurethane PUR adhesives are not approved for producing of wooden glued structures even in low-rise housing construction for walling and in Europe the production of polymer-isocyanate emulsion EPI is not approved. Resorcine-formaldehyde glue systems are used today very rare. RF forms a black color glue seam which is resistant to chemicals, aggressive compounds. To provide colorless glue seam, PUR adhesives, MUF, MF-adhesives may be used but they are quite expensive. Polyvinyl Acetates (PAE) as well as Urea-Formaldehyde adhesives (UF) are widely available, relatively cheap but they are not approved for producing of glued wooden structures of any responsibility classes and structure types. The ban is explained by the very nature of this chemical compound and its inability to bear the long-lasting static load. Therefore, the search of modifiers for cheap glue compositions is relevant and timely; they provide the necessary indicators of the strength characteristics and heat-water and frost-resistance.

Key words: Slats, adhesives, modification, durability, heat resistance, frost resistance, water resistance

INTRODUCTION

To ensure the requirements for heat-frost and water resistance as a modifier of the adhesive compound hydrolytic lignin was proposed it is a solid remainder of wood hydrolysis saturated with an acid its amount is counted by not hundreds and thousands but millions tons (at present >2 million tons of lignin have been accumulated in Krasnoyarsk Region and about the same amount of it on the territory of Zima hydrolysis plant in Irkutsk Region). A significant part of lignin is not used and taken out to the dump, so the large land areas are filled by lignin, roadside area, air and land adjacent to the landfills are polluted, long-term storage of lignin ignites spontaneously (Plotnikov *et al.*, 2014). All mentioned above is a cause of significant economic and ecological damage to the environment.

Hydrolytic lignin is an amorphous powdery substance its density is 1.25-1.45 g/cm^3 its color is from light cream to dark brown and it has a specific smell, molecular weight is 5000-10 000, the size of lignin particles from several millimeters to microns (or less). Lignin exhibits plastic properties at high pressure and temperature, especially when it is damp. Having properties of phenol and resorcinol lignin, under certain conditions is able to modify the adhesives improving their chemical and weather resistance (Plotnikova *et al.*, 2013).

Lignin is prone to the reactions of chain cross linking which are called the reactions "condensation" in the lignin chemistry, moreover these reactions proceed both in the acid and in alkaline medium.

The condensation reactions are accompanied by the formation of new carbon-carbon bonds as a result the chemical structure of lignin macromolecules has greatly changed and the molecular weight has increased (Plotnikov *et al.*, 2012). Being the potentially valuable modifier (lignin compound contains methoxyl (-OCH 3), hydroxyl (-OH) as phenolic as aliphatic (alcohol) groups,

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carbonyl (C = O) and quinone groups being formed in the process of oxidation, carboxyl groups (-COOH) and lignin is quite inert. Therefore, the search of lignin "activators" is also a relevant and important task.

The research purpose is an improving of adhesive bonding technology of solid timber for wooden housing construction in conditions of Siberia by means of cost reducing of glued wooden structures without reducing of the quality by adhesive modification.

MATERIALS AND METHODS

An active experiment has been adopted to obtain the description of manufacturing process of Wooden Glued Designs (WGD) (Plotnikova *et al*., 2015). The mode of WGD manufacturing and the key indicators of properties are the function of positive reaction of the model. Output values have been taken as quality indicators of the output:

- Y 1: WGD strength limit at chopping on the adhesive layer (τ), MPa SS 15613.1
- Y 2: WGD frost resistance, % SS 18446
- Y 3: WGD heat resistance, % SS 18446
- Y 4: WGD separation, % SS 27812-2005
- Basic part

Different ways of hydrolytic lignin "activation" for urea-formaldehyde adhesive were tested:

- Polyvinyl-Acetate Emulsion (PAE)
- Urea Solution 40% (US)

For PAE:

- Ultra-High Frequency currents (OHF)
- Thermal activation at t = 100°C
- Urea Solution 40% (US)

RESULTS AND DISCUSSION

The main characteristic of adhesive bonding quality which must constantly be recorded in the manufacturing control process is the bonding strength at chopping on the adhesive layer.

The histogram of the dependence of solid timber slat chopping on the adhesive layer and heat-/frost resistance indicators on the kind of a modifier is presented in Fig. 1.

Analyzing the histogram, it should be made a conclusion about the polyvinyl acetate and urea solution 40% "activation" expedience of hydrolytic lignin. Tests of chopping on the adhesive layer show sufficient frost/heat resistance.

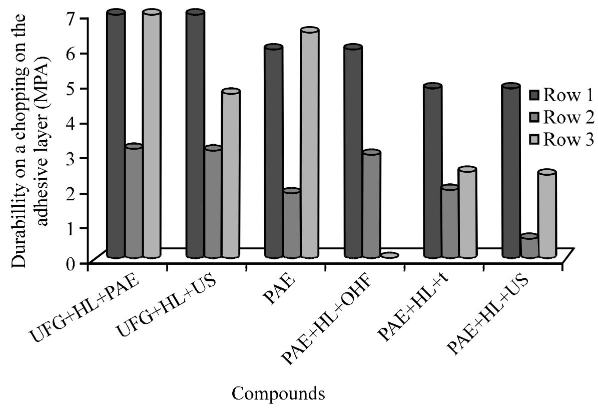

Fig. 1: The dependence of solid timber slat chopping on the adhesive layer and heat/frost resistance indicators on the kind of a modifier; Row 1: tests of chopping on the adhesive layer; Row 2: tests of chopping on the adhesive layer after determinating of heat resistance; Row 3: tests of chopping on the adhesive layer after determinating of frost resistance

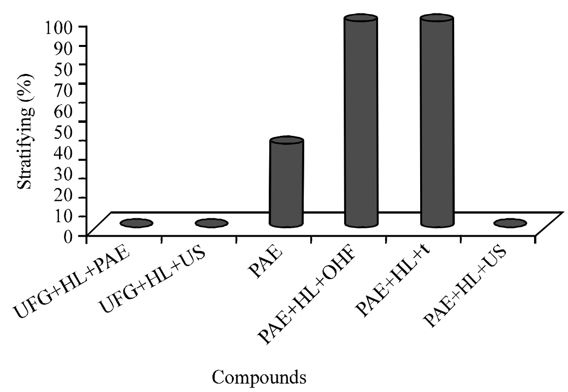

Fig. 2: The histogram of the dependence of glued solid timber slat separation after the cyclic tests (ret-drying)

Urea-effective "activator" of lignin on the chemical level: active hydrogen of the amide NH_2 group of urea interacts with hydroxyl OH groups (aliphatic, aromatic) and carboxyl COOH lignin groups with the formation of methylol reactive groups (Plotnikov and Plotnikova, 2013).

The histogram of the dependence of glued solid timber slat separation after the cyclic tests (ret-drying) is presented in Fig. 2. In Russia separation tests are performed in accordance with SS 27812 which corresponds to EN391 "glued solid. Tests of glue seams on separation". The method provides intensive moisture

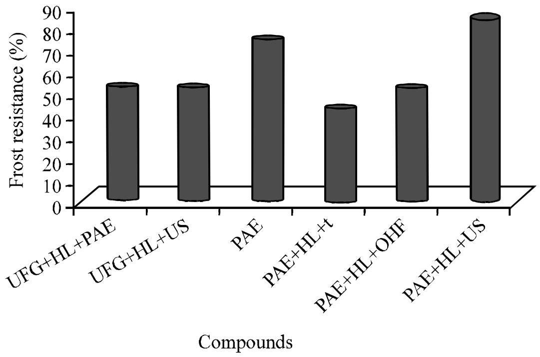

Fig. 3: The histogram of the dependence of glued solid timber slat frost resistance on a modifier

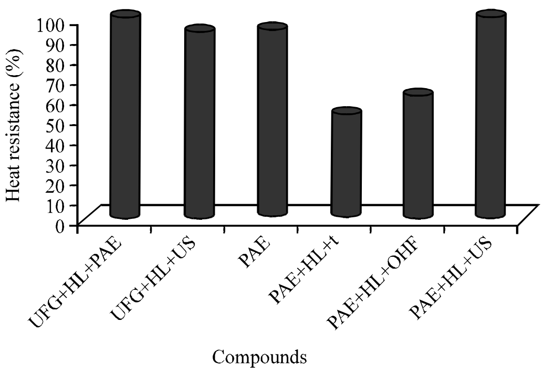

Fig. 4: The histogram of dependence of glued solid timber slat heat resistance on a modifier

of a multilayer element face cuts and their intensive drying to the original weight. Analyzing the histogram it should be concluded that the cyclic tests on separation are contrasted to the samples of the following compound:

- UF+HL, activated PAE
- UF+HL, activated by Urea Solution 40% (US)
- PAE+HL, activated by Urea Solution 40% (US)

The histogram of the dependence of glued solid timber slat frost resistance on a modifier is presented in Fig. 3.

Analyzing the histogram it should be concluded that curing adhesives, in particular, polymer of vinyl acetate have the highest frost resistance (tests of chopping after sustaining at t = -40 C and humidity 65% for 2 weeks) but at the same time the lignin raw material PAE activated by urea has higher frost resistance indicator.

The histogram of the dependence of glued solid timber slat heat resistance (tests of chopping after sustaining at t = +60 C and humidity 65% for 2 weeks) on a modifier is presented in Fig. 4.

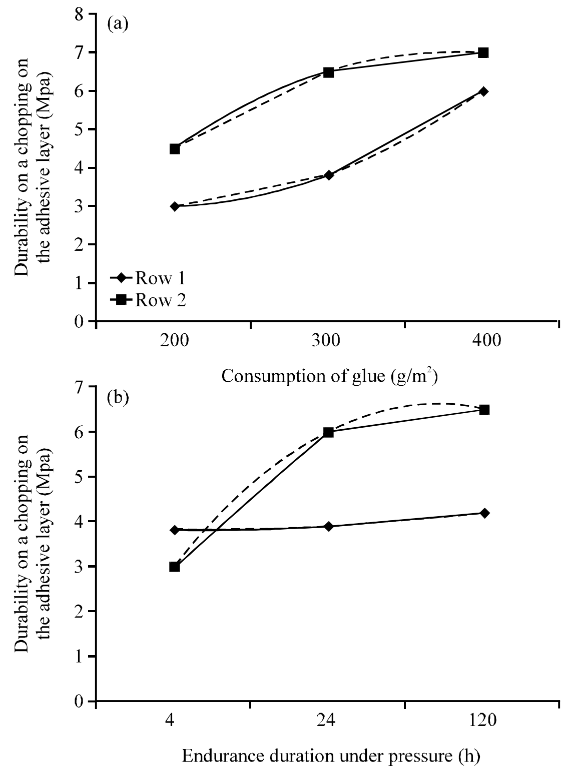

Fig. 5: a) The dependence of durability at chopping on the adhesive layer WGD on a consumption of an adhesive and b) duration of sustaining under pressure; Row 1: PAE+HL, activated Urea Solution 40% (US); Row 2: UF+HL, activated Urea Solution 40% (US)

Analyzing the histogram it should be concluded that the following adhesive compounds have the highest heat resistance-100%:

- UF, modified HL, activated PAE
- PAE, modified HL, activated with a Solution of Urea (US)

The dependence of durability at chopping on the adhesive layer WGD on a consumption of an adhesive (a) and duration of sustaining under pressure in a cold press (b) is presented in Fig. 5.

The dependence of frost resistance of adhesive bonding WGD on a consumption of an adhesive (a) and duration of sustaining under pressure (b) is presented in Fig. 6.

The dependence of heat resistance of adhesive bonding WGD on a consumption of an adhesive (a) and duration of sustaining under pressure (b) is presented in Fig. 7.

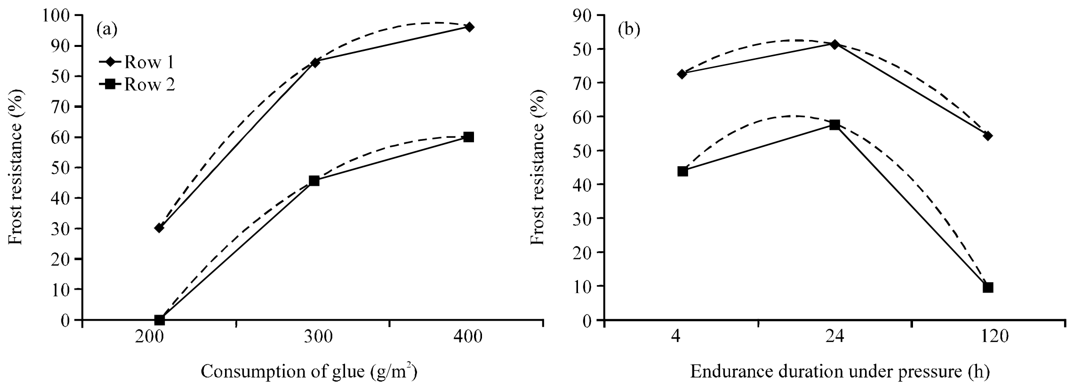

Fig. 6: a) The dependence of frost resistance of adhesive bonding WGD on a consumption of an adhesive and b) duration of sustaining under pressure; Row 1: PAE+HL, activated Urea Solution 40% (US); Row 2: UF+HL, activated Urea Solution 40% (US)

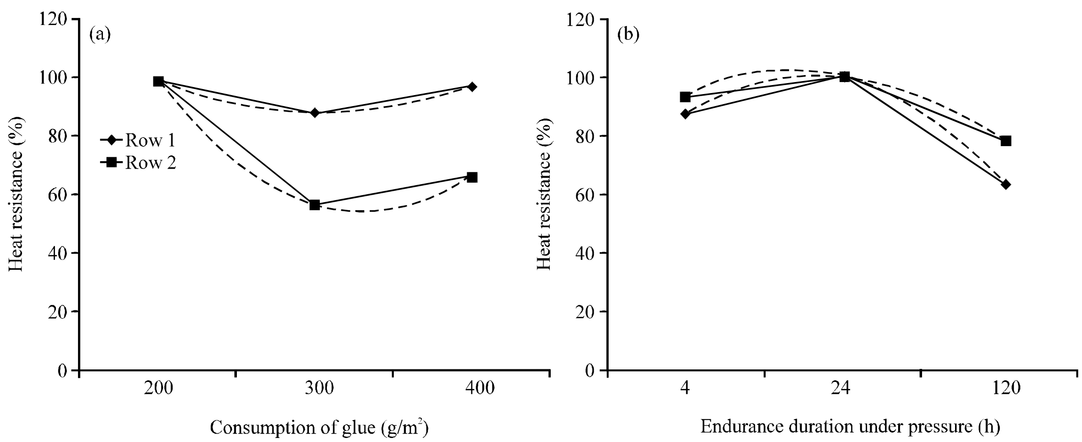

Fig. 7: a) The dependence of heat resistance of adhesive bonding WGD on a consumption of an adhesive and b) duration of sustaining under pressure; Row 1: PAE+HL, activated Urea Solution 40% (US); Row 2: UF+HL, activated Urea Solution 40% (US)

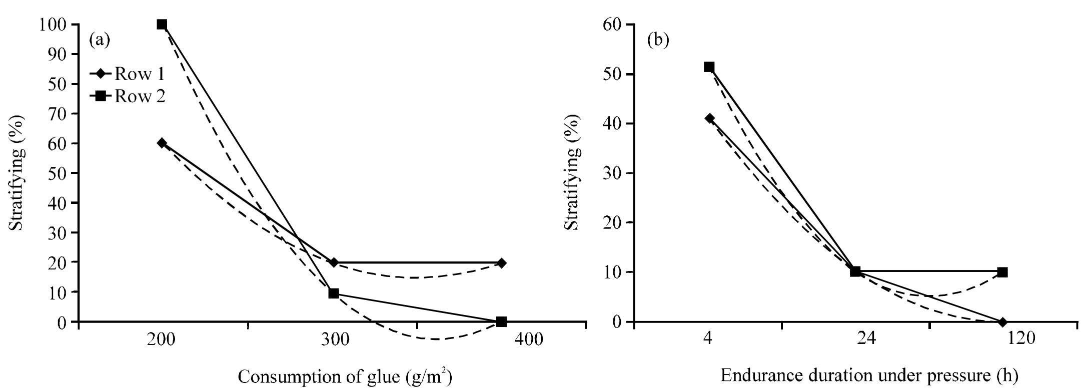

Fig. 8: a) The dependence of separation of adhesive bonding WGD on a consumption of an adhesive and b) duration of sustaining under pressure; Row 1: PAE+HL, activated Urea Solution 40% (US); Row 2: UF+HL, activated Urea Solution 40% (US)

The dependence of separation of adhesive bonding WGD on a consumption of an adhesive (a) and duration of sustaining under pressure (b) is presented in Fig. 8. Analyzing the obtained dependences it should be concluded that the following adhesive systems have the best durability, frost, heat, separation resistance indicators: PAE, modified HL, activated Urea Solution 40% (US). Modified PAE does not lose its durability during long cyclic loading at a flow rate of 300-400 g/m^2 and the duration of sustaining under pressure of adhesive bonding not less than a day.

SUMMARY

The basic theoretical premises about higher cohesive durability of a system containing the groups with high energy of interaction, found in HL (-OH, -COOH) have been confirmed by the result of experimental studies. The presence of groups with high energy of interaction in lignin increases the cohesive durability of the system and increases weather resistance of the adhesive bonding WGD at the chemical level.

On the base of the integrated assessment of the impact of controllable factors on the quality indicators WGD, the following recommendations have been formulated:

- It is possible to use PAE-systems, modified hydrolytic lignin HL, activated Urea Solution 40% (US) for producing of WGD
- The consumption of an adhesive compound must be 300-400 g/m^2
- The duration of sustaining under pressure in a cold press when bonding should be not less than a day

CONCLUSION

In accordance with the made researches it should be concluded:

- The possibility in the production of WGD to use PAE under the condition of its modification with the help of substances containing the groups with high energy of interaction such as phenolic hydroxyl, carboxyl has been shown
- The adhesive system allows to recycle the waste of timber-chemical complex and to increase ecological safety of Siberian territory to reduce their fire risk

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