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# Bonding quality of wood with selected reinforcing materials

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**Abstract:** *Bonding quality of wood with selected reinforcing materials*. The paper presents an analysis of the psychical and mechanical parameters of adhesive joints, important for connecting layers: wood - glue line - material with high bending strength. The hardness of selected types of cured resins was investigated. Only epoxy and polyester glue line was stiff enough to obtain conclusive results of Brinell hardness. Also contact angle and surface energy caused by adhesives was tested. On the basis of study it was concluded that epoxy and trial polyurethane adhesives are the most suitable adhesives that may be used to join timber and reinforcement materials.

*Keywords*: adhesive, Brinell hardness, contact angle, surface energy

## INTRODUCTION

The quality of gluing is dependent on variable factors. It is influenced by both the chemical parameters and adhesive strength, as well as the components intended to be joined. In addition, bonding conditions and surface preparation are important. A very wide range of bonding applications forces finding the optimum conditions for this process, as well as identifying the factors significantly affecting the strength of adhesive joints. Structural and technological factors are included [Cagle 1977].

Considering the fact, that the bonding quality is the primary factor influencing safety, it is subjected to control. Adhesive bond can be evaluated visually (presence of air bubbles, the degree of filling of the space allocated to glue, glue line thickness), as well as basing on its physical and chemical properties. It is also possible to carry out strength tests, providing direct knowledge about the quality of the connection.

The aim of study was to evaluate the properties of glue that allows finding a correlation between the chemical structure and the properties of the adhesive and its physical and mechanical properties in the scope of its suitability for bonding layers of composite materials. Bonding technology creates new possibilities for joining, allowing reduction of the dimensions of the parts to be joined, by simplifying their design. It allows reduction of the maintenance costs, which is especially important in the case of repair and reinforcement of timber structures.

## METHODS AND MATERIALS

Research methodology includes determination of physical and mechanical properties of adhesives, in aim of selection of adhesive with the most appropriate parameters characterizing the binder of composite material. Properties of the composite material, composed of pine wood - glue joint - reinforcing material, should be relevant to the repair engineering procedures. Adhesive joint, which is a layer responsible for handling the stresses from reinforced to reinforcement material, is a key element, providing the strength of the whole system. This is due to the fact that decisive influence on the strength of the composite has the weakest link in the chain.

The study analyzed adhesives that meet the initial criteria for good adhesion to wood and other tested materials, working as a reinforcement (natural materials - strip of bamboo, synthetic materials - fiber reinforced polymers). The study involved six kinds of glue, which the general characteristics are given in table 1.

**Table 1**. General characteristics of the adhesives

| Type of adhesive | Product name | Properties |
|---|---|---|
| Acryl | SikaFast-5221 | fast curing, flexible, two component structural adhesive, curing by polymerization |
| Polyester | Sika anchorfix | fast curing anchoring adhesive, two component, solvent-free |
| Polyurethane | Novol gravit 630 | sealing compound, single component, curing by reaction with moisture in the air, elastic coating, does not chip or crack, resistant to water, low resistant to UV |
| | Inter Troton | one component sealing compound, hardening under the influence of moisture in the air. |
| | Chemolan B v. 45 | waterproof, single component polyurethane, moisture-curing |
| | Ekoprodur MZ2/A | test polyurethane system, not contain organic solvents, no shrinkage after hardening |
| Polymer | Titebond III | one component, waterproof wood glue, extended curing time |
| Epoxy | Havel adhesive G60 | two component, universal |
| Neoprene | Adesivo neoprenico meccanocar | fast curing, flexible, for bonding rubber, sponge, leather, etc. |

The cured adhesives are characterized in terms of Brinell hardness and interaction with water (contact angle and surface energy).

Brinell hardness was determined on the basis of the recommendations of the PN-EN 1534. The denting force of 1kN was applied through the 25s time using hardness testing machine. Ball diameter, which was pressed into the material, was 10mm. For each type of glue, six measurements were made.

In addition, a contact angle and surface energy measurements were made, using the Phoenix 300 apparatus. Surface energy determinates the strength of bonding electrons in the atoms of the material surface, namely the potential of electrons to interact with the adjacent atoms of material surface. Surfaces with a high surface energy values are usually polar. Liquids wetting only the areas where the surface energy is greater than the surface energy of the liquid.

The contact angle was determined using a static method, by measuring the geometry of the drop after reaching its dimensional stability. The measurements were carried out 30 seconds after application of drops. Surface energy was determined 5 seconds after application of the drop. This was due to the use of substances Diiodomethane of Sigma-Aldrich concern, which quickly blurred. It is important that the drop was applied from the smallest height, in order to avoid spillage of drops. Otherwise it is impossible to measure the contact angle and the surface energy. Five measurements of contact angle and surface energy for each sample were made (fig. 1a, b).

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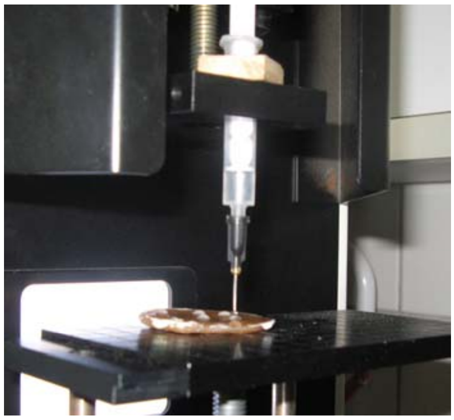
a)  b) 

**Figure 1.** Phoenix 300 apparatus (a), application of drops (b)

RESULTS AND DISCUSSION

Hardness of cured resins was determined only for the two types of adhesives- epoxy (Havel adhesive) and polyester (Sika AnchorFix) (table 2). For other adhesives hardness could not be measured, what was related to insufficient hardness of tested adhesives. Other adhesives (neoprene, acrylic polymer, polyurethane) were characterized by a high degree of flexibility, causing interference of diameter equal to the diameter of the pushed ball.

**Table 2.** Results of Brinell hardness

| | Brinell hardness [N/mm2] | | |
|---|---|---|---|
| Type of adhesive | Mean value | Standard deviation | Characteristic value |
| Epoxy | 194.39 | 11.75 | 170.67 |
| Polyester | 273.99 | 14.56 | 244.57 |

Figure 2 shows an exemplary measurement of interference diameter for epoxy (a) and polyester (b) adhesive.

a) 

b) 


**Figure 2.** Exemplary measurement of Brinell hardness for a) epoxy, b) polyester adhesive

Measurements of contact angle, defined as the angle between the flat surface and a solid surface tangent to the surface of the liquid (water) are shown below in table 3.

Measurements of surface energy are also included. The measurement of the surface energy could not be performed for polyurethane Chemolan B and neoprene adhesives. Drop of Diiodomethane, applied to the surface underwent immediate spillaged. Figure 3 shows sample images used to estimate the contact angle and surface energy.

**Table 3.** Results of contact angle and surface energy for various adhesives

| Type of adhesive | Contact angle [°] | Surface energy [mN/m] |
|---|---|---|
| SikaFast-5221 | 82.4 | 35.8 |
| Sika anchorfix | 71.0 | 64.1 |
| Novol gravit 630 | 66.7 | 63.6 |
| Inter Troton | 64.8 | 66.5 |
| Chemolan B | 76.3 | - |
| Ekoprodur MZ2/A | 47.9 | 136.4 |
| Titebond III | 67.2 | 64.8 |
| Havel adhesive G60 | 46.1 | 64.8 |
| Adesivo neoprenico meccanocar | 65.7 | - |

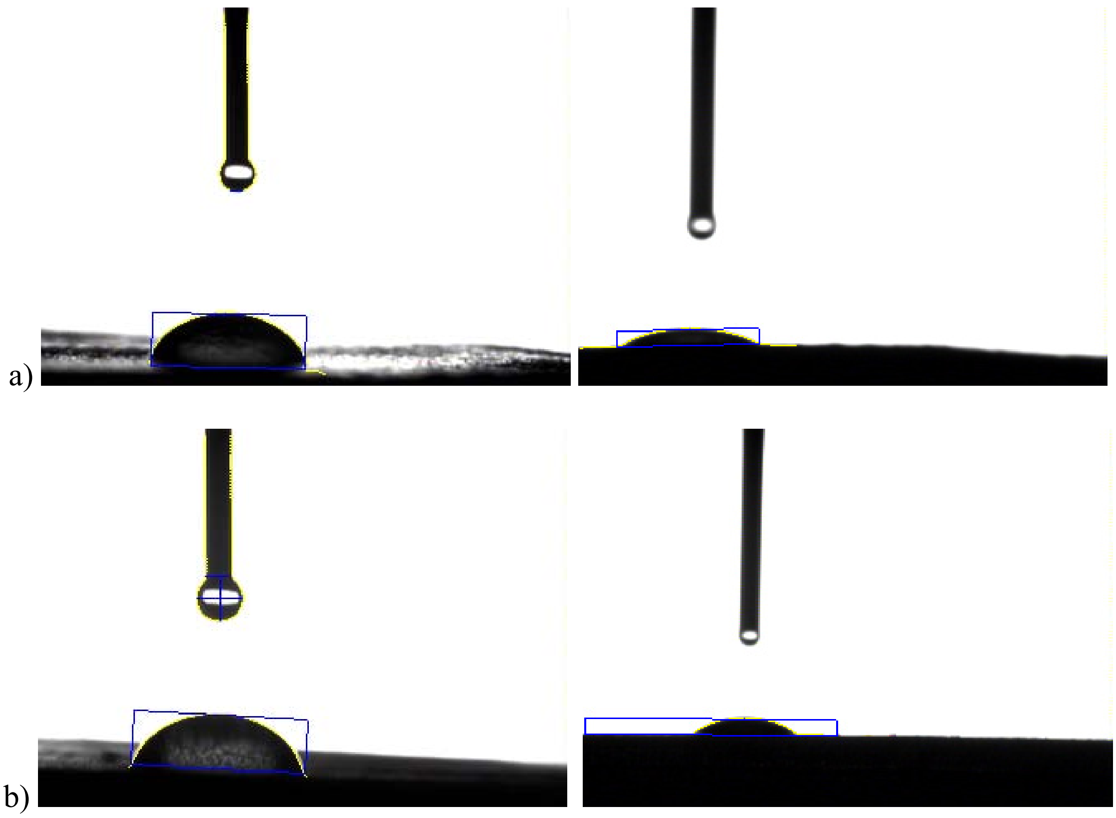



**Figure 3.** Exemplary measurement of contact angle (left) and surface energy (right) of polymer adhesive Titebond III (a) and polymer adhesive Inter Troton (b)

The lowest value of the contact angle was obtained with epoxy glue (46.1 °), while for the highest with acrylic adhesive (82.4 °). The low contact angle indicates hydrophilic wetted area, while the high - hydrophobic. Therefore, epoxy adhesive with a low contact angle have high adhesion to many substances. This statement confirmed in strength tests. It was found that the epoxy adhesive is a binder of very high strength, including a pull-off and shear [Burawska et al 2012].

Low contact angle is generally associated with high surface energy of the material. When the adhesive has a low surface energy, adhesion difficulties can be seen. For tested adhesives, the highest value of the surface energy was obtained for a polyurethane adhesive Ecoprodur MZ2/A (136.4 mN/m), while the lowest for acrylic adhesive SikaFast -5221 (35.8 mN/m).

Among the tested adhesives, epoxy and polyurethane (Ecoprodur MZ2/A) adhesives deserve special attention. Rigid epoxy adhesive, having a high hydrophilicity and the average value of surface energy, providing a sufficient bonding parameters, can successfully be used to adhere the layers of a composite consisting of a timber and a reinforcing material. Flexible polyurethane adhesive has a very high surface energy value, which testifies high performance bonding. Polyurethane glue is highly appropriate for use as a bonding layer between wood and FRP composites particularly. It is related to the chemical structure of the adhesive, which allows the reaction of the hydroxyl functional groups of wood and epoxy resin - a binder for the fiber reinforced polymers. It is possible to have a strong chemical bond, resulting in the very strong glue line.

## CONCLUSIONS

Results of hardness, contact angle and surface energy clearly indicate epoxy and polyurethane as binder of particular use in the repair engineering. Epoxy adhesive has excellent adhesion properties to different materials, forming a rigid joint. Polyurethane glue forms a flexible joint, by functional groups can be joined with high adhesion to synthetic FRP composite materials. However, further diagnosis is needed, and determination which type of bond - flexible or rigid, is more desirable in the reinforcement technology.

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**Streszczenie**: *Badanie wytrzymałości połączeń klejowych między drewnem a wybranymi materiałami wzmacniającymi.* W pracy dokonano analizy parametrów fizykomechanicznych spoin klejowych, mających znaczenie dla łączenia warstw układu drewno - spoina - materiał o wysokich parametrach wytrzymałościowych na zginanie. Zbadano twardość wybranych typów utwardzonych klejów. Jedynie klej epoksydowy oraz poliestrowy okazał się na tyle sztywny, by otrzymać jednoznaczne wyniki twardości Brinella. Zbadano również kąt zwilżania i energię powierzchniową powodowaną przez kleje. Na podstawie badań stwierdzono, że klej epoksydowy oraz testowy poliuretanowy stanowią najbardziej odpowiednie kleje, które mogą być stosowane do łączenia drewna oraz materiałów wzmacniających.



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