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Foaming the polyvinyl acetate (PVA) and poly urethane (PU) wood adhesive and characterization

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Abstract – In this study, polyvinyl acetate (PVA) and polyurethane (PU) wood adhesives were foamed. It was aimed to achieve adhesive savings by allowing the adhesives to cover a larger surface area through foaming. Egg white (EW), wheat flour (WF), and Sodium Lauretha Sulfate (SLES) were used as foaming agents for the adhesives. The foaming agents were mechanically mixed within a glass container to foaming, and then adhesive was added to the foam and mixed again using a mechanical mixer. The characterization of the foamed adhesives was conducted through viscosity and perpendicular adhesive strength (PB) analyses according to TSE standards. According to the analysis results, it has been determined that foaming PU adhesive with foaming agents is more successful. The foam stability of PVA adhesive was significantly low, as the foam completely deflated after approximately 30 minutes. The addition of EW and WF to PU resulted in a more solid and rigid foam. Thanks to this characteristic, PU foams can be used in the production of wood sandwich panels. According to the study results, further research is anticipated to be conducted on the foaming of PU adhesive, and the obtained foams are predicted to be used in the furniture industry for panel production.

Keywords – Black Pine, Wood Glue, Polyvinyl Acetate, Poly Urethane, Foaming

I. INTRODUCTION

Researchers have long focused on the challenge of foaming adhesives to develop an effective gluing process. Early investigations conducted in the United States, such as the study by Menger et al. [1], explored the preparation of a glue mixture for plywood production. This mixture included various ingredients like urea formaldehyde condensation product, casein, ammonia solution, and wood meal. Air was introduced into the mixture through stirring, expanding its volume significantly. The resulting foam was then applied to wood veneers using roller machines, and the plywood assembly involved coating camwood veneer with the foamy glue and placing untreated veneers on either side. Pressing the assembly under specific temperature and pressure conditions ensured adhesion and eliminated the foam structure of the glue. The researchers proposed three different processes, each utilizing a liquid foam adhesive with variations in ingredients like casein, bone glue, or blood albumen, but all achieved wood bonding through pressing at controlled conditions of temperature and pressure.

In their research, Gillern et al. [2] presented a novel method to bond materials, particularly wood, by employing foamed adhesives that possess excellent gap-filling characteristics. These adhesives were created by blending foaming agents with amine-modified aldehyde condensation polymers. The resulting resins exhibited impressive curing properties at ambient temperature and displayed remarkable effectiveness as construction adhesives. This innovative approach offers great potential for enhancing the bonding capabilities of materials in various construction applications.

Also, some studies were carried out on improving the adhesion properties by combining wood glues.

Keaton et al. [3] describes a method for producing an adhesive that involves combining coacting resins and utilizing them to bond bondable members. The adhesive is designed to be activated precisely when the two parts of a joint are joined together, ensuring optimal bonding. Additionally, the invention encompasses the bonded joint itself, which is formed by activating two resins that readily mix and create an adhesive when combined, along with the method for manufacturing the resins, adhesive.

Foaming of polymers provides several advantages to the materials. Foamed polymers are lightweight materials which were desired in many sectors. Sisson JB et al. [4] devised innovative techniques and equipment to create layered structures consisting of a foamed plastic layer sandwiched between webs of sheet material. This invention encompasses procedures and machinery employed to produce laminates or sandwiches where a foamed plastic layer is securely bonded between and adhered to flexible sheet materials like paper. This invention finds particular suitability in manufacturing sandwich materials used for constructing shipping cartons, among other potential applications.

In this study, Polyvinyl acetate (PVA) and Poly urethane (PU) glues were foamed, and the tensile strength and fluidity of glues were determined. In literature, various studies have been carried out on PVA and PU foams. Colosi et al. [5] utilized a microfluidic foaming technique to create highly uniform bubbles of gas-in-liquid, serving as templates for scaffolds with an ordered and homogeneous porous texture. By injecting an aqueous PVA solution containing a surfactant and argon gas into a flow-focusing device, monodisperse bubbles were generated and subsequently collected, frozen, freeze-dried, and cross-linked. A comparison between the microfluidic-produced scaffold and a traditionally gas-foamed scaffold revealed superior morphological quality in terms of narrower pore size, better interconnection, and wall thickness distributions, although limited pore interconnectivity, low pore volume, and production rate still present challenges for the microfluidic foaming method to overcome. This study is similar with ours but exclude foaming process. We use different method in foaming the PVA which was including naturel foaming agents.

Hou et al. [6] examined the impact of polyvinyl alcohol (PVA) properties on foam formation, encompassing foam generation rate, liquid drainage rate, suspension properties, and foam stability. They also investigated the influence of surfactant, air content, and stirring speed on foam behavior and characteristics. The findings reveal that foams produced at a rotational speed of 1200 rpm and room temperature (25 °C), with a specific surfactant loading ranging from 0.75 % to 1.25 %, exhibited a lifespan of 7.5 minutes and uniform bubble size. The degree of PVA hydrolysis was observed to affect bubble size and foam stability. Ultimately, the researchers successfully manufactured fiber-based materials with a highly porous structure and low-density using foam forming technology. In our study, the viscosity, volume increase and adhesion strength of the glues were investigated rather than the foam formation. Bubble size and foam stability are very important issue in foaming process, but in our study, we prepared the foamed glue and instantly applied it on the wood surfaces.

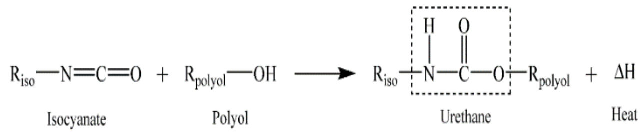

Fig. 1 Reaction scheme of urethane production [7]

PUs are composite substances formed through a series of interconnected steps. Initially, the constituents are blended together, followed by a concurrent occurrence of polymerization (a chemical reaction involving isocyanate and polyol, as depicted in Fig. 1) and expansion (a reaction between isocyanate and water, illustrated in Fig. 2) [8], [9].

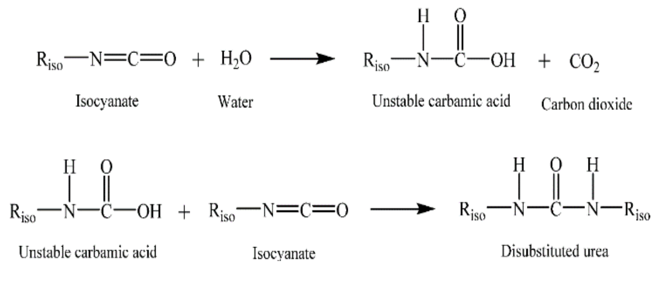

Fig. 2 Reaction scheme of the isocyanate with water [7]

In our study, PVA and PU glues were foamed with a few supplements which were natural and synthetic. It was aimed to examine the foaming properties of PVA and PU wood glues with egg white (EW), wheat flour (WF) and Sodium Laureth Sulfate (SLES). The purpose of foaming is to enable the adhesive to cover a larger surface area, thereby promoting adhesive savings.

II. Materials and Method

A. *Materials*

Polyvinyl acetate (PVA) and polyurethane (PU) were used as wood adhesives. The adhesives were obtained through local market procurement. PVA had a water resistance class of D3, and PU adhesive had a D4 class. Black pine (*Pinus nigra*) timber was used for the bonding analysis samples. The timber was purchased from the local market. As natural fillers, egg white (EW) was used, which was purchased from a local supermarket. Wheat flour (WF) was obtained as ready-to-use bread flour from the local market. Sodium Lauretha Sulfate (SLES) was used as a synthetic filler in gel form, which was purchased from the local market. The materials used for preparing the samples are given in Table 1.

Table 1. Material ratios of samples

Sample Code	PU (gr)	PVA (gr)	EW (gr)	WF (gr)	SLE (gr)	Water (gr)
CTRL1	100	-	-	-	-	-
CTRL2	-	100	-	-	-	-
EW1	100	-	10	-	-	-
WF1	100	-	-	10	-	5
SLES1	100	-	-		5	5
EW2	-	100	10	-	-	-
WF2	-	100	-	10	-	5
SLES2	-	100	-		5	5

B. *Preparation of samples*

In the preparation of EW1 sample, 10 g of egg white was foamed by mixing it with a mechanical stirrer at 3000 rpm. Then, 100 g of PU was added to the obtained foam and mixed for 10 seconds using the mechanical stirrer. For PU samples, the mixing time was kept short as PU tends to foam and increase in volume after 10 seconds.

Similarly, for the preparation of WF1 sample, 10 g of wheat flour was foamed by mixing it with 5 g of distilled water using a mechanical stirrer at 3000 rpm. Then, 100 g of PU was added to the foam and mixed again for 10 seconds.

For SLES1 sample preparation, 5 g of SLES was foamed by mixing it with 5 g of water using a mechanical stirrer at 3000 rpm. Then, 100 g of PU was added to the foam and mixed for 10 seconds.

The samples prepared with PU adhesive were immediately used for perpendicular bonding without waiting, due to the rapid foaming of PU. The same method was followed for sample preparation of EW2, WF2 and SLES2 with PVA glue, except for the mixing time (PVA was mixed with foaming agents for 120 seconds for foaming). Two pieces of 150 mm x 30 mm x 20 mm Scots pine timber were bonded to each other at a 90° angle for the bonding samples (Fig. 3)

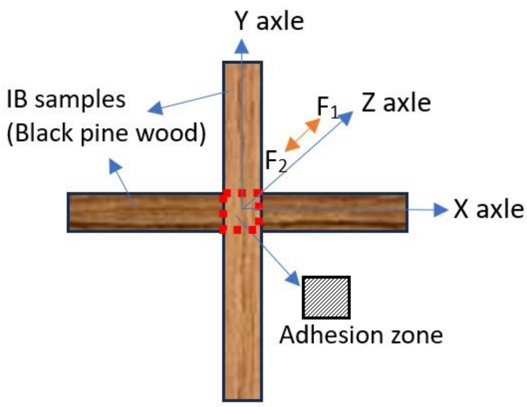

Fig.3 perpendicular adhesion sample

For the characterization of the flowability of adhesive samples, a 18 mm x 500 mm x 400 mm laminate surface was used. The laminate surface was tilted at a 45° angle. The foamed 100g adhesive samples were poured and released onto the upper part of the surface. The samples flowed downwards at a 45° angle (Fig. 4). The time taken for the flowing adhesive samples to travel a distance of 500 mm was measured and recorded. The recorded values were used for comparing the flowability characteristics of the adhesive samples.

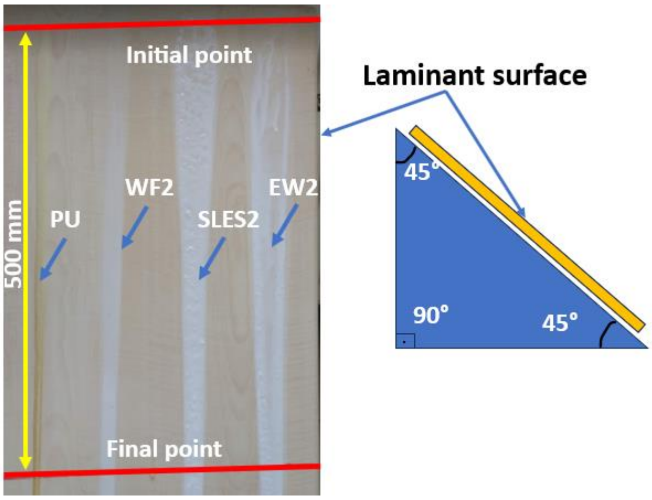

Fig. 4 Device for flowability measurements of adhesives

The density measurements of the foamed PU adhesive samples were conducted in cardboard cups (Fig. 5). However, density measurements for the foamed PVA samples could not be performed because the foams had extinguished within the curing time of PVA. Density measurements were carried out for the deflated foamed PVA samples, but no significant difference was observed compared to the PVA control sample.

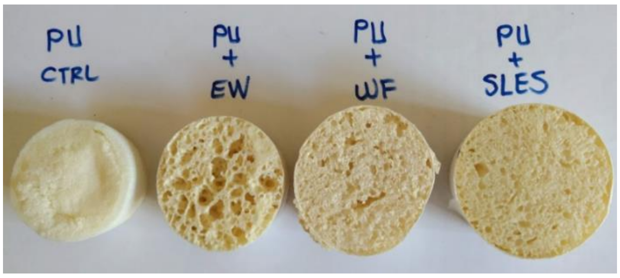

Fig. 5 Foamed PU samples for density analysis

C. *Characterization of samples*

The characterization of perpendicular bonding samples was conducted according to TS EN 319. Density measurements were performed according to TS EN 323. The flowability analysis of adhesives was carried out using a new method introduced for the first time in this study.

D. *Statistical analysis*

The conducted analyses were statistically analyzed using the SPSS software package. One-way ANOVA analysis was performed on the samples, and Duncan analysis was conducted additionally. Significant differences between the samples were determined based on a significance level of $P < 0.05$.

III. RESULTS

The analysis results of the foamed adhesive samples are given in Table 2. When the polyurethane (PU) was mixed with foaming agents, it was determined that it lost its fluidity (EW1, WF1, SLES1). In this case, mechanical mixing of the polyurethane was effective. When PVA was mixed with foaming agents, it was generally observed that the fluidity value increased (EW2, WF2, SLES2).

When the adhesion resistance of the samples was examined on wood, it was determined that SLES1 had the highest adhesion resistance, while WF1 had the lowest adhesion resistance. Except for SLES, the other foaming agents reduced the adhesion strength of PU.

When the density values of the samples were examined, it was found that the densities of both PU and PVA decreased with the addition of foaming agents. Mechanical mixing of PU with foaming agents for 10 seconds was sufficient for foaming. On the other hand, PVA was mixed with foaming agents for 120 seconds for foaming.

Table 2 Analysis result of foamed glues

Samples	Fluidity (s)	PB (N/mm^2)	DN (g/cm^3)
CTRL1	5,5 (±1,7) c	13,30 (±0,4) e	0,473 (±0,01) c
CTRL2	19 (±2,7) f	8,40 (±0,1) c	1,148 (±0,06) e
EW1	0 (±1,7) a	2,63 (±0,7) a	0,323 (±0,02) b
WF1	0 (±1,7) a	2,25 (±0,2) a	0,055 (±0,01) a
SLES1	0 (±1,7) a	21,25 (±1,7) f	0,094 (±1,7) a
EW2	7,2 (±2,8) e	10,00 (±0,3) d	1,018 (±0,01) d
WF2	6,1 (±3,0) d	8,75 (±0,2) c	1,259 (±0,09) f
SLES2	5,3 (±2,5) b	7,13 (±0,6) b	1,148 (±0,5) e

IV. DISCUSSION

More efficient results were obtained in the foaming of PU adhesives compared to PVA. After being mixed with foaming agents, PU foamed and then hardened in its foam state. However, PVA adhesive, after being mechanically foamed with foaming agents, experienced deflation of the foam approximately 30 minutes later.

The aim of the study was to reduce the densities of the adhesives and increase their adhesion strengths using foaming agents. This goal was partially successful because the addition of SLES foamed PU, reducing its density and increasing the adhesion strength (Fig. 6 and Fig. 7).

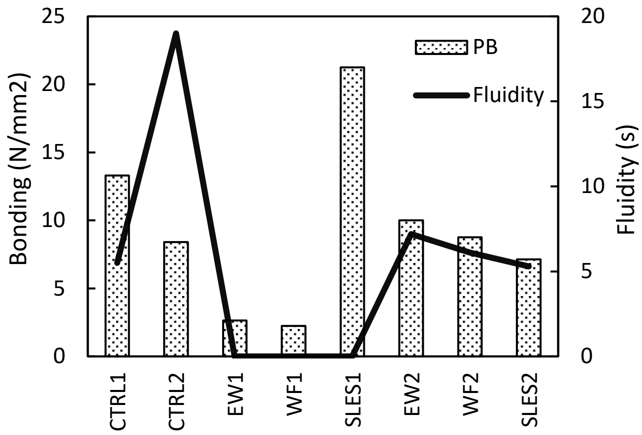

Fig. 6 Fluidity and bonding relation

When examining Fig. 6 and Fig. 7, it can be observed that as the density decreases in PU adhesive, the adhesion strength decreases except for SLES1. It has been determined that the addition of SLES enhances the adhesion properties of PU. On the other hand, in PVA adhesive, the adhesion strength (PB) decreases with the addition of SLES, while WF and EW additions increase the adhesion strength of PVA. In this study, the addition of SLES had different effects on PU and PVA. While it increased the adhesion strength in PU, it decreased it in PVA. The foaming agents also had different effects on the fluidity of PU and PVA adhesives. The foaming agents increased the flowability of PVA on the laminated surface, while completely stopping the flowability of PU adhesive. While high foam quality was a positive feature in PU, the short foaming time was a negative feature because the foamed PU adhesive hardened quickly. The addition of egg white and wheat flour made the more rigid PU foam even harder. By using foaming agents, it is possible to make the PU foam even harder and use it in the production of wooden sandwich panels.

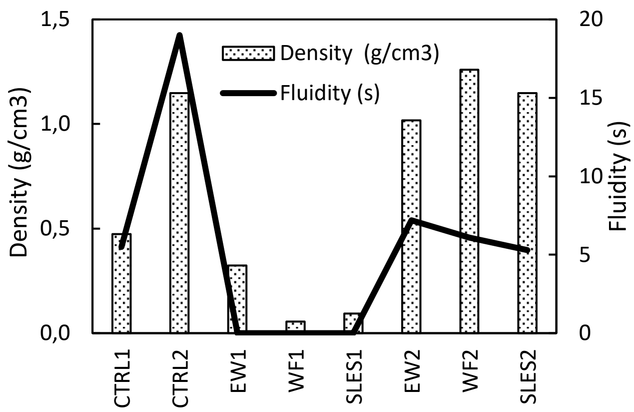

Fig. 7 Fluidity and density relation

V. CONCLUSION

In the study, natural and synthetic foaming agents were used to foam PVA and PU wood adhesives with the aim of reducing their volume and increasing their adhesion strength. This would lead to more efficient bonding and cost reduction. Foaming was more successful in PU adhesive. Foaming of PVA adhesive was partially successful because the foam stability in PVA is quite low. The foam completely deflates after approximately 30 minutes. Therefore, after foaming PVA, it needs to be applied to the wood surface within 30 minutes. In PU adhesive, rapid solidification occurs after foaming. It should be applied to the wood surface before solidification occurs in PU adhesive (approximately 60 seconds).

Furthermore, the study concluded that the foaming agents create a more solid and rigid material after foaming of PU adhesive. Due to this characteristic, foamed PU can be used in the production of wood sandwich panels.

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