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BONDING AND PROTECTING PAPER-BASED BUILDING ELEMENTS VS. THE ECOLOGICAL IMPACT

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ABSTRACT

Paper is one of the most eco-friendly mass-produced materials – recyclable, biodegradable and renewable. However, various factors can significantly affect the overall environmental impact of paper-based structure, therefore designers should pay particular attention to issues such as lamination, impregnation and type of paper used.

Paper production is a complex process and the technology of production strongly influence the environmental impact of the end product. Most of the energy consumed by European paper mills is produced from biomass and carbon dioxide emission during production is constantly reduced by increasing the share of renewable energy sources [1]. Consumption of water can not be reduced without compromising paper properties [2] however, water can be used in the closed-loop. Currently, 90% of water consumed in European paper production is recycled and returned to the source [1]. Used paper can be recycled up to seven times and the recycling rate of paper in Europe in 2019 was 72% [3].

Various factors should be considered aiming towards pro-ecological paper-based designs. First of all, recycled-fibre, non-bleached products should be used when possible. The geometry of paper-based products plays an important role when using them as insulative materials – the highest thermal conductivity compared to material consumption is provided by thin honeycomb panels and high-flute corrugated cardboard.

Recyclability is one of the key advantages of paper-based products. However, to take full advantage of this, the design should allow for material separation. On the other hand, adhesives are the most effective manner of joining paper elements, as mechanical joints (e.g. screws and nails) can compromise the material properties.

Traditional adhesives can be simply divided into two groups, natural and artificial adhesives. Natural adhesives are materials received from plants or animal tissues that can bond surfaces. Such materials include starch and cellulose.

Starch is widely used due to high availability of its raw material, simple process, and good adhesion. Despite these features, starch shows l water resistance, limited mechanical properties and high permeability [4]. To overcome the drawbacks starch may be chemically modified. These operations can increase bond strength, water resistance and often affinity to certain materials [5].

Due to its physical properties (semicrystalline structure and high amount of hydrogen bonds) pure cellulose cannot be used as an adhesive [6]. By chemical modification, cellulose derivatives can be obtained and then used as adhesives, for example, cellulose ethers and nitrocellulose, where functional groups, that provide better solubility and adhesion, are present.

Artificial adhesives are polymeric materials made of non-renewable raw materials in the way of chemical reactions. The most popular adhesives used for paper gluing are polyvinyl acetate, copolymer ethylene – vinyl acetate, phenolic – formaldehyde resin and epoxy resin.

Polyvinyl acetate, PVA, is a cheap and non-toxic material used in various kinds of adhesives. Moreover, it is soluble in water and it forms hard films after drying. Unfortunately, it has limited mechanical properties [7].

Copolymer ethylene – vinyl acetate, EVA, belongs to the adhesive group called hot melt adhesives. They are polymeric adhesives that can be used after melting without the use of often harmless solvents. This type of adhesive also does not show the release of by-products into the environment during setting, which makes it environmentally friendly. The properties of EVA depend on the content of each monomer, vinyl acetate and ethylene. More vinyl content makes the material more polar, so in the case of paper, which is also polar, is a good phenomenon[8-9].

Phenolic – formaldehyde resins, PF, show good water resistance, good chemical stability, good heat and wear resistance. Their most important disadvantage is formaldehyde release while setting, which as a toxic chemical compound is very harmful to live organisms. Nevertheless, PFs are often used in the timber industry both as adhesives and as an impregnants [10-12].

Epoxy resins, due to their chemical structure, are highly reactive, what makes them suitable adhesives for almost all kind of surfaces. Their curing reaction proceeds without the release of side compounds and

their joints show good mechanical, cohesive and adhesive strength and high chemical stability. Due to their high reactivity, epoxy resins are more efficient than other adhesives, therefore less adhesive material is required to bond two surfaces [13-14].

Another important factor that should be analysed while designing eco-friendly paper structures is protection against destructive factors. Paper is extremely sensitive to water, losing its strength with the increase of air humidity. Moreover, paper-based products with air cavities, like honeycomb panels or corrugated cardboard, are highly flammable. On the other hand, coating and additives often hinder paper recycling. To ensure users safety and structure stability, paper-based elements can be protected, by impregnation, lamination or additional facings made of traditional materials, like metal sheets or mineral boards.

Paper can be laminated with synthetic polymers like low-density polyethene or polypropylene, but there are some other compounds that are used, for example, rosin-alum, alkyl-ketene dimers or alkenyl succinic anhydrides. These materials can increase the hydrophobicity of paper elements [15-18]. As an alternative to polyethene and polypropylene, biodegradable polymers may be used, for example a thin layer of poly(lactic acid), PLA [19-20]. However, the disadvantage of this solution is the difference in the biodegradation environment. PLA degrades under industrial compost conditions. Using waxes is also a good method of impregnating, but final components have disadvantages like poor crack resistance and low thermal resistance [21]. Besides lamination and coating, physical and chemical modification of paper are also a good method to increase the hydrophobic properties. Such modifications as atmospheric pressure plasma etching or modification of cellulose fibres with succinic anhydride were carried out [22-23].

Cellulose due to its chemical composition is highly combustible. To prevent fire destruction, compounds known as flame retardants, are utilized in papermaking production. They can be both inorganic and organic chemical compounds. The efficiency of inorganic retardants is limited and it is required to add a large amount of them to be effective. Inorganic flame retardants include metal oxides, metal hydroxides, boron compounds and silicon compounds. Organic compounds used as fillers are for example guanidine phosphate and guanidine sulfamate.

Despite its limitations, paper can be an environmentally friendly and inexpensive building material. With a careful selection of products and raw material, as well as a mindful design, a balance between durability and ecological performance of paper-based structures can be achieved.

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