**Technology to increase the resistance of composite paper materials including plant cellulose and basalt fibers based on synthetic flocculants**

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**Abstract.** This article goes over tests to get composite paper goods from plant (Jerusalem artichoke) cellulose and basalt fibers. It also talks about increasing their resistance. The work used new types of flocculants, Poly(ethylene terephthalate) (PETF-1) and PETF-2, that were made from local and recycled polymer waste. Their interaction with polyaluminum hydrocomplexes was studied. The paper looks at how using flocculants as binders at different pH levels impacts the mechanical resistance of cellulose-based paper materials and how well the parts are kept. The research found the best amount of flocculant and pH levels, which made the resistance of composite materials go up by 2-7 times. This method lets paper be made in an environmentally safe and cost-effective way using local resources.

**INTRODUCTION**

In recent years, the modernization of the chemical and pulp-and-paper industries is among the key strategic priorities for developing countries, including Uzbekistan. The focus has shifted toward environmentally benign, resource-efficient, and sustainable technologies capable of producing high-quality products from renewable and locally available feedstocks (1-3). The global pulp and paper sectors (are) undergoing transformation due to increasing ecological requirements, high raw material costs, and the scarcity of natural cellulose sources such as wood. As a result, the utilization of non-wood lignocellulosic biomass-including agricultural residues and fast-growing plants-has gained significant attention as an alternative cellulose source (4-6).

Several studies have emphasized the potential of Jerusalem artichoke (Helianthus tuberosus) as a promising non-wood feedstock. Its biomass is rich in hemicellulose and cellulose, and it grows rapidly even under suboptimal climatic conditions (7). Cellulose obtained from such plants can be used to produce eco-friendly paper products and composite materials. The integration of basalt fibers as reinforcement in cellulose-based matrices has also been shown to markedly enhance the strength thermal stability, and water resistance of the final composite products (8). Basalt fibers are derived from natural volcanic rocks and possess high tensile strength good thermal stability, and chemical inertness, making them a cost-effective and sustainable alternative to glass or carbon fibers (9). However, one of the main challenges in producing such hybrid composites lies in the weak inter-fiber bonding and poor adhesion between hydrophilic cellulose and inert mineral fibers (10). This limitation directly affects the mechanical strength and durability of paper-based composite materials. To address these researchers have explored flocculation and coagulation mechanisms to enhance fiber-fiber interactions during sheet formation (11).

The use of synthetic polyelectrolytes and flocculants, such as polyacrylamide (PAA), polyethyleneimine (PEI), and poly(diallyldimethylammonium chloride) (PDADMAC), has been widely reported to improve fiber retention, drainage, and mechanical integrity in paper pulp systems (12). Recent attention has been drawn to developing new-generation flocculants derived from recycled polymers, particularly polyethylene terephthalate (PET) waste. PET, one of the most abundant plastic wastes, can undergo chemical alcoholysis or glycolysis to yield polymeric products with active functional groups suitable for flocculation and binding applications (13). In this context two newly synthesized flocculants, Poly(ethylene terephthalate) (PETF-1) and PETF-2 derived from PET waste alcoholysis, represent a sustainable approach to improving interfacial adhesion in composite paper systems. Their structural similarity to polyester-type polyelectrolytes allows strong electrostatic and hydrogen-bond interactions with cellulose and aluminum polyhydroxy complexes in the pulp matrix (14). The introduction of aluminum polyhydroxy complexes (Al(OH)x3-x into paper pulp is another crucial aspect of strengthening mechanisms. These complexes function as coagulating bridges between negatively charged cellulose fibers and anionic flocculants, facilitating fiber aggregation and forming a stable, dense paper web (15). Previous research by Egamberdiev et al. (16,17) and Oksman et al. (25) demonstrated that combining polyaluminum species with synthetic flocculants in controlled pH environments could increase mechanical strength up to 5-8 times compared to unmodified cellulose paper. The influence of pH control during flocculation is also vital as it determines the ionization state of both the polymeric flocculant and the aluminum species. Studies indicate that optimal flocculation typically occurs near neutral or slightly acidic pH(6.0-7.0), where aluminum polycations are most stable and polymer chains achieve maximum extension (18). Maintaining this equilibrium ensures efficiency aggregation and minimizes fiber loss in the filtrate, leading to higher retention efficiency and improved composite paper technology combining Jerusalem artichoke cellulose and basalt fibers, using locally synthesized PETF-1 and PETF-2 flocculants derived from recycled PET.

The study investigates the effects of pH and aluminum polyhydroxy complex concentration on fiber retention, pulp coagulation, and mechanical resistance of the resulting paper sheets. This work not only provides a scientific foundation for environmentally safe and resource-saving composite paper production but also contributes to Uzbekistan’s national strategy for waste polymer utilization and import substation in the paper industry.

**MATERIALS AND METHODS**

Technical cellulose extracted from Jerusalem artichoke (Helianthus tuberosus), basalt fibers, aluminum polyhydroxy complexes, and new synthetic flocculants, PETF-1 and PETF-2, selected in making composite paper materials. PETF-1 and PETF-2, made through alcoholysis of recycled polyethylene terephthalate (PET) in the laboratory, were tested and studied against existing industrial flocculants (polyacrylamide – PAA, polyethyleneimine – PEI) for their ability to promote aggregation.

As research subjects, Jerusalem artichoke cellulose was picked as the main binding part of the paper pulp because it's a water-loving fiber material. Basalt fibers were used to make the paper pulp stronger. Aluminum sulfate (18% by weight) was a key part in making aluminum polyhydroxy complexes through hydrolysis. PETF-1 and PETF-2 flocculants, prepare from PET waste alcoholysis, were tested at different pH levels with amounts ranging from 0.25% to 2.5% by weight. Experimental paper pulps were made in pH environments from 4.5 to 9.0, where flocculant activity, how well the binding polymers (aluminum complexes) stayed together, and how fibers interacted were studied. The key research methods included: coagulation-flocculation analysis, used to find out how well flocculants coagulated things at different pH levels; finding mechanical strength by measuring the tensile strength (MPa) of the made samples; assessing particle aggregation and pulp density with an optical microscope; figuring out how well binding agents stayed together by measuring the amount of aluminum polycomplexes in the paper pulp using gravimetric and titrimetric methods; and evaluating physical and chemical properties of the samples using FTIR-spectral analysis, pH-meter, and measuring dry and wet flexibility.

**RESULTS AND DISCUSSION**

When the paper pulp is based on plant cellulose and basalt fiber, cutting down the b-potential in constituent parts is just one way to make parts stay together better, since fiber hydration, fillers, and fiber network forming are serious factors in how stable the system is. It's especially key to talk about how well the binder – aluminum polyhydroxy complexes – stays together, because the more binder that stays in the paper during the papermaking process, the more probable it is to make a stronger material. The binder staying put also helps meet ecological demands for water released from under the wire.

When synthetic flocculants are used to help the binder stay in the making of paper goods from plant cellulose and basalt fiber, there's a chance to make mineral fiber-based paper stronger. Special experiments were done for this, where polyacrylamide (PAA) and polyethyleneimines (PEI), used in papermaking, were used to make aluminum polyhydroxy complexes work better.

Previous studies by several researchers have shown in this field and used synthetic polyelectrolytes, polyethyleneimine Polymin KM, and Polymin R as flocculants.

Right now, turning plastic household waste like polyethylene terephthalate (PET) bottles into useful things is being done for uses such as filter membranes, adsorption, and the paper business. To do this, we made two kinds of products (alcoholysis product) with PET and tried using it as a flocculant in the paper business. We called these products PETF-1 and PETF-2. These flocculants were used after being evaluated against flocculants already out there in the business world.

Samples were prepared with 18% aluminum sulfate, Jerusalem artichoke cellulose, and basalt fibers by weight, and the pH was changed from 4.5 to 9.0 during sheet forming. PETF-1 and PETF-2 were used as flocculants, with amounts ranging from 0.25% to 2.5% by weight.

The results are shown in Figures 1, 2, and 3. Figure 1 shows the curves for the control sample without flocculants.

Looking at the graphs, some things are true for all the flocculants and reinforcing additives tested. For all the polyelectrolytes tested, it's doable to pick conditions where the presence of aluminum connections boosts the reinforcing effect. Plus, with polyelectrolytes around, how aluminum polyhydroxy complexes act relies heavily on pH environment values, and this relying becomes more complex. In this case, we can guess that the b-potential changes because of the polyelectrolyte's effect.

Besides, we should keep in mind that changing the pH value touches not just how active the polyhydroxy complexes are, but also the shape of the flocculant molecules, since a coil-spiral type switch happens. The system gets a bit complex, but within the range of tasks we have, we need to zero in on the features of the factors that decide things and then pick a recipe that makes sure the composite has the needed level of quality.

It's been spotted that the biggest effect was reached when 0.25% of local anion polyacrylamide was used. It should be said that on the charts of how strength changes with pH value, the highest points are in the neutral zone. The control values of how strong samples made without flocculants are, for the most part, lower than the values gotten with PAA. It should be said that this is also true for when polyethyleneimine is used.

(a)

(b)

**FIGURE 1.** The influence of PAA on the stability of samples:   
(a) Jerusalem artichoke cellulose and aluminum sulfate, and (b) Jerusalem artichoke cellulose, basalt fiber, and aluminum sulfate in flocculant consumption (%), where:   
*1 - 0.25; 2 - 0.5; 3 - 1.0; 4 - 2.0; 5 – without flocculants.*

When using polyethyleneimine (as shown in Figures 1 and 2), the maximum values are somewhat general, ranging from a low-acid to a low-alkaline surrounding. Still, in all cases, the strength of samples clearly relies on the pH values. This means that when a synthetic flocculant is used for any reason in the systems studied, the needed control over pH during casting should be somewhat stricter.

(a)

(b)

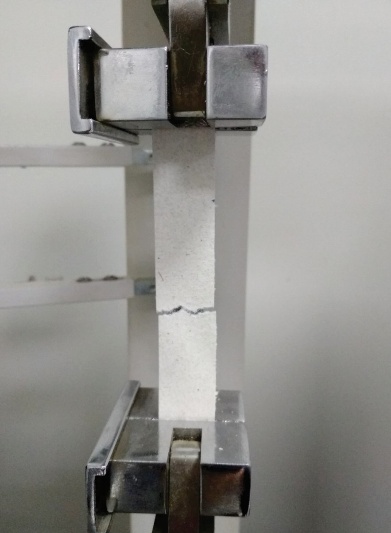
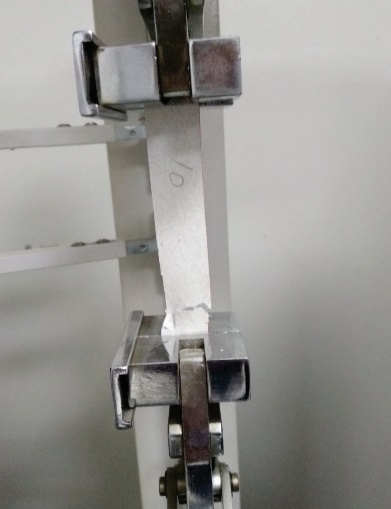
**FIGURE 2.** The influence of PETF-1 polyethyleneimine on the stability of samples containing Jerusalem artichoke cellulose and aluminum sulfate (a), as well as Jerusalem artichoke cellulose, basalt fiber, and aluminum sulfate (b) when consuming flocculant (%), with the following concentrations:   
*1 – 0.25; 2 – 0.5; 3 – 1.5; 4 – 2.5.*

(a)

(b)

**FIGURE 3.** Shows how PETF-2 impacts the stability of flocculant consumption (%) in samples using:   
*(a) Jerusalem artichoke cellulose and aluminum sulfate; and (b) Jerusalem artichoke cellulose, basalt fiber, and aluminum sulfate. The concentrations are: 1 – 0.25; 2 – 0.5; 3 – 1.5; 4 – 2.5.*

Thus, using synthetic polyelectrolytes in mineral fiber-based paper-like material is a good way to up its strength. The best results came from using polyethyleneimine: the strengths of materials with 10-12% aluminum polyhydroxy complexes rose sevenfold with these polyelectrolytes present (to 3.0 and 2.0 MPa with PETF-1 and PETF-2, respectively). It should be noted that the strengthening impact is on holding more aluminum hydroxides with the flocculant. Of course, it's vital to first run tests and a cost study to figure out the right ways to use binders and choose the best ways to up how much of the paper pulp components are retained.

**FIGURE 4.** Image of the obtained samples.

In general, a method has been created that lets composite materials get stronger with polyhydroxy complexes of metals on a base of mineral fibers. To ensure sufficient component retention when casting the mass, it is planned to use proper flocculants when fixing the pH surrounding.

**CONCLUSION**

Research shows that using synthetic flocculants, like PETF-1 and PETF-2 products made from recycled PET, with plant cellulose (Jerusalem artichoke) and basalt fiber composite paper materials greatly improves the paper pulp's mechanical strength.

Experiments showed that samples made with PETF-1 and PETF-2 flocculants react to changes in pH, reaching highest strength in a neutral environment (pH ≈ 6.5–7.5). The presence of aluminum polyhydroxy complexes boosts the flocculants coagulation, making the pulp’s network structure more stable. PETF-1 treated samples had the best mechanical results (up to 3.0–7.0 MPa), suggesting they could be used in industrial applications. This study also shows chances to introduce resource-saving, environmentally friendly, and cost-effective technologies in the paper industry by creating innovative flocculants from local waste (PET bottles).

It was confirmed that managing the flocculation, mainly its sensitivity to pH, is important when binding mineral and plant fibers to create composite materials. Overall, the technology and new flocculants developed lay a vital scientific base for introducing new technologies in Uzbekistan’s paper industry, improving product quality, and growing local raw material-based production that can replace imports.

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