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Oil-palm fiber as natural reinforcement for polymer composites

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The importance of natural fibers as reinforcement or fillers in polymers is increasing, but limitations have prevented them from totally replacing synthetic fibers.

Natural fibers (NFs) are increasingly in demand across a wide range of polymer-composite materials. They originate from plants, crops, animals, agro waste, or other natural sources that are natural, renewable, and biodegradable after their end use. Global environmental concerns such as climate change and sustainability are encouraging development of totally green materials that can deliver eco-social system change. Synthetic fibers are discouraged, while—conversely—NFs are the best available alternative reinforcements or fillers to make polymer-composite materials partially biodegradable. However, even though NFs enjoy some specific superior properties compared to synthetic fibers, they also suffer from serious problems caused by their polar nature,[1] such as poor moisture resistance, limited processing temperatures and low dimensional stability.[2] This is, for example, the case for oil-palm fibers (OPFs), which are natural fibers found abundantly in southeast Asia.[3] We reviewed developments in the field of OPF polymer composites[3] to inspire and explore further development in this area.

We began by surveying research literature on OPF polymer-composite materials. We found that researchers have most commonly attempted to reinforce OPFs with synthetic polymers such as polypropylene (PP), polyester (PE), polyvinyl chloride (PVC), phenol formaldehyde (PF), and polyurethane (PU), but none have done research using natural matrices such as bioresins or biopolymers.

We reviewed types of OPFs and their physical characteristics and structures. We also considered chemical composition, because the bonding at the matrix-fiber interface is primarily dependent on the surface morphology and chemical composition of the fibers.[4] We then considered OPF composites with both thermoplastic and thermoset polymers, noting the water-absorption characteristics and mechanical properties of the composites. We classified PVC and PP as thermoplastic polymers, but included PU, PE, and PF as thermoset polymers because they are widely used as binders in composite materials.

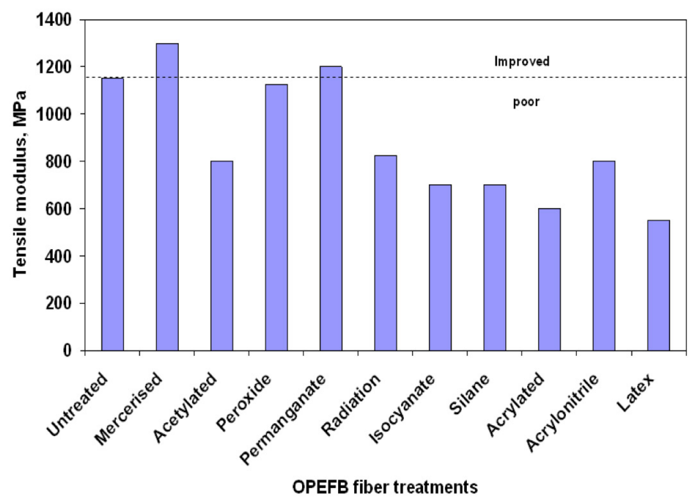

Figure 1. *Tensile modulus of untreated and treated oil-palm-fiber-reinforced phenol formaldehyde composite material. OPEFB: Oil-palm empty fruit bunches.*

We found that the mechanical properties and water-absorption characteristics of OPF polymer-composite materials were interdependent. Moreover, the processability and mechanical properties of the biocomposites depend on fiber orientation, loading, and chemical treatment.[5]

One of the main reasons for the lack of commercialization of OPFs is their hydrophilic nature, which is due to the presence of a hydroxyl group (−OH) in the lignocellulosic components. This results in water absorption and disrupts the interfacial bonding between fibers and matrices in the composite material, and so OPF polymer composites have poor mechanical properties. Various treatments, such as using

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compatibilizers and adhesion promoters, fiber-surface and hydrothermal treatments, and the duralin process, can help to tackle the hydrophilic nature.[6] This study reports on both the consequences that water absorption would have on the mechanical properties and also provides an overview of the different techniques or methods used by researchers to minimize the uptake of water in biocomposite materials. Nevertheless, biocomposite materials face major problems during processing and end use because of water absorption, which affects their mechanical properties. Various treatments have been identified to overcome this hurdle, but it remains a challenge.

As a result, researchers have attempted to occupy, replace, neutralize, or remove the hydroxyl group and so convert natural fibers from hydrophilic to hydrophobic. They have had some success but at the expense of the OPFs' mechanical properties. For instance, OPFs have been chemically modified to improve their compatibility with polymers,[7] but this mostly results in a lower tensile modulus (see Figure 1).[7]

Although many researchers have tried to develop biocomposite materials by reinforcing various polymers with OPFs, few have considered the potential applications of these biocomposites. They mostly used synthetic polymers and, as a result, biodegradability could most probably be improved using OPFs to reinforce recently developed biopolymers. Interest in OPFs could be improved by identifying potential applications of OPF polymer-composite materials. More OPF products are likely to reach the commercial market if researchers focus their activities on specific applications.

In summary, present use of OPFs is limited and struggling to compete against synthetic fibers in the market. There are gaps in both fundamental and applied research that need to be filled before OPFs and OPF polymer composites can penetrate the market more effectively. The complex nature of OPFs and their composites means that confidence in their suitability for end-use applications requires more data on properties. A notable difficulty is that OPFs are chemically hydrophilic and so absorb water. This leads to poor adhesion between the matrix and OPFs after aging and adversely affects the mechanical properties. It is, therefore, necessary to identify effective physical, chemical, or thermal treatments to reduce water absorption, so that OPFs can be used as reinforcement for polymer composites. Hybrid composites, prepared by combining synthetic fibers with NFs, can also overcome the limitations of OPFs. Although they have been used commercially in applications such as fiber board, medium-density board, and fiber mats, until now collaboration between industries, research institutes, and universities has been inadequate.

In recent times, development of novel renewable or biobased polymers has started. Renewable biopolymers are preferable to man-made materials for the protection of the environment. A variety of such biopolymers or renewable-based resins obtained from vegetable oil, starch, agroproducts, or biomass have been reported.[8–11] As a result, we are working to develop biopolymer or renewable resins. We are looking into how to produce bioresins from organic waste such as biomass or agricultural waste. For instance, we are currently trying to develop a phenolic-based resin from oil-palm biomass and would like to test its physical and mechanical properties by reinforcing it with different NFs such as OPFs, banana, or pineapple fibers. Furthermore, we are continuing work to identify the best technique to eradicate or reduce water absorption in biocomposite materials.

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