Natural Fiber Composites: Now and the Future

Results of current studies of natural fiber composites and future trends

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Focus and restrictions – The focus of this paper is on natural fiber composites that have potential to be used in building structures. Not all the composites and process methods will be discussed and only recent studies will be taken into account. And the results of the studies will not be in fully detail.

Abstract – Because of the environmental awareness, materials made from renewable sources are becoming more attractive. That is why biocomposites have a lot of potential to be used in building structures. However, at this moment they are not used in many applications because of the existing drawbacks. These reoccurring problems are water absorption, ultra violet resistance, fire resistance, dimensional instability, biological resistance and strength. Many researchers are trying to improve biocomposites in various ways. But what is the current development of NFC's and what are the possibilities for the future. The researchers have made some impressive progress, but there is still a lot more development needed, before the biocomposites meet the requirements of building structures.

Key words – biocomposites, natural, fibers, nano, cellulose, resin, future, trends.

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1 Introduction

Due to the environmental awareness, materials made from renewable sources are becoming more attractive. Nowadays there is a growing utilization of FRP's in the building structures. FRP's have an energy intensive production process and because of the synthetic fibres and plastic causes a limited recyclability. This leads to an increase of research of high performance and bio-degradable materials (Shah,2013). An alternative is biocomposites, these can be made out of natural fibers. Natural fibers can be obtained from renewable sources such as plants and animals. These fibers have a lower cost and lower weight compared to synthetic fibers, but the other advantages compared to synthetic fibers, see table 1.

Properties	Natural fibers	Synthetic fibers
Mechanical	Moderate	High
Water sensitivity	High	Low
Thermal sensitivity	High	Low
Resources	Infinite	Limited
Production procces	Low	High
Recyclability	Good	Moderate

Table 1. comparison between natural and synthetic fibers
Note. Reprinted from Applications of Natural fibers and Its composites: An overview, M. R. Sanjay, G. R. Arpitha, L. Laxmana Naik, K. Gopalakrishna, B. Yogesha, 2016, Natural Resources, 2016, P. 109, 2016 by authors and Scientific Research Publishing Inc.

There are a lot of studies and great potential of NFC's. However, what are the current state and limits of this material and can NFC's be applied in the building structures at this moment. And what are the possibilities for the future, will this material be improved?
This is the main objective for this paper, to show what the current development is of NFC's and what the possibilities are for the future.

The structure of this paper is as following; first off, an overall introduction of the NFC's will be explained. Second, a summary of the current drawbacks of NFC's. Third, the current development and results will be presented through a couple of reports, these are in a time frame from 2005 till present. And at last what are the future trends and possibilities of NFC's.

2 Methodology

The literature that is used are results of reports from different researchers. The results are compared with each other, to see if there similarities and confirmation of the results. This paper is based on a literature study regarding natural fiber composites. The results literature found is reliable due to the scientific publisher or universities and the studies are from 2005 till present.
All the studies are derived through google scholar and have been published by different associations. The keywords used are: biocomposites, natural, fibers, nano, cellulose, resin, future, trends.

3 Early stages of NFC's

First off, an overall introduction of NFC's will be given. This include a short summary of how a natural is constructed, an explanation why it is essential to pretreat the fibers and the overall process methods that are used at the moment.

3.1 Natural fibers

Biocomposites are the combination of natural fibers or biofibers with polymer matrices. These fibrous material are derived from minerals, plants, or animals. The fibers of the plant or mostly used for engineering purposes. Natural fibers of plants are complex, three-dimensional, mainly build of cellulose, hemicellulose, pectins and lignin (Yatim et al. 2010).

Celluose: a long chained of linked sugar, a highly crystalline, linear polymer of anhydroglucose molecules with a degree of polymerization. This is the main component for strength, stiffness and structural stability (Sense, 2010).

Lignin: It is a complex polymer found between the tissues of the plant It serves as an chemical adhesive within and between fibers. The more lignin a plant contains, the woodier it becomes. In addition to providing support and structure, the polymer also helps the plant to conduct water (McMahon 2016).

Pectins: These are key components in non-wood fibers, especially bast fibers. The lignin, hemicellloses, and pectins collectively function as matrix and adhesive, providing stability of the cellulosic framework structure of the natural

composite fiber (Yatim et al. 2010).
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3.2 Pretreatmens and handling

Due to the hydroxyl groups from the cellulose and lignin, the natural fibers are responsive to modification. With different treatments *(isocyanate, acrylation, permanganate, acetylation, silane and peroxide)* together with a diverse coupling agents, the natural fibers will improve their strength and matrix. Easy chemical treatments can be used to change the surface tension and polarity of the fiber. The extensive chemical components of natural fibers contain hydroxyl and oxygen containing groups that absorbs water through hydrogen bonding. Natural fibers absorbs less water in the final composite, because they are partly enclosed by the polymer matrix. Nonetheless, even small quantities of water can influence the performance. Before the fibers are used, it is important to use a process that cause insensitive to water or fibers must be dried before or during the process. The methods of reducing water absorption are dispersing and enclosing the fibers in matrix during compounding, limiting fiber content, improving fiber matrix bonding, chemically modifying the fiber or protecting the composite from exposure to water. (Yatim et al. 2010).

3.3 Manufacturing process for biocomposites

There are different methods to process biocomposites that range from low cost and simple to high cost and complex. According to yatim et al. (2010) the selection of the molding process is usually based on two major factors: First, the volume of the product to be manufactured and second, the required end-use properties of the product. Table 2. show the different methods of production processes that are used manufacturing NFC's products.

Process	Production spee	Cost	Strength	Size	Shape
Filament winding	Slow to fast	Low to high	High	Small to large	Cylindrical and axisymmetric
Pultrusion	Fast	Low to medium	High (along longitudinal direction)	No restriction on length; small to medium size cross-section	Constant cross-section
Hand lay-up	Slow	High	High	Small to large	Simple to complex
Wet lay-up	Slow	Medium	Medium to high	Medium to large	Simple to complex
Spray-up	Medium to fast	Low	Low	Small to medium	Simple to complex
RTM	Medium	Low to medium	Medium	Small to medium	Simple to complex
SRIM	Fast	Low	Medium	Small to medium	Simple to complex
Compression molding	Fast	Medium	Medium	Small to medium	Simple to complex
Stamping	Fast	Low	Medum	Medium	Simple to contoured
Injection molding	Fast	Low	Low to medium	Small	Complex
Roll wrapping	Medium to fast	Low to medium	High	Small to medium	Tubular

Table 2 Production process Note. Reprinted from Yatim, J. M., Khalid, N. H. B. A., Mahjoub, R. (2010). Biocomposites for the construction materials and structures. Faculty of Civil engineering, Universiti Teknologi Malaysia

4 Drawbacks of NFC's

At this moment the bio composites still have room for improvement. After treatments the disadvantages of bio composites in building structures are not completely solved. These drawbacks mentioned by Yatim et al. (2010) are water absorption, ultra violet resistance, fire resistance, dimensional instability, biological resistance and strength.

(1) Water absorption: One of the critical problem is the water absorption from the environment. The hydroxyl and oxygen containing groups, causes the absorption of water through hydrogen bonding. If the moisture composition of the fiber is changed, it will causes swelling and the fiber will shrink if it loses the moisture. This will have an enormous impact on the performance of the biocomposites.

(2) Ultra violet resistance: When the NFC's are exposed to UV light photochemical degradation will occur. This is due to the existing lignin which leads to colour alternation. When the first layer of lignin starts to degrade, the content of the cellulose derive to the surface. Which causes the carbon hydrate rich fibers corrode from the surface and a second layer lignin will be exposed to UV light, that will eventually degrade as well.

(3) Fire resistance: Flammability is a very important criterion the variety of applications. As a result of the low fire resistance, NFC's are not often used as a construction component. The challenge is to create a higher fire resistance of the two main components (binder and filler). To ensure that it will maintain it mechanical properties for a period of time (Giancaspro, et al. 2008).

(4) Dimensional uncertainties: NFC's have dimensional instabilities in thickness and in the continuous expansion. This is because they have two types of expansions, reversible expansion (normal expansion) and irreversible expansion. The irreversible expansion is caused by the release of compressive stresses transmitted by the production process.

(5) Biological resistance: NFC's are branded as biodegradable. The advantage is that overtime, it will break down in to natural elements that are not harmful for the environment. However, this is a disadvantage for building structures. These are mainly long lasting products and required to provide stability until end of life.

(6) Strength: The strength of NFC's are still not meet the requirements for building structures. The main weakness is the impact properties. Also the long-term performance still needs improvement (Faruk, 2011).

5 Recent results of NFC's studies

Below is a summary of couple research results of NFC's. The materials or methods that are discussed have a potential to improve the material, based on the drawbacks that are mentioned earlier. By overcoming the drawbacks the material will be more suitable for building structures. This summary include a short definition and motives of the material, how the research was conducted and the results.

5.1 Resin transfer molding

The way of how a material is processed have great effects of the end properties. It is important to realise what process fits the material the most. A promising process method for NFC's within building structures is Resin transfermolding (RTM). It is often used in the aerospace and automotive industries to manufacture complex and large components. Pothan et al. (2008) reported that RTM is an acceptable processing method. By testing sisal fiber by using RTM, the tensile strength were tested through a universal tester, with a extensometer to gain accurate measurement of the tensile young's modulus. Pothan et al. proved that good products can be manufactured with this method with acceptable qualities. Sreekumar et al. (2008) have also done a research on sisal fibers produced with RTM, but with treated and untreated sisal. By using thermogravimetric analysis they concluded that if the fiber is treated it will increase its thermal stability and decrease water absorption.

Pothan et al. and Sreekumar et al. have already proven that acceptable products can be made with natural fibers and RTM. The product can even be improved if fiber is pre-treated. Rouison et al. (2005) took a different approach to improve the NFC's properties. The aim of this study is to see if the optimize the process RTM will have effect on the material properties. In this study different proportions of hemp fibers were used. Hemp fibers were used because of the good mechanical properties (Saheb & Jog 1999). The tensile, flexural and impact properties were tested with a Sintech Model 20 testing machine connected to a computer. The creep properties were obtained with flexural creep equipment. In the first experiments the standard RTM process was used, with this process the maximum fiber content that could be reached was 23%. This was due the immense spring back movement of the fibers and because the mold was closed manually. Rouison et al. solved this problem with prepressing under 100°C. This reduced the spring back of the fibers and made the closing of the mold much easier and a higher fiber content can be obtained. By prepressing the hemp fiber it reduced the process time of RTM with 40 minutes. Not only did it speed up the process, the NPC's also of higher quality. The impact, tensile and flexural properties increased linearly with the higher fiber content. The specimen had obtained a complete homogeneity and no voids were detected. However, with the higher fiber content the NPC's still have much lower properties compared to glass fibers.

5.2 Fire retardant
A great drawback of NFC's is the poor fire resistance. To be used in building structures, they must meet the safety requirements. Therefore, the fire retardant strategies and the flammability characteristics of NPC's needs to be developed further.

Guan et al. (2015) have reported an effective fire retardant strategy. In this research they used a wood flour and plastic composite. To improve the fire retardancy, ammonium polyphosphate, modified via ion exchange reaction with ethanolamine (ETA-APP) was infused within the biocomposite. The testing of the flammability was done by limiting oxygen index, UL-94 vertical burning test and cone calorimeter. The results of this report shows that is a great improvement of the flame retardant properties. The limiting oxygen index increased with 71.6% and the vertical burning test van pass UL-04 V-0 rating. Because of the good compatibility of the biocomposite and the ETA-APP it also improved the mechanical properties.

5.3 Nano and microfibers
An important factor of the material for building structures is strength. The NFC's at this moment do not meet the required properties yet. This leads to a great challenge for researchers to develop new methods to reinforce the NFC's.

Recent studies have shown that using nanoparticles as reinforcement will enhance the mechanical and dimensional stability of the composites, along with a lower density. This can be achieved due the large surface to volume ratio (Reddy et al., 2012). In an earlier study done by Nakagaito and Yano (2003) reported that a fabricated composite with bamboo microfibers and phenlic resin can achieved a Young's modulus of 19 GPa. Huang and Netravali (2008) have also made a report about composites made from bamboo nano-fiber. Due to the microfibers, the composites can have a high tensile strength and aspect ratio. The objective of their study was to develop a fully biodegradable and environment friendly composite with reasonable strength and stiffness. Therefore they used soy protein concentrate (SPC) powder to reinforce the composite. With this method they achieved a Young's modulus of 1816 MPa and fracture stress of 59.3 MPa.

6 The future trends of NPC's

The NPC's still have the same recurring problems that are mentioned in the drawbacks. Despite the fact that the properties are improving, it is not enough to meet the requirements. Therefore the NPC's are not often used in building structures. However, the variety of application can increase depending on the further developments. According to Winandy (2007) these future NPC's need to exceed the current expectations. It must have lower cost, improved reliability and adaptability and lower maintenance together with reducing the effects on the environment. Faruk et al. also stated that the drawbacks will be solved with further developments, especially nanofiber-technology. His prediction is that nanofiber composites can conquer the drawback and be fully sustainable at the same time. Miao and Hamad (2013) made a similar statement, they reported that nanofibers have the potential to achieve highly-durable and high-tenacity composites derived from renewable resources. These developments will eventually lead to applications in the building structure. Until now the nanofiber-composites have been only manufactured by film casting or by template impregnation. The challenge for the engineers is to also make it possible for more cost-effective manufacturing methods, such as molding and extrusion. This will be more commercial attractive and this will lower the production cost and different scales of components can be made.

7 Conclusions

The potential of NFC is very high, because of their renewable nature. However, they are not often used in building structures, because the NFC's still have the reoccurring drawbacks. On the other hand the NFC's are still in development. Engineers are not only trying to improve the material properties, but the manufacturing process as well. By optimizing the process, it can shorten the process and higher quality products can be obtained. And by intelligently choosing materials that have good compatibility, they can improve the material properties.

Further research will be needed to eventually overcome the drawbacks and exceed the current expectations. If all these problems are solved, the NFC's will be suitable for building structure applications.

8 Discussion

The future trends mentioned by different researchers are questionable. This is due to the fact that they are predictions. There is a chance that the development of NFC's will not get the results that is desired. The results that are discussed in this paper are not very in detail. Therefore this will not be useful in further studies.

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