RICE STRAW FIBER BIOCOMPOSITES POTENTIALS IN CONTEMPORARY ARCHITECTURE

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ABSTRACT

Compared to synthetic fibers, natural fibers have many advantages such as renewability, availability, low cost, biodegradability, non-toxicity and other excellent properties. Rice Straw Fiber (RSF) is considered to be an important but still abundant natural fiber when compared to other known industrial natural fibers like jute, kenaf and hemp. Inspite of the fact that RSF is considered one of the highest biomasses in the world, it still lacks much more deep research to investigate all its possible potentials in different industrial fields, especially in the building industry. On the other hand and as a result, this fibre with all its potentials is still illegally burnt in huge amounts worldwide causing extreme environmental damage as it's still considered an agricultural "waste", much more than a "resource" of its own.

Thus, the main objective of this paperwork is to highlight the potentials of rice straw fiber as an active filler together with its reinforcement activities in biocomposites as well as the "as –is" method of using this fibre in its raw form in direct building applications that should be also discussed. This will be achieved through the analysis and synthesis of a number of technologies, examples and applications of rice straw fiber composite materials. In addition, different technologies used in the industrialization of such biocomposites will be illustrated according to the outcome product reached, and categorized.

Key words: Rice Straw Fiber, Agricultural Waste, Biocomposites, Straw-based fibre and particleboards, Straw Bales

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1. INTRODUCTION

One of the main types of biomass is the agricultural residues. Agricultural residues in specific has been for a long time only directed towards the conventional cattle fodder usages, or beddings. It has even been burnt in huge amounts, especially straws, due to its huge amounts that overflow such usages. One of the most promising applications of such wastes' "resources" is the natural fibre reinforced polymers- Biocomposites- and their applications in building industry.
Natural industrial fibres include specifically jute and hemp that are planted especially for the fibre usage and not for feedstock purposes. Unlike such fibre types, wheat, rice and maize are planted especially for feedstock purposes, whether for humans or for cattle or both. In any case, the main interest in such annual crops' agriculture is the seed itself- the cereal- and not the residues left over after harvesting. That's why huge quantities of such residues are so often burnt after re-using relatively small amounts of them in conventional applications.
On the other hand, and as the problems of conventional limited usages of straw aren't completely been solved, fibre application industries are in great thirst to new available and cheap fibre types. Paper, furniture, boards and fibre reinforced composites' industries are examples of such industries that have long depended mainly on wood as a main source for such industries. The steady increase in the demand of the wood fibre is gradually leading to a worldwide shortage of wood fiber supplies. Since the 1980's, depletion of the world's forests has steadily increased the price of raw wood and wood-based products (Sun 2010). One possible solution to this problem lies in the use of annual non-wood plants, where straw is a direct available presenter of them.
Legislations had even participated within this issue, especially in North America and Europe (Mo 2005). In Europe, many legislations were set to force to find other solutions than landfilling (EU Legislation), the thing that led industrial owners fetch through researchers on other methods to become more sustainable.

2. WHY RICE STRAW

2.1. Cereal straws' quantities

Cereal grains compose up to 80% of the world food supply according to the United Nations Food and Agricultural Organization (FAO) in 1984. The total amount of cereal production in 2010 is approximately 2422 million of metric tons – fig.(1) , whereas the highest cereal crops' productions are the maize, rice and wheat respectively, forming around 87% of the whole cereal annual production- fig.(2).

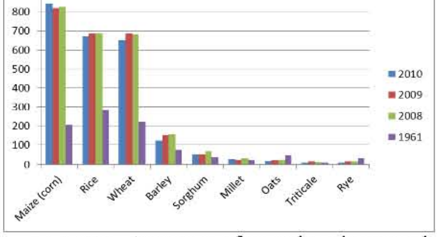

Figure 1. Amounts of cereal grain annual production for the years 1961 in comparison to 2008, 2009 and 2010 . (wiki-cereal)

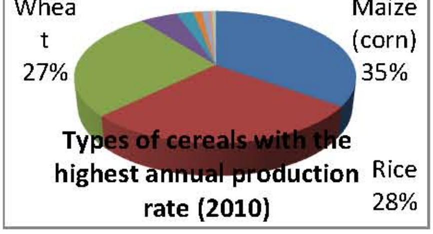

Figure 2. Percentages of the highest crops' production rates for the year 2010. (Derived from the data available –see left.)

Straw, the stem of the cereal plant that remains after the seed needed for nutrition is removed, composes about half the total dry weight of the crop (Sun 2010). For many centuries, straw has been utilized as animals feeding livestocks, bedding and many other limited applications. However, these limited applications have never been enough to consume the huge straw amounts produced annually worldwide.

In addition, the drawbacks of the straw as an animal fodder increased dramatically the problems of the accumulated straw. The feed value (digestibility) problems are the main reasons for such drawbacks of the straw when used as a fodder due to the chemical structure of the straw. (Han et al 1974)

2.2. Rice Structural and chemical composition of rice straw in comparison to soft- and hardwood

Rice straw is a plant similar to wood in its inner components of cellulose, hemicelluloses and Lignin but with different percentages that makes the inner properties totally different and of other potentials.The length of rice straw varies widely from 30 to 500cm, depending on cultivation methods (Mo 2005). The top section of the straw is branched and consists of the thretched-out remains of the grain-bearing particle.Rice straw fiber (RSF) has a length in the range of 0.65-3.48 mm and diameter of 5-14 μm, with a long aspect ratio of 170 (Atchison 1983).

Rice straw has the highest silica contents within all crops species (9-14%). Secondly comes wheat straw with high potentials as well uptill (4-10%), while wood has less than 1% silica contents (Pekarovic et al 2008). These huge silica contents are of great potential benefits regarding the flame retardant when used in building industry (Buzarovska et al 2008).

Chemical composition of rice straw in comparison to wheat straw and wood , in percent of dry matter, can be described within table. (1) as follows:

Straw/Plant	Cellulose	Hemi-cellulose	Lignin	Silica	Ash
Rice straw	28-36 [a]	18–25 [c]	12-16 [a]	9-14[a],[d]	15-20 [a]
Wheat straw	38-46 [a]	20–32 [c]	16-21[a]	3-7[a]/4-10 [d]	5-9 [a]
Soft wood	40-45 [a]	7-12 [e]	26-34 [a]	-[a]/<1[d]	<1 [a]
Hard wood	38-48 [a]	20-25 [e]	23-30 [a]	-[a]/<1[d]	<1 [a]

[a] Tappi, 1983. [b] Roxas et al (1984). [c] Galletti A. et al.2011 [d] Pekarovic et al 2008. [e] Chander et al 2007.

<u>Through the previous comparison, the following facts can be after analysis concluded as follows:</u>

- Potentials of cereal straws and rice straw specifically, are focused in the high contents of ash and silica, which are of anti-flammable characteristics that can be well used in building applications. In addition, silica works against rapid biodegradability which can be of much higher potentials when combined with biodegradable polymers, to increase the life time span as well as increasing fire resistance and mechanical behavior.

- Lower lignin contents are as well a factor that shows the non-tendency towards rapid combustion as in the case of soft and hard-woods.
- Hemicellulose content is much higher in straw than wood, which is an important source of many chemical industries including adhesives, paints and others (Sun 2010).
- Layers of wax, silica and protein represent together a dense coating on the straw's surface working for natural defense for the epidermis, ie. the single-layered group of cells covering the inner plants' parts (wiki-epidermis), against moisture loss. These layers prohibit the proper bonding of the fiber with the resin, posing problems in straw-fiber and particlebordas production (Schmidt et al 2002). In many researches, chemical treatments are applied for better compounding and polymer binding to obtain better mechanical properties (John et al 2008). However this cause an extra cost factor in the manufacturing process in addition to losing important potentials of the fibre as silica contents that has already its high potential as discussed. It's here therefore suggested that the fibres are better to be mechanically treated by chopping without extra chemical modifications, better than making another burden on the environment through chemical wastes released, instead of only agricultural wastes present, which makes the problem doubles. Chopping will give the opportunity for the outer surface of the fibre to be opened and easily subjected to the polymer when combined and hence better encapsulation and performance (Mantanis et al 2001).

3. STRAW-BASED BIOCOMPOSITES; PARTICLE-; FIBRE- BOARDS AND PANELS

As straw contains the same basic chemical components of wood, as previously declared, it can be crushed to chips or particles that can replace the wood particles and fibres in boards applications. But the difference in the chemical properties between them still poses challenges to produce straw-based panels using existing manufacturing technology for wood panels (Xiaoqun 2005) Therefore, great efforts for developing straw-based panels with similar and alternative technologies in addition to various fibre physical and chemical pre-treatment before compounding, has been highly established.
Compatability between the fibre and the binding polymer in this case is of great concern. This is in addition to the manufacturing technique itself. Polymers have huge varieties through which varieties in types and forms of achieved products can take place. Through the following criteria, a collection of different possibilities of rice straw biocomposites' manufacturing and applications according to the binding materials- the polymer types- being applied with the fibre:

3.1.Applications with organic binders:

This includes the 3 known branches of polymers including the thermoplastic, thermoset and elastomeric types, where each type can be of either bio-based or petro-based origin and can be either bio-degradable or not.
Generally, the mechanical properties of thermosetting polymers have much higher mechanical performance than that of thermoplastic ones (H.Ku et al 2011).

3.1.1.Thermoplastic Biocomposites

3.1.1.1 Non-biodegradable composites

This was achieved in many researches including binding rice straw with petro-based thermoplastics including PE (Polyethylene), PP (Polypropylene)and PVC (Polyvinyl chloride).

Commercially, examples of available products out of other straw types (as wheat straw) and recycled plastics are: TerraFenceTM and TerraDeckTM, in addition to Ricycled TM from recycled PVC and rice husk .

3.1.1.2. Biodegradable composites

Many researches since the past decade have been applied in this area, examining the improvement of the mechanical properties of the biodegradable polymers using natural fibres, including straw (Avella 1993,2000). In addition, many investigations on reinforcing bio-foams like PLA by straw fibres as an effective eco-filler, has been applied. In France, the research team in Materials Research Centre in Ecole des Mines d'Alès , has established a new material generation in this direction of biodegradable wheat straw fibre reinforced starch foam (Bergeret et al 2011). The applications for such composites are still limited in the packaging systems, agricultural purposes, but not yet in the building industry.

The challenge is always the critical limited life time of the final product that is crucially needed in case of building applications, regardless of the biodegradation at the end of its useful life time (v.s.). Fire behavior is also a great issue that can either be improved through mineral phosphorus additives (Matko 2005), or through the fiber itself,as here suggested through the natural high silica contents present.

The authors have already tackled this area through flammability tests (according to UL-1694 and UL-94) occurred on poly lactic acid /Rice straw fibre (PLA/RSF) and conventional polypropylene/Rice straw fibre (PP/RSF) samples, in which only the fire behavior was studied without reaching a specific material class. The result was that PLA/RSF showed much more stability when ignited and was in many samples first self-distinguished before being secondly ignited. On the other side PP/RSF started melting directly after ignition and parts were dropped on the indicator directly combusting it. It is believed that the high compatibility between the natural fibre and the biopolymer are the reasons behind the better behavior of the green composite. The comparison was achieved between the two composites, where the same fibre type and the same fibre loading (uptill 20% by weight) was applied. This shows another positive aspect for the rice straw in biocomposites' applications.

3.1.2.Thermoset Biocomposites:Natural fibres are here bonded by thermoset polymers whether petro-based ones like conventional polyesters and epoxies, or plant-oil bio-based polymers.

Products out of such bio-based thermoset resins to binde rice straw of different origins were designed and produced by the authors and students of the third year in the faculty of architecture- University of Stuttgart within the framework of a course named "Do it Yourself" in SS11, supervised by the first author. The products are composed up to 40% by weight of fibre contents, figs. (3) and (4) .In addition, Rice straw/classic epoxy resin with different coloring and textures were also achieved, fig.(5)

Figure 3. TraShell™ from rice straw, organic ash and bio-resin.

Figure 4. BiOrnament™ applied as inner cladding, out of rice straw, bio-resin and natural pigments.

Figure 5. Strawave™ applied as inner cladding, out of rice straw and uncolored conventional epoxy resin.

3.1.3.Elastomeric Biocomposites:Waste tires binding rice straw is an example on this type (Yang 2004). After physical treatment of cutting and milling the fibre, polyurethane binders applied together with hot pressing to produce sound absorbing insulating boards. The produced products are recyclable, but not bio-degradable.
Another example achieved by the authors is a biocomposite of rice straw and thermoplastic elastomer in powder form, through which uptill 80% fibre -by weight- were binded to form insulation inner boards.

3.2. Applications with inorganic binders
This includes the cement and phosphate binders' technologies. In case of Cement bonded boards and blocks, fibre is applied to reinforce the cement when bonded with it, as well as decreasing the amount of cement being used by replacing it through the added fibre content. Another application with cement is the replacement of the cement itself through the straw ash, due to its pozzolanic activity, according to (El-Sayed et al. 2006). Applications include building blocks and ceiling panels

3.3.Applications without binders or fiber modifications- 'as-is':
3.3.1. Non-adhesive bonded boards for insulation:This is often known as "self-binding", and it occurs if the fibres are pressed in high temperature and pressure releasing its inner lignin components (van Dam,J.E.G. et al. 2003), hence combining the straw fibres without the need of external binders.
Such boards are not for structural purposes, but more for heat and sound insulation, inner partitions as well as decoration purposes.
3.3.2. Baling, walls and filling systems:There are two systems to build with straw bales, either when stacked tightly to form load bearing walls systems that can hold

its own load in addition to the roofing, or can be stacked as a non-structural insulating walls between timber, metal, or masonary structural frame supporters of the roof. In both cases, the bale walls are either plastered or stuccoed on both sides, indoors and outdoors. This system guarantees perfect heat and sound insulation in addition to fire resistance due to the dense packing of the bales as well as the natural inner high silica components (John et al 1996).

In addition to all previously mentioned potentials, many chemical industries serving the building industry can be derived from the inner chemical components of the rice straw, especially the hemicellulose, including coatings, paints, adhesives and chemicals (Sun 2010).

4. CHALLENGES AND LIMITATIONS:

4.1. Compatibility with polymers:

Compatibility of the natural fibre with the thermoset resins in specific is not that high because of the hydrophilic nature of the natural fibres in opposition to the hydrophobic nature of the resins. This causes plasticity nature during the compounding process that causes undesirable lower mechanical properties than expected. That's why alkali-treatment was the solution for many researchers to overcome the uncontrolled humidity in the natural fibre, through strengthening another aspect in the fibre-resin adhesion factors, which on the other side caused chemical wastes with recovery difficulties.On the other side, the fibre's combination with thermoplastics is pushed back with the limited processing temperature (maximum 200 degrees), otherwise the natural fibre itself would decompose. That’s why the compounding of the natural fibres with thermoplastics are limited to plastics with relatively low-melting points like PP and PE (Kakroodi et al 2007).

Some applications and forms (especially free form panels of thickness more than 2-3 mm) would need more than 200 degrees to be thermoformed for instance. In such cases, a partial degradation of the fibre might occur before even being applied and hence lowering the desired and needed mechanical properties. However, using plasticizers and additives can overcome such temperature problems.

4.2.Manufacturing techniques

<u>4.2.1. Humidity control:</u> One of the main problems is the humidity control, which is a drawback for natural fibres in general. Chemical modifications can improve this problem greatly, however has its own problems concerning releasing chemical wastes and cost effectiveness.

<u>4.2.2. Machining:</u> Most of the machining used for thermoplastics are applicable with natural fibre reinforced thermoplastics as well especially in the case of short fibres’ usage. This includes extrusion, injection molding and thermoforming. In case of thermoset polymers, limitations for short fibres’ applications largely exist, especially that lots of these techniques are based on long fibres’ processing. Press moulding therefore together with Hand layup are applicable in short fibres’ appliance, while filament winding technique is applicable in case of continuous fibres. Technologies for production of rice straw mats should be further applied to increase the

opportunity of the fibre's processing potentials and manufacturing possibilities. In fig (6), an example of a weaving straw machine is shown.

4.2.3. Dust control during chopping: One of the main problems in the chopping process is the huge dust released causing dust clouds, with risks of lung diseases. Therefore, an appropriate ventilation system together with an acceptable method of soaking out the dust at the same time should be applied and connected directly to the machine at the same time of chopping/milling- as shown in fig. (7).

Figure 6. weaving straw machine, supported by Zhengzhou Thoyu Import & Export Trading CO., LTD

Figure 7. The chopping machines is directly linked and integrated with the collector and dust absorber, avoiding the dust clouds. Machine is supported by

6. CONCLUSION

Current applications of straw-based biocomposites and boards are still in the early stages of development. Chemical modifications of the natural fibre before compounding to optimize the adhesion quality between the fibre and the matrix applied, might not be the optimal method to be used. Hence, other compatible matrices with the natural fibre with the least possible applied chemical modification should be further investigated. One of the suggestions would go further towards bio-based polymers which are derived from a much nearer base than a fossil-base, to the natural fibre itself. In this case, further investigations on life time of the final product and aging should be properly examined so as to suit the applications in building industry.

Rice straw can have much further applications when rice straw mats are applied in industry on much wider scales. In addition, the problematic huge volume of the loose straw or even the bales themselves can be much decreased, especially when straw mats can be directly manufactured in fields and moved in this form to industrial applications.

In addition,further efforts are needed to take place to raise up the level of the architectural applications and reach up to much more attractive architectural products. Colouring, textures and forms are very important keys in the architectural design of the products. With the help of natural pigments, laser cutting, free-form panels' manufacturing much more attractive products could be reached replacing the conventional ones in the market.

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