"Crop residues, the alternate raw materials of tomorrow for the preparation of composite board"

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Abstract

The rapidly changing economic and environmental needs of society are putting ever-increasing pressures on the forest industry to "do more with less". In practical terms this means, increasing the conversion and efficient use of wood fibre resources, producing more fibre on a shrinking land base, using environmentally friendly processes and technologies considering the use of non-wood ligno-cellulosic fibres for industrial products.

One of the ways the forest industry has responded to the global challenges in fibre utilization and processing efficiency was through the accelerated development of composites.

A new environmentally friendly technology for turning agricultural residues like bamboo, rice husk, jute, coconut coirs, bagasse. wheat straw, chir pine needles, cotton stalks, casuarina leaves, banana stem etc., into quality value-added composite products using conventional formaldehyde-based resins have been developed. The new technology highly favours environmental protection and sustainable development by recovering and re-utilizing organic wastes such as crop residue. Adoption of these technologies also leads to Implementation of a green solution as an alternative to crop residues being burnt and disposed into soil. Composites from crop residues eliminates the release of carbon from decaying crop residues into air, which contributes to the global warming through greenhouse effect and also decreases the constantly growing pressure over the forests for wood resources. The crop residues were not being utilized earlier for board production with the use of conventional formaldehyde based resins due to its fibre cells being surrounded by a layer of wax/silica. This layer prevents the water based formaldehyde resins which are widely used today in all plywood industries from forming a sufficiently strong bond between the fibres. However, the new technology enables the destruction of the wax/silica layer by using mechanical high shear forces accompanied by a thermal and chemical treatment. This combined chemi-thermo-mechanical process allows the formaldehyde resins to penetrate and adhere the individual fibres. The panel products produced meets the requirement of strength properties as per the relevant specifications.

*Int*roduction

With dwindling wood resources on one hand and increasing demand for the wood based panel products on the other, attention is gaining momentum on the utilization of agro-residues and also recycling of wood waste for manufacture of panel products. Unlike plywood, Particle Board (PB) and Medium Density Fibre Board (MDF) provide enough scope for the substitution of wood by non-wood fibre resources. However growth of PB and MDF industry in India has been sluggish compared to world trend in this field because of high production cost, high cost of petroleum-based resin adhesives and resistance by the carpenters who have been playing key role in shaping the consumer acceptance with this material.

The PB production in India was started in 1950 and as on date there are approximately 14 units working. Out of these, two units which have started production of PB and prelaminated PB and marketing their products under the trade name “Eco Board” is totally based on sugarcane bagasse raw material. Both the units are situated in Maharashtra State and set up with imported machinery. One at Jambhulwadi in Sangli district which has the production capacity of 15 lakhs sq. mtrs. Per annum and onother unit at Velapur in Solapur district which has the production capacity of 26 lakhs sq. mtrs. Per annum. PB production has largely remained wood based despite availability of non-wood raw materials whose stability to produce PB conforming to Indian standards specification, has been thoroughly investigated at the Institute, for example, Rice Husk Particle Board, Pine Needle Particle Board, etc. some of these products have been demonstrated at the pilot scale level and commercialized. However, the greatest obstacles to increase the utilization of non-wood fibre/utilization of agro –residues are difficult in collection and storage of raw material is available in sufficient quantity but not used due to problems associated with technical intractability or alternate use considerations or both.

However, the appetite of the construction industry for structural wood products continued to grow. Thus, the 1970s and 1980s witnessed the rapid development of structural wood composites, both panels and lumber substitutes The rapid evolution and manufacture of these wood composites would not have been possible without high performance synthetic adhesives. Indeed the wood composites and adhesives industries developed a profitable interdependence. Even in India , with its huge forest resource, there is increased demand and competition for wood residues by the paper industry and the rapidly growing composites industry. This makes the use of alternative fibre such as agricultural/crop residues more attractive and feasible. In addition, the move to find substitutes for solid wood has been stimulated by factors, such as diminishing resource quality, rising timber prices, and growing world demand for wood products. Composites are an attractive application for these materials because their manufacturing processes are highly automated and adaptable to various types and forms of raw material.

The paper and wood-based panels industries make use of forest wood as a raw material for their products. The use of other renewable resources such as agricultural residues (wheat straw, rice straw, etc.) in the production of composite panels (i.e. particleboards, fibreboards) and paper products has recently been considered attractive both from the economical and environmental point of view. The use of straw can by this way help to protect the virgin forests in regions where there is a shortage of wood.

In addition, great quantities of straw residues are available today in other parts of the world where the burning of straw has been prohibited, and no proper (efficient) uses for these wastes have been found up to day. An innovative environmentally friendly process for turning agricultural residues (agriwaste) into quality boards suitable for use in the furniture and construction industries has been developed

POTENTIAL FOR USE IN COMPOSITEPRODUCTS

In India, grain and other seeds are the main objectives of the farming activity, there is great interest in developing uses for residues that are currently burned or ploughed back into the ground.

Most of the developing countries are very rich in agricultural and natural fibre. Except a few exceptions, a large part of agricultural waste is being used as fuel. India alone produces more than 400 million tonnes of agricultural waste annually. It has got a very large percentage of the total world production of rice husk, jute, stalk, baggase and coconut fibre. All these natural fibres have excellent physical and mechanical properties and can be utilised more effectively in the development of composite materials for various building applications. The quantity of these materials available are shown in Table I

From centuries, mankind has used natural fibre for various types of application including building materials. In most of the countries, users have explored the possibilities of using natural fibre from different plants, which includes bagasse, cereal straw, corn stalk, cotton stalk, kenaf, rice husk/rice straw etc. Most of the fibre were used mainly for the production of hard board and particle board. Emergence of polymers in the beginning of the 19th century has provided the researcher new dimensions to use natural fibre in more diversified fields. At the same time, necessity has also increased the interest in synthetic fibre like glass fibre which, due to its superior dimensional and other properties seems to be gaining popularity and slowly replacing natural fibre in different applications. As a result of this change in the raw material and production process of synthetic fibre based composites, energy consumption has increased.

The environmental loss suffered by society due to pollution generation during the production and recycling of these synthetic based materials has once again drawn attention to the use of natural fibre. The renewed interest resulted in new ways of natural fibre modifications/use and brought it to be at par/superior to synthetic fibres. Now it is in use from making rope to spacecraft applications and the building industry has also come up as one of its main beneficiaries.

Table I
AGRO & FOREST RESIDUES AVAILIABLE IN INDIA

No	Particulars	Tonnes/ annum (in millions)
1	Rice Straw	18.0
2	Wheat Straw	73.5
3	Rice Husk	20.0
4	Coconut Husk	37.5

5	Cotton Stalk	4.4
6	Bagasse	6.0
7	Pine Needles	2.7
8	Non edible grasses	170.0

Natural fibre and crop residues composites in India

Due to the light weight, high strength to weight ratio, corrosion resistance and other advantages, natural fibre-based composites are becoming important composite materials in building and civil engineering fields. In case of synthetic fibre based composites, despite the usefulness in service, these are difficult to be recycled after designed service life. However, natural fibre based composites are environment friendly to a large extent.

The present requirement of wood in India is about 29 million cubic metres, whereas the estimated production is about 16 million cubic metres only. Apart from wood, natural fibre composites are emerging with an increasing role in building industry to replace timber, steel, aluminium, concrete, etc. Composites are being used for prefabricated, portable and modular buildings as well as for exterior cladding panels. So far, the utilisation of sisal, jute, coir and baggase fibres has found many successful applications.

Rice Husk Particle Board

Among, all the agricultural residues, the most abundantly available is rice husk. It is the by-product of the most important agro-based industry in the country, namely pady milling. Rice husk is available in the country to the extent of 2 million tones per annum. Research work to find ways and means to utilize rice husk for the production of useful materials has been under way for the past two decade or so. However due to its high silica content the conventional process of making particle board was not **successful.**

Research work to find ways and means to utilize rice husk for the production of useful materials has been underway for the past three decades or so. However, because of its unique chemical composition, not many successful methods have been evolved.


Rice Husk Particle Board ***Ceiling in Class Room***

The major chemical constituents of rice husk are:

Cellulose - a polymer of glucose, about 28% by weight; pentosan - a polymer of hexoses and pentoses, about 26% by weight; Silica - about 15 to 22 % by weight. It is important to note that the structure of the siliceous and organic components is in association through out the husk.

Because of the silica content and contagious association mentioned above, rice husk is difficult to burn. In processes making use of the ash, 80% of the material gets burnt off. When used as a raw material for chemicals as Furfural, the yields are very low when compared with such raw materials such as Corn cobs. Moreover, in this and similar other processes intended for the utilization of rice husk, significantly large quantities of secondary waste by-products are obtained which is not at all a desirable proposition.

Of all the methods of utilization of rice husk developed so far, manufacture of boards by the admixture of suitable binding agents is undoubtedly the best method from the point of view of both value added and the complete utilization of the husk without any further secondary by-products.

Commercialization of the technology

The RHPB technology developed by IPIRTI was transferred in 1985 to National Development Corporation (NRDC) of New Delhi, India, A GOI Enterprise, for further development and commercialization. NRDC licensed the technology to M/S Padmavathy Panel Boards Pvt. Ltd (PPBL), Bangalore, Karnataka in 1987 and also worked through PPBL to overcome the problem generally encountered in transferring any technology from lab to factory.

As on date, NRDC has licensed the technology to seven other units in the country. The technology has also got adapted internationally through establishment of a unit in Malaysia, namely Rh Sdn Bhd. Another unit in Indonesia is reported to be in the pipeline.

IPIRTI has refined a technology for manufacturing multilayered particle board using modified phenol cardanol formaldehyde resins. The strength properties of the panels meets the requirement as per relevant specifications. The boards processes high termite decay and fire resistant.

The resulting board has emerged as a versatile substitute for wood in a wide range of applications. Moreover, the board can also be decorated by incorporating suitable colors and, therefore, can be more attractive than any wood/plywood substitute. These boards processes high decay resistance, Improved fire resistance with excellent mechanical properties like internal bond strength, elasticity, dimensional stability, screw and nail holding capacity, abrasion resistance, etc. These boards are water resistant

The proposed technology has a high environmental impact, since utilization of rice husk in one way prevents deforestation.

Bagasse Particle Board

In a study of the pulping prospects in India indertaken by FAO (1984), it was stated that by 1990, a substantial increase would occur in the capacity for pulping of bagasse. Although it was not achieved and only some beginning was made in the early nineties, it is clearly foreseen that bagasse will play a major role in the next millennium. The technology for production of paper and newprint out of bagasse is very much in place and various steps taken to "release" bagasse from sugar mills have begun to yield results. Hence, decks have been cleared for utilizing this abundant source (Anon. 1997).

Bagasse is the fibrous residue left after extraction of juice from sugarcane. The fibre content varies between 26-30 to 33-36%. On an average, it constitutes about one third of sugarcane crushed. India is the largest producer of sugar in the world, but in terms of utilization o bagasse for paper making, it ranks 14^{th}, as most of this valuable material is burnt as fuel in sugar mills and only the "saved or substitute bagasse" is available for pulping.

Bagasse is the residual pulp from sugar cane (Saccharus officinarum L.) after the juice has been extracted. A considerable amount of excess bagasse generated from sugar mills are only le`ft to rot or burned to do away with storage. As a fire and an environmental hazard, this waste material possesses a challenge in waste management to the sugar mills and a concern to the environmentalists for it presents a serious disposal problem.

Eco-board in Maharastra has been successful in producing particle board from bagasse and market acceptance of the product is encouraging. The long lasting problem of storage as been overcome by adopting technological innovations by Eco-Board.

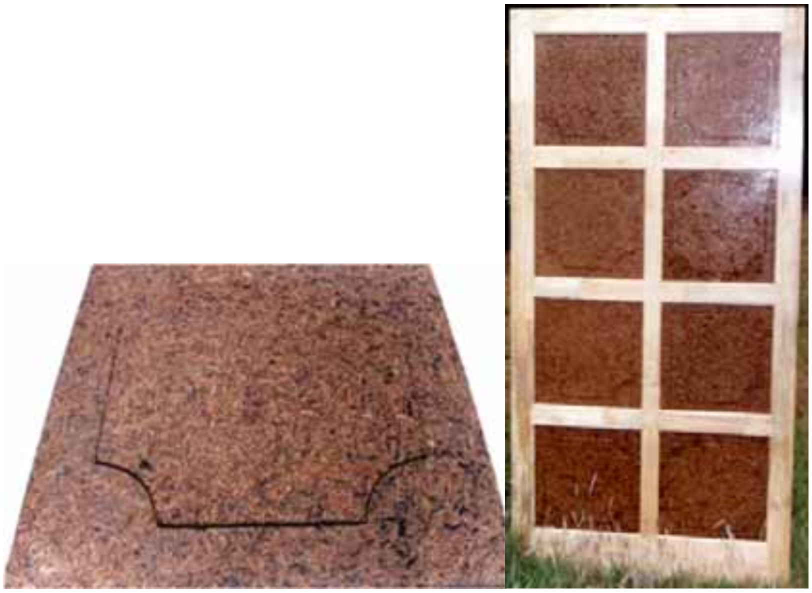
The presence of pith in the bagasse has an unfavourable effect on the qulity of board produced as it deceases the value of mechanical properties. Hence depith bagasse have been utilized in the studies. Bagasse waste attracts scientists and researchers with a greater challenge to utilize and convert this waste material into useful and low-cost marketable products. The widest application of bagasse is in the manufacture of particleboards as low-cost construction materials and for the furniture industries. About 25-30% of the sugar cane volume coming out from the sugar mills is bagasse which is more than enough to supply the raw material requirements of the existing number of particleboard factories in the country. IPIRTI has developed a technology for the manufacture of Bagasse particle boards which emits less formaldehyde and meets the requirement of strength properties as per IS: 3087- "Specification for medium density particle boards".

Bagasse particle board

Chir Pine Needle & Casuarina Needle Particle Board

Needles that are modified leaves from chir pine or casuarinas trees fall on the forest floor and make a thick layer since their decomposition is slow due to prevalent climatic conditions. Thick layer of un-decomposed needles is a major source of ground fires in the forests recurring annually. Attempts have been made to use these needles to develop usable materials. Investigations were carried out at IPIRTI to use these needles for making panel boards. To minimize the use of energy and chemicals, air dried needles were chopped and blended with modified phenolic resin especially developed to bond pine/casuarina needle particles and hot pressed to make particle boards. The pine needle board achieved all properties of wood particle board except MOR & MOE. However, three different proto types i.e., three layered particle board, film and veneer overlaid particle board & designed hard board for ceiling tiles were developed. A panel door and a teapoy were also developed to demonstrate the application potential of pine needle boards.

Chir pine/casuarinas needles can be efficiently and effectively used for manufacturing Pine Needle particle boards and overlaid particle board & hard board that will be ideal for ceiling tiles, door infills – table tops etc.



Designed door infill made from chir pine needle particle board

Jute Composites

Jute can be obtained in various physical forms from raw fibre to woven / non-woven fabrics and sticks. This gives wide option for choice of jute substrates for fabrication of composite materials. It is also abundantly available in eastern & northeastern part of the country.

Subsequently jute stick particle board has been developed and then commercialized by several manufacturers as low cost partition panels for sound and thermal insulation. Jute fabric–phenolic composite has been commercialized and used as ceiling in railway coaches replacing asbestos. The same board of higher thickness is being tried out as flooring material in railway coaches replacing plywood.

Jute-coir composite provides an economic alternative to wood for the construction industry. It involves the production of jute as face veneer and wood inside. The composite board namely Jute-ply boards as plywood substitute and natural fibre reinforced boards (jute+coir) as MDF substitute can be used in place of wood or MDF boards for partitioning, false ceiling, surface paneling, roofing, furniture, cupboards, wardrobes, etc. In collaboration with National Institute of Research on Jute and Applied Fibre Technology (NIRJAFT), Kolkata, IPIRTI has developed jute overlaid flush doors. Number of technologies using jute viz, Jute overlaid bamboo mat corrugated sheets, jute overlaid bamboo mat moulded skin board door and jute felt as an alternative to core veneers etc have been developed at IPIRTI which help to a great extent for the commercialization of jute based composites.

Jute overlaid flush doors

Coffee Husk Particle Board

Coffee Husk is also a agricultural residue which has not yet found suitable use for producing value added products. Coffee is grown abundantly in Western Ghats. It also grows in Eastern Ghats of Andhra Pradesh, South Orissa and in small quantity in Bihar, West Bengal and Assam.

The ripe seeds are sun dried and pounded or hulled to separate the fleshy cotyledons which forms the coffee powder used daily by all.
The husk remains as waste. These coffee seed husk is suitable for making particle board. Partial grinding of the husk (containing both inner and outer husk) to requisite sizes are required to achieve good bonding properties. Since coffee husk properties are similar to that of rice husk particle board , a modified phenolic cardanol resin was used to bond the material. The panel meets requirements of strength properties as per IS: 3087- "Specification for medium density particle boards".However the resin consumption for rice husk and coffee husk particle boards are found to be slightly higher than the conventional wood particle boards.

Rice straw

The residue: paddy grain ration estimated by the crop research stations is 1: 1.53 (NPC. 1990). On the basis of 1994-95 recorded production of rice, the estimated quantity of straw is about 2.2 million tones. With increased crop production (after allowing for the possible fall in residue grain ratio, on account of emphasis on high grain yielding dwarf varieties), the availability of straw is bound to increase.

The competitive uses for straw are varied and intense. The utilization pattern has shown that about 72% is used by the households themselves as fodder, fuel, roof thatching, etc. about 26% is sold to other landless households or intermediaries which is in turn sell them to industrial units. The rest is just wasted or burnt in the fields themselves. In states like Punjab and Haryana where it is not utilized as cattle feed, quantity disposed as waste or burnt is as high as 24.5% and 14% respectively. It is estimated that in 1994-95, about 1.1 and 0.3 million tonnes of rice straw was wasted or burnt in these two states.

Wheat straw

Wheat is a major cereal and extensively grown in northern India. The estimated production in 1995-96 was 70 million tones.

Although the potential is very high, possibility of utilization this quantity is not very bright, because of scattered distribution and exorbitant transport cost. Although modest scale mechanization has been introduced in harvesting operations in Stated like Punjab, the harvest combines are without baling attachments. As result, a large quantity of surplus straw (after meeting household needs and disposing to other users) is left behind and burnt.

In respect of both rice and wheat straw, no significant increase in utilization is foreseen because of the high cost involved in collection, storage and transport.

Pulverized Wheat straw Board

Cotton stalks

India has the largest area under cotton, accounting for about one fourth of worl's area of cultivated cotton. Extending over about 8 million ha, the production of cotton is 8.4% of world total. The species cultivated are: *Gossypium arboretum; G. Barbadense; G. Herbaceum; and G. hirsutum.*

Cotton stalk (stem and branches) and cotton liners (short fibres remaining on the seed after the staple fibres are removed by ginning) are important by products of cotton cultivation. The annual production of cotton stalk has been estimated as 4.4 million tonnes based on crop residue ratio of 1:3 (NPC 1990). About 1.1 million TPA is estimated to be surplus. A few small paper mills in the cotton belt have been utilizing this seasonal residue (harvested mostly in January-March and October-December), which is otherwise used as domestic fuel. According to NPC (1990) study, at least 1.1 million tonnes of cotton stalk is available for industrial exploitation.

Presently, very little quantity is, however, used. Its potential received much attention when the first MDF plant in the world based on this non wood source was established with an installed capacity of 39,000 TPA. The success of this venture would have ensured emergence of proven technology for utilizing this material.

Ground husk

India is the largest producer of groundnut, the area under this corp being about 8.5 million ha and annual production about 6.6 million tonnes. Assuming that on an average, 4 tonnes of nut yield a tonne of husk, the annual availability of this residue is almost 1.7 million tonnes. At present, this valuable resource is burnt as fuel in brick kilns and lime kilns and nut decorticating factories. It is also used as domestic fuel for parboiling rice, heating water and as separators in packaging. Although techno economic feasibility of producing particle boards from this material was established in India as far back as 1970, the technology has not been commercialized. In view of its abuindance, it is promising material (Mars, 1970).

Coconut husk and by-products

In India, the area under coconut cultivation is about 1.6 million ha and some 12,400 million nuts are produced annually (Anon. 1996). The dry weight of husk in each nut is 0.3 kg (George. J. 1970). Thus, about 3.7 million tonnes of husk is produced annually. Almost 1.2 million tonnes is utilized for making coir. Nearly, a million tonne burnt as fuel. To this, if the by-products of coir industry viz., pith from the husk used for coir, shearing waste and coir dust are added, an enormous quantity of this residue is potentially available. The feasibility of manufacturing particleboard out of dry husk by chipping and hardboard by defibration, has been established. Similarly, the feasibility of producing particleboard from retted green husk and fiberboard from shearing waste and coir dust has also been established. If it's economical replacement as domestic fuel is made feasible, he surplus, after meeting the demand of coir industry would be available to the panels industry. Since, after economical alternative fuel is unlikely to be available in the next few years, its utilization for production of panels in the near future is not foreseen. Another by-product of similar value is areca nut husk. This is, at present, burnt as fuel.

Coir composites

Since coconut is available in India in abundance, the second highest in the world after the Philippines, the coir fibre has been investigated most extensively. Most importantly, coir fibre has been recognised as highly durable fibre in all types of matrices, viz, polymer, bitumen, cement, gypsum, flyash-lime, mud, etc. Technologies for the manufacture of coir boards, coir trays as a replacement for existing metal trays, compregs and coir corrugated sheets have been developed at IPIRTI. The properties of these composites meets the requirement of strength properties with reference to relevant specification.

Investigations have also been carried out at IPIRTI to develop particle boards, insulation boards and hardboards using coconut coir pith and found it to be successful.

Coconut coir composites

Coconut coir pith

The husk of mature coconut consists of numerous fibres embedded, in a soft cork like ground tissue usually referred to as pith. The bulk density of air dried pith is about 11042 kg/m^3. It is made up of pectins, tannins and other water soluble substances and hemi cellulose. Particle boards, insulation boards and hard boards have been successfully made with and without the use of binders.

Areca nut husk

Boards are made using the Asplund process and treating them with an alkali prior to forming to reduce moisture absorption and swelling. Asplund process consists of pre disintegration of the material - soaking in cold water screening and washing of the pulp-formation felt like sheets-pressing at 100 ^{o} C and 35 to 70 kg/m^2 pressure-driving and conditioning. The amount of husk available in country is roughly 75,000 tons per annum.

Sisal fibre and its applications

Sisal fibre obtained from the leaf of sisal plant has been proved to be very suitable reinforcement in various polymeric matrices. Sisal fibre can be used to make acoustic panels and also certain composites which can be used for interiror applications. However it is observed that the extraction process of fibre is cumbersome and requires a detailed study to achieve higher yield of fibres and also its storage.

Banana Leaf sheath

Banana leaf sheath is a waste from the Banana plantation that gets rot and is of a nuisance value. Technology has been developed to produce particle board for ceiling tiles, door infill, etc.

Woven banana fibre mats are made manually or mechanically by first removing the fibrous layer from banana leaf sheath and twisting them into rope and then weaving them into mats. These mats are produced by some NGO's and are sold as table mats, etc. If these mats can be converted into as overlays for wood based panel products lots of job opportunities can be created for rural folk/farming community thus improving the economic conditions of these sectors of people.

Laboratory technology to manufacture panel materials from Banana leaf sheath in combination with wood veneer have been developed by RRL Thiruvananthapuram (RRL.T) under the project funded by BMTPC. Up-gradation /up-scaling this technology to pilot scale was carried out at IPIRTI to evolve industrial scale parameters as also to study its techno-economic feasibility for its successful commercialization. Its adoption will help to reduce wood consumption while utilizing a waste from horticulture i.e. banana sheath. In addition to easing pressure on wood, the usage of banana leaf sheath for commercial purpose for making wood alternate would also generate additional income to the farmers who grow banana plants in large scale and would help to improve their economic status. Technology has been developed to produce particle board for ceiling tiles, door infill, etc. However, further refinement in technology is required for commercial viability of the product.

Banana Leaf sheath particle board

Natural fibre composites in other countries

World production of the plant fibres is estimated to be around 3100 million tonnes in which the share of cotton fibre is around 1750 million tonnes and of straws is about 1300 million tonnes. Compared to the cost of various fibres, cotton fibre is the most expensive, followed by flax, abaca, sisal, coir and jute. Straw is cheapest one if we compare the worldwide cost of all fibres. A focused research work is in progress in almost all natural fibre-rich countries, for developing appropriate technologies for fibre-reinforced composites. A survey of planned facilities in North American countries indicates use of over 700 thousand cubic metres of agricultural fibre in the manufacturing of MDF and particles board.

A literature search was conducted at the USDA (USA) forest service. Forest Products Laboratory survey showed that almost every conceivable type of natural fibrous material could be considered for some type of building material and many of them are being used worldwide today. This account provides a good encouragement and opportunity for utilisation of natural fibres in India also for production of composites for building.

Building components made from agricultural materials fall into the same product categories as other wood based composition products. Low-density insulation boards, medium-density fibre boards, hard boards, particle board and other building components such as walling and roofing can be manufactured using natural fibres. Binders used may be synthetic, thermosetting/thermoplastics, resins, modified naturally occurring resins like tannin or lignin, starches and other organic and inorganic binders.

Table below gives you the state of art of various forest and agricultural residues. State of art on the research carried out on agricultural waste for the manufacture of particle composites

Sl. No.	Raw material	Insulation Board	Hard Board	Particle Board	Others
1	Areca nut Husk	**E**	**E**	**--**	--
2	Bagasse	**E1**	**E1**	**E1**	**E** Plaster boards
3	Banana Stem	**--**	**E**	**--**	--
4	Cassava Stalk	**E**	**E**	**--**	--
5	Coir dust Husk	**E1**	**E1**	**E**	--
6	Cotton stalk	**E**	**E**	**--**	--
7	Ground nut shell Husk	**--**	**E**	**E1**	--
8	Jute sticks	**--**	**E**	**E1**	**E** Asphalted roofing material
9	Pine needle	--	--	**E** Tried in pilot plant and found to be suitable for commercial production	--

COMPARISON OF STRENGTH PROPERTIES OF PARTICLE COMPOSITES

Sl. No.	Property Unit	Wood Particle Board	Rice Husk Particle Board	Bamboo Mat overlaid Rice Husk Particle Board	Wheat straw Particle Board	Groundnut Husk Board	Bagasse Board
1.	Density Kg/m^3	755	790	845	800-900	700	683
2.	Water absorption % 2 hr. 24 hrs.	7.5 16.0	16 30	7.0 15.5	61	-	20.7 60.4
3.	Thickness Swelling %	6.5	7.4	3.3	25	23.65	9.00
4.	Modulus of Rupture N/mm^2	16.6	14.53	32.9	25.74	11.8	21.0
5.	Modulus of elasticity N/mm^2	2800	2290	3700	3169	1396	2617
6.	Internal Bond strength N/mm^2 Dry Wet	0.55 0.18	0.37 0.12	0.39 0.13	0.368	0.3 0.15	0.52 0.13
7.	Screw withdrawal strength N/mm^2 Face Edge	1475 950	1375 1100	2200 1275	-	- -	2220 977

10	Rice Husk	**E**	**-**	**E1**	**E** with cement for bricks

Note:

E : indicates that the material has been subject of laboratory experiments only.

E1: indicates that the materials are commercialized and used industrially for board manufacture.

CONCLUSIONS

As a consequence of industrialization, change in concept on environment and increasing standard of living, types of products required by people have changed considerably. In the past wood used to constitute basic raw material for making many of our personal and domestic need. Concept on protection of environment has necessitated the stop of felling trees in forest and thus use of wood has been curtailed manifold. A new environmentally friendly technology for turning agricultural residues into quality value-added composite products using conventional formaldehyde-based resins has been developed. The implementation of the new technology will result in waste materials (agriwaste) being efficiently utilized as a sustainable resource for the industrial manufacture of commodity products like particleboards and fiberboards reducing the amounts of agricultural wastes and eliminating the pollution occasioned by the burning of such residues.

Future Research Needs

1. Research on cost effective adhesives with special reference to adhesive based on bio materials.

2. Development of suitable machineries for plantation timbers, bamboo processing and agro waste with special focus on defibrating machine, Resin applicator, mat former etc.,
3. Technological capacity mechanism for commercialization of research results and transfer of technology needs to be established.
4. Training of the technical personnel in particle Board industries.
5. Marketing strategies

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