Thermal Insulation of Rice Hull and Waste Polystyrene Foam as a Composite Material

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Abstract

This study is conducted to ascertain the insulation potential of waste materials, namely, rice hull and polystyrene foam combined, and assess their usefulness as alternative construction materials. It also attempts to determine the properties of the composite material such as Mass, Density and Thermal Conductivity Coefficient. Further, it ascertains whether there is a significant difference of temperature in the model building with and without the composite material installed.

Keywords: Thermal insulation, composite materials, insulation properties

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This study utilizes a completely randomized experimental design, which employs the fixed effect model to evaluate the average temperature reduction on the model building.

Three density group variations, namely, 400 kg/m³, 300 kg/m³ and 200 kg/m³ are used for each of the five polystyrene to rice hull proportions by volume, namely, 1:1, 1:3, 1:2, 3:1 and 2:1.

The findings of the study reveal that: (a) the composite material possesses an insulation potential comparable to some common commercial insulation materials; (b) heavier density composition of the composite material causes relatively high temperature reduction in the model building; (c) generally, the composite material develops smaller thermal conductivity coefficient when a lighter density is used; (d) the difference of temperature in the model building with respect to density is statistically significant at 95% confidence level; and (e) the thermal conductivity is statistically significant with respect to density and proportion variations at 95% confidence level.

Introduction

The Philippines, like any other developing countries in the world has been producing different kinds of solid wastes which contributed so much on the degradation of our environment. Categorically, these wastes are from industrial, domestic, institutional and agricultural sources, the volume of which varies from region to region in the country.

Specifically on agricultural waste, rice hull is one of the most significant items which is generally left in the field either burned or spread in the farmlands or left rotten in the backyards of the rice mill buildings.

The growing abundance of rice hull is a continuing environmental concern. In the Philippines, approximately 25 million tons of rice hull were produced in year 2000 (Aldas et. al., 2002). Expectedly, more and more volumes of this waste will be produced because of the increasing demand of rice in the Philippines and perhaps abroad in the near future.

In the cities and or urbanized communities, another type of solid waste is polystyrene foam which is likewise increasing. This is very popular and is commonly used in the packaging of food, equipment and other dry goods.

Polystyrene is favored for the above-cited uses due to its combined properties of strength, lightness and durability to protect valuable objects and food. It is sanitary, sturdy, efficient, economical and convenient (Polystyrene Packaging Council, 2001).

However, the increase of volume of this kind of waste is not off-setted, recycled, and or re-used, according to the survey of the literature; although there are already undergoing studies at this moment on the utilization of this waste which, if proven useful, will somehow aid in their disposal.

Considering today's atmospheric conditions, buildings and other similar structures have to be equipped with insulating materials to protect the occupants from the entry of so much heat from the outside. Usually, these insulating materials are installed in the roofs underladen by the roof sheets.

However, like any other building materials today, roof insulation material is significantly expensive which the common masses living in marginal family dwellings cannot afford to buy.

It is on this aspect that the researcher would like to make an in-depth investigation on the insulating potential of the combined rice hull and polystyrene waste material in order to come up with good, usable insulating construction materials.

Objectives of the Study

Generally, the objectives of this study are:

- to ascertain the insulation potential of the composite material; and,
- to assess the usefulness of the composite material as an alternative to construction material.

In an attempt to address the general objectives, the following specific objectives are:

- to determine the density of the raw materials;
- to determine the properties of the composite material such as density, specific weight and thermal conductivity;

- to compare the average room temperature reduction inside the model building before and when using the composite material;
- to examine whether there are significant differences to the average room temperature reduction and on thermal conductivity coefficient values, and vis-à-vis, various proportions and densities used.
- to make recommendations for the improvement of the quality of the finished product.

Review of Related Literature

Rice hull

An agricultural fibrous waste leftover after the edible seed of rice has been removed is called rice hull. Usually, these are left in the field or burnt to ashes after being produced. Worldwide rice production generates more than 100 million tonnes of rice hull waste a year. (Hall, 2001). Thus, the problem of disposal as well as its commercial potential are both huge.

Uses

In an attempt to utilize rice hull, hereunder are some of the identified uses of this agricultural waste:

Energy Source

Indigenous bio-fuels such as rice hull and other agricultural wastes can be a useful and a significant source of energy in the developing countries of Southeast Asia. These second class fuels that are produced as a processing by-product offer better economic opportunities. Their manufacturing process leading to their creation produces a concentration of materials that, although of relatively low specific energy when compared to oil or coal, is still valuable because of its immediate availability; although their drawback is that some of these fuels are produced on a seasonal basis. (Clarke, 1992)

In the Philippines, the National Electrification Administration (NEA), which is aimed to establish dendrothermal projects in cooperation with rural electric cooperatives, has implemented rice-hull fired power plant. The realistic potential aggregate contribution of rice-hull fired capacity is conservatively placed at 40 MW.

Low Cost Building Materials

John A. Youngquist, et.al.(1996), cited that there is an increasing interest in using agricultural fibers for building components, either to complement or replace wood. Building components made from agricultural materials fall into the same product categories as other low-based composition products such as low-density insulation boards, medium-density fiber boards, hard-boards, particle-boards and other building system. In the Philippines, these types of alternative materials are commonly in use in an attempt to address the country's housing problem.

Composting Garbage

Jo M. Clemente of the Philippine Daily Inquirer (November 3, 2003), cited the case of San Carlos City's rehabilitation of its garbage dump site.

The city government still dumps its waste into this two-hectare site while setting up its new solid waste management facility. But each day, the city throws in about two tons of garbage which are covered with rice hull to form windrows that measure about 8m high and 5m wide. The rice hull covered garbage is then left standing for six months to cleanse and transform everything biodegradable into a humus substance enough to fertilize a vegetable plot or a flower garden.

Insulating Material

According to the study conducted by R.E Aldas, et.al.(2002), the 50/50 mixture of rice hull and rice hull ash proved to be good insulation material for the reactor of a small-scale gasification system for pumping irrigation water. They further stressed that the 50/50 mixture of rice hull and rice hull ash with thermal conductivity of 465W-mk and the compacted rice hull ash with thermal conductivity of 465 W-mk can be a better thermal insulator than loose rice ash and hull. Gasification tests using the mixture of hull and ash for the reactor lining proved feasible with its performance comparable to the use of concrete as linings. Using the light and indigenous materials can make the gasifier easier and relatively cheaper to transport and assemble on the farm and more appropriate and adaptable in rural farming communities of the Philippines.

Roadside Posts and Spacers for Shipping Steel

According to Barbara Hall (2004), waste rice husks, thermoplastic polymer resins and a dash of nylon carpet replacement off-cuts make up the recipe for a product that promises replacement of timber in road-side posts, building panels and spacers for shipping steel around the world. The product registered as Husk-I-Bond is being fine-tuned by the Rico Growers Cooperative and polymer researches at RMIT University while some 2500 Husk-I-Bond road-side posts made from rice hulls have already been installed on country roads. The steel shipping application for the blocks is being tested while the prototype of the housing panels appears to be the most commercial of the three applications.

For the rice hull blocks to be used as dunnage or spacers when shipping steel, they must survive high static loads plus the ship tilting due to rough seas.

Other Uses

Rice Hulls are used by many different industries. Typically, rough grind is used as a fiber source. In animal feed 20/80 and 30/80 are used as a premix in animal feed supplements, -80 as a pellet bind unground hulls as bedding material for poultry and livestock (Rice Hull Specially Products Inc, 2003).

In 1983 both IRRI (International Rice Research Institute) and Philrice (Philippine Rice Research Institute) have each developed a stove to make better use of rice hull and other biomass. The metal sheet cook stove, aside from being environment friendly, can be fabricated simply by local artisans. Also, developed by the Forest Product Research and Development Institute (FPRDI) of Los Baños Laguna, is the rice hull fired bakery oven that can generate 360-600% fuel savings per bag of flour processed compared with ovens using conventional fuels (Nicolas, 2000)

Polystyrene Foam

The Polystyrene Packaging in Arlington VA (2001) published and described polystyrene foam as follows:

Styrene.

A petroleum by-product, styrene is the primary raw material from which polystyrene is made. It is, first commercially produced in the 1930s, and played an important role during World War II in the production of synthetic rubber. After the war, much of the use of styrene shifted to the manufacture of commercial polystyrene products.

The polystyrene packaging council works with the Styrene Information and Research Center (SIRC) whose mission is to collect, develop, analyze and communicate pertinent information on styrene. Since 1987, SIRC has undertaken a comprehensive research program to enhance understanding of styrene's potential to affect human health and the environment.

With ever-evolving technology, some manufacturers use carbon dioxide (CO_2 or other hydrocarbons in some cases) as an expansion agent for polystyrene foam. CO_2 is non-toxic, non-flammable, does not contribute to low-level smog and has no stratospheric ozone depletion potential. In addition, the carbon dioxide used for this technology is recovered from existing commercial and natural sources. As a result, the use of this blowing agent technology does not increase the levels of CO_2 in the atmosphere.

Sanitary

Tests have shown that disposable food service wares such as polystyrene cups, plates and utensils are more sanitary than reusable service wares. Health officials who regulate food service operation in schools, hospitals and restaurants recognize this important product benefit.

Sturdy

Polystyrene protects against moisture and maintains its strength and shape even after long periods of time. Polystyrene packaging offers exceptional protection. Its shape can be molded (custom fit) to parts and products maximizing its excellent cushioning characteristics.

Efficient

Only about five percent of a foam package is polystyrene, the rest is air. Polystyrene provides the superior insulating quality that helps hold food at the optimal eating or drinking temperature longer than many alternatives. This helps to guard against waste. Polystyrene maintains hot food at temperatures required by many health departments yet it remains comfortable to hold.

Economical

Polystyrene food service products are generally more economical to use than disposable paperboard products and reusable food service items. The wholesale price of polystyrene disposable food service products is often approximately two to three times less than an equivalent disposable paper container, and four to five times less than a comparable reusable food service item when the costs of equipment, labor, water, electricity, and detergent costs are included.

Convenient

Today's busy lifestyle requires the convenience of affordable and quick take-out meals. Polystyrene packaging meets the demands of today's modern lifestyle by offering an economical and high quality food.

Thermal Insulation

Air-conditioning works well with standard materials. All materials resist the transfer of heat in direct proportion to their thickness. However, modern construction practices and the weight of materials limit the thickness of building materials that may economically be used. For this reason, the loss of heat from buildings in winter and the gain of heat in summer are controlled by thermal insulation such as spun glass, foamed glass vegetable fibers, mineral fibers, and certain foamed plastics. These materials may be pressed into boards, installed as loose blankets or batts, or blown in granular form into wall and ceilings. (Waston, 1992).

Insulation Testing

Most countries (including the Philippines) have laws requiring that commercially available insulation materials be tested and rated by an accepted methodology. In the United States, these standards are set by the American Society for Testing and Materials (ASTM). The "correct" test for insulation depends on the type of insulation material and the application. To provide useful and meaningful test results, the ASTM describes many different test "standards", each designed to scientifically duplicate heat-flow characteristics encountered in a particular environment. Commonly, specification designations include C177, C201, C236, C335, C518, C745, C976, C1114 and others. Within each of these specifications exists the possibility to further refine certain parameters to more closely match the requirements of individual applications. Each test, if properly conducted, gives accurate results for the conditions it is designed to mimic. However, it should be recognized that the thermal performance of a single insulation product will vary dramatically in different tests. Therefore, no single test method will properly describe the performance of an insulation material under all conditions. It is up to the engineer and / or their insulation consultant to identify the appropriate test method for any given application.

In the Glacier Bay thermal conductivity test instrument, an insulation test sample is placed between two temperature controlled plates – one hot and one cold. Since nearly all insulations vary in "R" value when the temperature rises or falls, these plates are maintained at temperatures which simulate the internal and external temperatures of a freezer box in a tropical environment.

As mentioned earlier, several of the previous studies were conducted for the utilization of rice hull, but almost none on the polystyrene foam. Inspired by that fact along with the knowledge that each of these materials possesses a thermal insulation characteristic, but has not been considered yet if combined, the researchers, thus, have embarked on ascertaining the insulation potential of the rice hull and waste polystyrene foam as an alternative composite insulation material.

Research Methodology

Research Design

Since the study is aimed to ascertain the insulation potential of the rice hull and polystyrene foam as a composite material and, subsequently to determine the values of its material properties, the research design used is descriptive- experimental. According to Slavin (1984) as cited by Villanueva (2004), descriptive research method simply seeks to describe a particular phenomenon as it is. This method describes the nature of the situation as it exists during the time of the study, in this case the properties of the materials that are used in this study, and explore the factors that may have caused the particular phenomenon. Experimental research, on the other hand, involves the observation and evaluation of change or changes that occur in a "tested subject" (or subjects) for which other variables are controlled while one variable is changed. Particularly, in this study, the average temperature reduction is expected to vary with the different proportions and densities of the composite material.

Flow of the Production Process

The production of the above-mentioned composite material starts from the hauling of the rice hull from any identified source. To ensure the dryness of the said raw material, drying was done by spreading them thinly in the solar drier for three days until the zero moisture content is attained.

Simultaneously, collection and washing of the polystyrene foams from the different commercial establishments were done. Figure 3.1 shows the dry rice hull and washed polystyrene foam.

Figure 3.1. Dry Rice hull and Washed Polystyrene Foams

After such preparation, the said foams are shredded using a fabricated mechanical shredder to sizes approximately 10mm x 10mm to approximate the size of the rice hull. Momentarily, both raw materials are stored in separate containers while the molds and other accessories are being prepared.

Mixing of the two materials with adhesive is the next step of the process, after which the composite material is molded to its final shape and size.

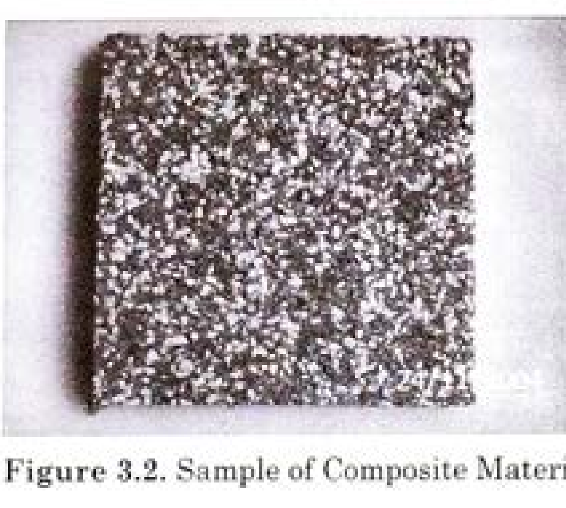

Figure 3.2. Sample of Composite Material

Sampling Procedure

The samples of the composite insulation material are made using the following steps:

1.) Gather enough volumes of rice hull from the field. Sundry the samples until the zero moisture condition is attained.
2.) Gather enough quantity of waste polystyrene foams from different fast foods, restaurants and other similar establishments. Thoroughly clean and air or sundry them.
3.) Shred the polystyrene foams such that its cutting is approximately 10mm x 10mm.
4.) Mix thoroughly the shredded foam and the rice hull using the following proportions (foam to rice hull); 1:1, 1:3, 1:2, 3:1, 2.1, by volume. Place them in separate containers and set them aside.
5.) Assemble the form or mold. Rub a thin film of oil (such as 2T, ATF) on the inner faces of the mold to prevent sticking of the sample during the molding and curing process. Figure 3.12 further shows the detail of the mold.
6.) Pour the respective pre-calculated amount of adhesive in the mixture obtained in step # 4. Again, mix them thoroughly to make sure that all surface areas of the materials are coated with a thin film of adhesive.
7.) Put the thoroughly-mixed sample in step #6 into the mold and subsequently compress it using a hydraulic press. After compression, lock the top of the mold by inserting 3-12mmϕ round bars in the two directions through the upper side of the perforated lid.
8.) While the sample is still in the mold, cure it by sun-drying for three days.
9.) After the sample is thoroughly cured/dried, extrude it from the mold and set it aside for subsequent laboratory testing later on.
10.) Repeat steps 7 to 9 using different proportions as in (4) and different density groups such as 400 kg/m^3, 300 kg/m^3, 200 kg/m^3.

Make nine (9) replications for each density variations per proportion

Results and Discussion

Properties of the Raw Materials

Table 4.1. Loose Mass Density of Raw Materials

Material	Density (kg/m^3)
Rice Hull	121.91
Shredded Polystyrene Foam	21.71

Table 4.1 shows that rice hull weighs roughly five times than the shredded polystyrene foam. Significantly, these data will be used in determining the total mass and volume of the respective raw material used in this study.

Properties of the Composite Material

Table 4.2. Summary of Actual Mass Density and Specific Weight of the Samples.

Proportion	Density Group	Density	
		(kg/m^3)	(N/m^3)
1 (1:1)	D_1 (400 kg/m^3)	308.26	3024.01
	D_2 (300 kg/m^3)	266.84	2617.68
	D_3 (200 kg/m^3)	184.88	1813.71
2 (1:3)	D_1 (400 kg/m^3)	327.38	3211.57
	D_2 (300 kg/m^3)	293.18	2876.06
	D_3 (200 kg/m^3)	209.54	2055.58
3 (1:2)	D_1 (400 kg/m^3)	326.48	3202.80
	D_2 (300 kg/m^3)	311.42	3055.06
	D_3 (200 kg/m^3)	219.11	2149.45
4 (3:1)	D_1 (400 kg/m^3)	291.69	2861.54
	D_2 (300 kg/m^3)	254.39	2495.59
	D_3 (200 kg/m^3)	203.32	1994.52
5 (2:1)	D_1 (400 kg/m^3)	346.86	3402.67
	D_2 (300 kg/m^3)	274.18	2689.75
	D_3 (200 kg/m^3)	206.03	2021.18

The table shows one very significant item, that is, the considerable difference of the predetermined density group namely D_1 (400 kg/m^3), D_2 (300 kg/m^3), D_3 (200 kg.m^3) to the actual mass density of the finished sample. The factors that explain this phenomenon are as follows: First, the difference of the actual dimensions, (thickness x width x length) of the samples compared to the predetermined dimensions of 25 mm thick by 300 mm long by 300 mm wide. Most of the actual dimensions exceed the control dimensions. This is due to the limitation of the mold structure which cannot hold the excessive rebound of the fresh sample upon removal from the hydraulic press machine. Second, the actual mass of samples likewise deviate from the theoretically computed mass. The former being mostly smaller than the latter consequently reducing the magnitude of the mass density. However, the values in the table above still show a varying amount of density and specific weight for every proportion which can still be used to describe the relative effect on thermal conductivity and temperature reduction.

Thermal Conductivity

Table 4.3. Average Thermal Conductivity Coefficient

Proportion	Density Group	K
1 (1:1)	D_1 (400 kg/m^3)	0.0591
	D_2 (300 kg/m^3)	0.0531
	D_3 (200 kg/m^3)	0.0510
2 (1:3)	D_1 (400 kg/m^3)	0.0623
	D_2 (300 kg/m^3)	0.0631
	D_3 (200 kg/m^3)	0.0575
3 (1:2)	D_1 (400 kg/m^3)	0.0667
	D_2 (300 kg/m^3)	0.0622
	D_3 (200 kg/m^3)	0.0612
4 (3:1)	D_1 (400 kg/m^3)	0.0530
	D_2 (300 kg/m^3)	0.0538
	D_3 (200 kg/m^3)	0.0518
5 (2:1)	D_1 (400 kg/m^3)	0.0666
	D_2 (300 kg/m^3)	0.0563
	D_3 (200 kg/m^3)	0.0495

The table shows that, density,D_3 of proportion 5 developed the smallest thermal conductivity value (0.0495), whereas density,D_1 of proportion 1 developed the largest (0.0667).

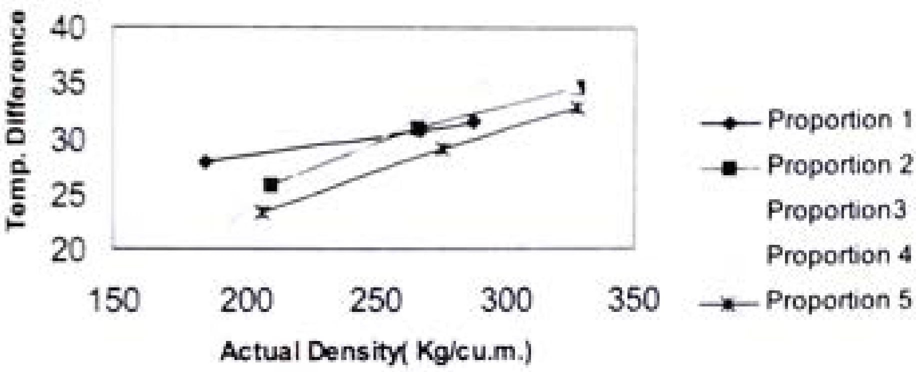

Figure 4.9. Relationship of Actual Mass Density and Average Temp. Difference

The figure discloses that for all proportions, if the actual density of the composite material is increased, the temperature reduction value likewise increases, thus, describing a direct relationship.

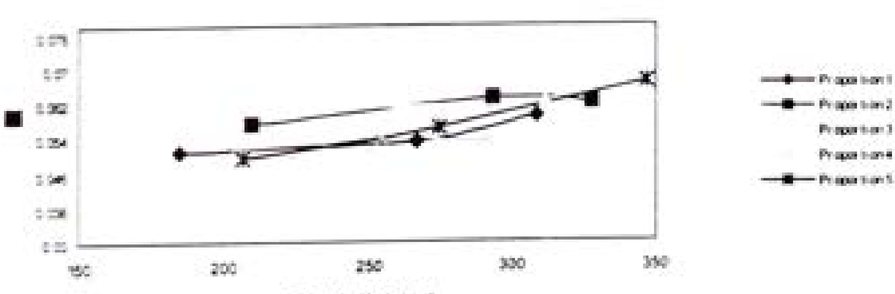

Figure 4.10. Relationship of Density and K-values

The above-cited figure shows that for the composite material, the thermal conductivity value increases as the density is increased. Actually, this phenomenon is not true to all other materials. Indeed, there are materials whose K-values decreases with increasing density.

Table 4.20. ANOVA Table For Average Temperature Difference

Source of Variation	SS	d.f.	MS	F	Fc (@ 0.05)	Interpre - tation	Decision for H_0
Between Columns (Density)	561.4312	2	280.716	55.727	3.32	S	Reject
Between Rows (Proportions)	19.49832	4	4.8746	0.9677	2.69	NS	Accept
Interaction (Density x Proportion)	83.50890	8	10.4386	2.0722	2.27	NS	Accept
Within group error	151.1202	30	5.03734				
Total	815.5587	46					

The ANOVA results shows sufficient evidence to reject the null hypothesis with regards to the difference of means of average temperature reduction considering density variation, as shown by the value of F = 55.727 which is much greater than that of the critical value (3.32) at 95% confidence level.

In addition, it can be deduced from the table that the five variations of proportion have no significant difference on the average temperature reduction as confirmed by the F value of 0.9677 which is less than the critical value of 2.69 at 95% confidence level. Hence, the null hypothesis is accepted.

Moreover, the ANOVA results finds no sufficient evidence to accept the null hypothesis on the interaction between density and proportion as shown by the F value of 2.0722 against the critical value at 5% level of significance (2.27). Hence, interaction is not statistically significant.

The overall result further implies that to produce a more efficient composite material, in order to be assured of a significant thermal reduction capacity, a densier material must be molded for any of the different proportions hence, density, D_1 for this matter.

Conclusions

Based on the findings of the study, the researchers advance the following conclusions:

1. Denser composite material reduces the average room temperature more than the less dense.
2. The more dense the composite material the bigger is the thermal conductivity coefficient. Thus, exhibiting a direct relationship.
3. Relative to time, the maximum temperature reduction in the model building when using the composite material occurs between forty to fifty minutes from the start of the observation. Also, the temperature reduction increases rapidly during the fourth to fifth ten-minute interval, and decreases moderately until the end of the three-hour observation period.
4. The magnitude of the average temperature difference is relatively large when using the composite material.
5. The average temperature reduction and thermal conductivity are statistically significant with respect to density.
6. The thermal conductivity coefficient of the composite material which averages 0.0578, for all the samples used is comparable to some commercial insulating materials.

Recommendations

Based on the findings and conclusions of the study the researcher advances the following recommendations:

1. Make an economic study for the cost comparison of the composite material to the common insulation materials in the market.
2. Investigate the possibility of a hot-pressed production method of the composite material so as to maintain the dimensions to tolerable limits.
3. Explore the possibility of using the composite material for sound proofing.
4. Investigate other proportions and densities of the composite material for possibly better thermal insulation.
5. Investigate the composite material relative to protection against termites, fungi and other decaying organisms.
6. Explore the use of bonding agents which are more economical, less hazardous to environment and with excellent bonding ability.
7. Study the possibility of an early curing period so as to facilitate mass production in a shorter time.
8. Investigate the appropriate installation methods of the composite material.
9. Investigate the flow of heat through the thickness of the composite material with respect to time.
10. Use weight rather than volume or number of scoops in determining the amount of raw materials for the composite material.
11. Make due consideration of the dry weight of the glue in the determination of the weight of the raw materials.
12. Include the effect of binder in the final properties of composite material.

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