5 Rice Hulls for Composites

5.1 Introduction

Rice is the staple diet of many people all over the world. More than 100 million metric tonnes of rice are produced annually, especially in Asia and the Far East. Rice hulls are the protective coatings of the rice seeds or grains. These hulls are formed by a hard material and are unique products of nature. They contain $\approx 20\%$ opaline silica in combination with a large amount of structural polymer called lignin. These hard coatings protect the rice seeds during the growing season until harvest.

Previously, separation of rice grains from hard coverings was a laborious process. However, modern processing employs many advanced machines that make it much easier, faster and more efficient. During milling, hulls are removed from raw grains to reveal whole brown rice grains, which may then be milled further to remove the brown (bran) layers, resulting in white rice. This abundant natural agricultural waste has posed problems with regard to disposal. The few traditional uses for these leftover hulls have not fully eliminated this problem. However, once the true nature and properties of these hulls (especially the high content of silica) had been discovered, more sustained efforts were made through research and development to find end uses for these versatile hulls. Two of the lucrative uses of these rice hulls are the production of polymeric composite resins with rice hulls for the processing of plastic products (cheaper resins) and the production of excellent lumber as an ideal substitute for natural timber. One may even say that these products have better properties than the naturally occurring ones. Also, they can be considered to be ‘green’ products with tremendous potential to ease global environmental concerns by reducing the felling of trees.

5.2 Properties of Rice Hulls

Rice hulls are unique within nature. This abundant agricultural waste has all the properties one could expect of some of the best insulating materials and, due to diligent research, its true potential is emerging. Tests carried out have shown that rice hulls: do not flame or smoulder very easily; are highly resistant to moisture penetration and fungal decomposition; do not transfer heat very well; are not odorous; do not emit gases; are not corrosive with respect to metals such as aluminium, copper or steel.
In their raw and unprocessed state, rice hulls constitute class-A insulation material. Therefore, they can be used very economically to insulate walls, floors and roof cavities in building construction. If used in panels or as reinforcement in composites, they function as cost-effective insulating materials for most applications. With the new emerging technology of polymeric composites with rice hulls, products made by injection moulding and compression moulding have wide ranges of applications, but the most versatile range is for products such as lumber made by extrusion. Until recently, this humble gift of nature has not been exploited by scientists and researchers, and only now are they beginning to understand the full potential of rice hulls.

Rice hulls are very tough and abrasive, consisting of two interlocking halves. These halves encapsulate the tiny space vacated by the milled grain and, in proximity to a myriad of other hulls, they form a thermal barrier that compares well with that of other excellent insulating materials. Using rice hulls in their natural, loose form is not practical, so ideally they should be made into products suitable for practical applications. Do rice hulls burn? Yes, they do but with difficulty. In fact, if a mass of loose rice hulls is set on fire (when used as a fuel for steam boilers), the ideal would be to sprinkle a little highly inflammable liquid such as kerosene oil and, once the mass is lit, it burns well with high heat content. Air cannot flow freely through a pile of rice hulls to provide oxygen to sustain rapid combustion so they do not combust easily. The bulk density of loose rice hulls is similar to that of baled straw and anyone who has tried to burn a bale of straw understands the problem associated with the availability of oxygen. Lack of oxygen may be one of the problems but is not the main problem.

The high percentage of opaline silica within rice hulls is most unusual in comparison with other plant materials. Some scientific evaluations have concluded that, during the combustion of rice hulls, the silica ash may form a ‘cocoon’ that prevents oxygen from reaching the carbon inside. Another school of thought among scientists is that, because silica and carbon may be partially bonded at the molecular level, silicone carbide is formed during high-temperature combustion and that the presence of this heat-resisting compound impedes the easy combustion of rice hulls. Other scholars say that, at certain temperatures, the molecular bond between the silica and carbon in the hull is strengthened, thereby preventing the thorough and uniform burning of the hull. The general conception is that, even if a pile of loose rice hulls can be ignited, it will tend to smoulder rather than flame. However, practical experience by the author (operation of steam boiler with rice hulls as fuel) can certify to the fact that, once a pile of loose rice hulls is truly lit and a good flame stage has been reached, it maintains this status with the constant feed of loose hulls and burns with a good flame and high heat content. The value of the resulting ash, which hitherto has not been exploited, is also emerging as material with many possibilities (see later).
Rice hulls (also called ‘rice husks’) are flame-retarding and self-extinguishing. A lighted match thrown onto a pile of rice hulls will, in general, cause it to burn and smoulder without producing a high flame. Production of a flame will require a flammable starter to ignite the pile. Depending on the length of burning, the resulting ash will be grey or black; both have many useful applications. Conventional cellulose insulation requires the addition of large quantities of flame- and smoulder-retardants. The concentration of flame- or smoulder-retardant chemicals such as boric acid, sodium borate ammonium sulfate, and aluminium sulfate in conventional cellulose may be $\leq 40\%$ by weight. These chemicals are expensive and incorporating them into the cellulose fibre is not easy. Importantly, rice hulls do not require flame- or smoulder-retardants and, if used in insulation applications, additional chemicals are not required.

In general, all organic materials absorb or release moisture until they come into equilibrium with the relative humidity of the surrounding air. The high presence of silica on the outer surface of rice hulls impedes the atmospheric transfer of moisture into the hull. Also the presence of a small percentage of a bio-polyester in the rice hull in combination with a wax produced by the rice plant forms a highly impermeable barrier to moisture and heat. The high concentration of opaline silica on the outer surface of the rice hull also strengthens and makes the outer shell hard. However, due to lignin within the rice hull, this hardness is tempered with flexibility and elasticity. The rice hull is hard and yet elastic, so it resists settling and compression far better than some materials.

Rice hulls are available at minimal cost and in some cases may be even available free. In applications where they are used as loose filling in their natural form for insulation, costs would be very much less as compared with other commercially available insulating materials, especially because rice hulls do not require shredding, hammer-milling, fluffing, fiberising or binding for this application. Perhaps the most significant cost associated with the utilisation of rice hulls is their transport. Having a bulk density of $\approx 5.6\, \text{kg/m}^3$ may cost extra unless they are compressed and packed in such a way as to reduce transport costs. In general, it is accepted that loose rice hulls can be compressed to a bulk density of $\approx 16\, \text{kg/m}^3$ without destroying their properties. Depending on the type of transport and costs, it may not be necessary to reach this maximum compression, and a lesser compression may be acceptable. Although rice hulls have many versatile and practical applications, this chapter details the use of rice hulls as a reinforcing component in polymeric composites.

### 5.3 Chemistry of Rice Hulls

Rice hulls are a unique gift of nature and their full potential is being exploited only now. Rice hulls do not need to be mined or manufactured in processes that generate
air pollution, water pollution or erosion. Rice hulls do not deplete our reserves of fossil fuels as do the processes for manufacturing polymeric compounds from petroleum sources. As an insulation material and utility reinforcement for composites, rice hulls now rank among the best. Their ready availability and cheap costs are important factors to consider.

To protect the rice seed during growth, the hull is formed from hard materials, including opaline silica and the polymer lignin. It is generally accepted that these hulls contain 20% opaline silica but, if they are burnt into ash, test results have shown silica content of ≤70% of volume. The production of ash goes through two stages: the first is a ‘grey’ state when the silica content is at its maximum and then a ‘black’ state. Rice hulls can be used to produce mesoporous molecular sieves, which are applied as catalysts for various chemical reactions as a support system. The ash is also a very fine thermal insulation material and can have finer particle size, even better than cement, and thus could have many applications in the building industry. Here, I would like to offer the theory that using the fine ash of rice hulls as the reinforcing component instead of rice hull flour would be more beneficial in the production of polymeric composites. Higher contents of silica, volume to volume, between fine ash and rice hull flour for added properties such as additional strength and weathering may justify this theory. Also, combined use of rice hull ash and rice hull flour in the production of polymeric composites should be tested to yield better products than those being made currently.

5.4 Uses for Rice Hulls

Most countries grow rice, more so in Asian and Eastern countries, where it is their staple diet. Rice hulls resulting from the growing, harvesting and processing of rice is a gift of nature as a recyclable resource having many current and potential uses. Up to recently, this lowly byproduct of growing rice has been regulated to being used only as animal feedstock and for the poultry industry, with most of it being discarded as waste. However, due to increasing global environmental concerns, researchers and scientists have realised the important potential of rice hulls in a wide range of applications, especially as an ideal substitute for natural wood in the form of lumber. Thus, the use of rice hulls in the production of polymeric composites is gaining ground fast via the production of: (i) polymeric composite resins for moulding, and (ii) lumber through extrusion. Some of the important uses of rice hulls are presented below.

5.4.1 Extrusion, Injection Moulding and Compression Moulding

Polymer resin moulders are always on the lookout for cheaper resins to be able to be competitive in the market because they also have to battle with rising labour costs
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and other manufacturing costs. Since the arrival of composite resins with rice hulls, moulders, though very interested, have been showing caution in using these resins (as with any new material). As the research and development of these composite resins continues, moulders who have already started using these resins can do so with more confidence. Here, I would like to recommend that the use of rice hull ash (grey state) or a combination of ash and rice hull flour would result in better-quality composite resins. Currently, these composite resins are being used only for extrusion, injection moulding and compression moulding, but it is expected that they will be used for other areas of plastic mouldings as well.

5.4.2 Animal Feed Industry

Rice hulls as a recyclable resource have many useful applications in the poultry and animal farming industries. In the former, they are used primarily as bedding for poultry and also as feed mix. In the animal feed industry, they are used as a fibre source, premix and pellet binders. Rice hulls are offered by specialty producers as different grades and grinds. The three main grades are 20/80 and 30/80 (rough) and 80. Typically, rough grind is used as a fibre source in animal feed, 20/80 and 30/80 are used as a premix animal feed, supplements and 80 grade as a pellet binder, and unground hulls are used as bedding for animals and poultry.

5.4.3 Lumber from Composites

Rice hull flour (finely ground hulls) is an ideal composite material for polymeric composites. Processing involves the mixing and compounding of plastic resins with rice hull flour with additives such as fillers, lubricants, binders, and colours depending on the end result desired, and then using an extrusion process to produce profiled lumber. Depending on the type and size of the extrusion system, there will be limits to the size of the profile section and width that can be produced, but lengths carry few limitations. These products are ideal substitutes for natural wood, and reports after testing and usage reveal many excellent and beneficial properties.

5.4.4 Building Materials

Rice hulls are class-A thermal insulating materials because they are difficult to burn and resist penetration by moisture (which stops the propagation of mould or fungi). Tests have shown that if they are burned, rice hulls will produce a significant amount of silica. Rice hulls are also a potential source of amorphous reactive silica. If burned completely, the ash can have a Blaine number (particle size) of ≤3,600 as compared
with a Blaine number of 2,800–3,000 for concrete (i.e., it is finer than cement). Silica is the basic component of sand, which is used with cement for plastering and concreting. This fine silica from rice hulls provides very compact concrete. This ash is also a very good thermal insulating material. The fineness of the ash also makes it a very good material for sealing fine cracks in civil structures, in which it can penetrate deeper than conventional cement-and-sand mixtures.

5.4.5 Production of Glass

The fact that rice hulls contain 20% opaline silica is significant in the manufacture of glass because glass is composed primarily of silica. Heating rice hulls to high temperatures will turn it into glass spheres. This opaline silica may be combined with silicone dioxide (sand) to form a glass composite. This composite material can then be used to produce all types of glass products. Some home-insulation products are glass that has been blown into strands, and rice hulls would make excellent materials for insulation. These glass spheres can also be used as filler in the manufacture of plastic foams (e.g., flexible polyurethane foams).

5.4.6 Rice Hulls Ash in Road Building

Recycling of increasing volumes of plastic wastes, whether it is from domestic or industrial activity, is a challenge with regard to environmental pollution. Although there are many recycling programmes, one might say it is a ‘losing battle’ because of the volumes produced. However, recently, a little-known town in India, faced with this problem, came up with a unique way to deal with this. With little or no knowledge of science or chemistry, they experimented using a combination of plastic wastes and bitumen to discover a novel way to recycle plastic wastes so as to minimise pollution. They have perfected a way of using this combination in road building.

The plastic waste is shredded into small pieces using a granulator or shredder and then added into heated bitumen (≤60% by volume) and mixed thoroughly. The high temperature melts the plastic easily. If this mixture is used on a road surface, it gives a very smooth and flexible coating. According to reports, a road surface made in this way does not crack, can bear high loads, and water seepage is minimal. I suggest that addition of a small proportion of rice hull ash, which is rich in silica, will greatly improve these properties. I recommend a basic combination of 40% bitumen; 50% plastic waste; and 10% silica ash. The silica will blend easily and give additional strength and form a surface coating to prevent rainwater absorption and seepage.
5.4.7 Fuel for Steam Boilers

Most rice-producing farmers use rice hulls as fuel for their rice-mill steam boilers. These boilers are low-pressure/low-volume and, because only small volumes of steam are required, the rice hulls can be fed directly into the furnace through an additional opening close to the ‘peep hole’. A more important application is that rice hulls can be used for industrial steam boilers too. I present the following case study from actual design and practice.

5.4.7.1 Case Study

*Products*: Expanded polystyrene (Styrofoam) fish boxes, insulation board, fishing floats and hot/cold containers.

*Output*: 2 metric tonnes per month.

The basic equipment was a block mould, separate moulds for all items, and a hotwire cutting machine. All moulds were connected through steam lines to a steam boiler with specifications of 100 psi and steam volume of 500 lbs steam/hour. Use of diesel oil as fuel proved to be expensive and an alternate fuel had to be found. After some research and experimentation, a method was found on how to use rice hulls in the natural state. The rice hull feed design contained a pipe (diameter, 3 inches; and length, 5 feet) with a flange at one end attached to a blower motor turning at 3,000 rpm. Halfway along the pipe was an opening in which a hopper with a control valve was mounted. The other end of the pipe opening had an elbow bend containing an adjustable nozzle that was connected through a flange to the base of the boiler furnace. Rice hulls were introduced into the hopper and the blower motor started. Rice hulls were blown along the pipe, with the stream controlled by the valve, and a cascade effect was created inside the furnace. To promote initial ignition, a small amount of kerosene oil was sprayed onto the cascading rice hulls and the whole mass ignited. By good control of stream using the control valve in the hopper, a sustained and continuous fire was achieved. An immediate reward was a reduction in the cost of the boiler fuel by 90%.

5.4.8 Rice Hulls in Fertilisers

Rice hulls are a renewable resource of fertiliser. Rice hulls in fertiliser can recycle nutrients and eliminate wastes. Using rice hulls and rice hull/manure composts and vermicomposts improve the fertility, organic matter, physical properties and structure of soil over long periods. Rice hull composts are especially useful for boosting the humus content of the organic matter of soil, thereby providing a long-term source of nutrients.
Nature also helps by way of worms in the soil, which can play a key part in rice-hull decomposition because rice hulls can be difficult to compost due to their high content of cellulose and lignin. Their waxy surface cover also impedes microbial attack due to their low capacity to absorb water. Using composts made by mixing rice hulls with manure greatly contributes to micronutrient content and improves the soil structure because of greater retention of water and air. This is a good example of utilisation of crop residue and its transformation into a resource. Rice hulls with their high contents of lignin and cellulose are a source of the precursor of humus (the organic-matter component with the greatest stability and nutrient availability). Researchers have developed composting practices of rice hulls to obtain fertilisers that are suitable for use in other applications (e.g., public and domestic gardens). These ready-to-use organic fertilisers are also sold in bags made from recycled paper or plastics.

### 5.4.9 Rice Hulls in Cement Bricks

Traditionally, most rice hulls have been disposed of as waste. However, for some time, the practical possibilities of such agricultural waste have been emerging in applications, particularly in building construction. Two significant factors to promote the search for alternate materials are (i) environmental concerns, and (ii) the shortage and increasing costs of traditional materials used for particular applications. Examples include cement bricks or clay bricks for building construction.

Many manufacturers of cement and clay bricks are now mixing in a high proportion of rice hulls in the form of ash or in its natural state to produce excellent bricks. According to reports from researchers and actual users of these bricks, they perform well against the elements, vermin and mould, and could easily replace the part of natural sand (silica) because rice hulls (especially in the form of ash) are high in silica. Reduced material costs are also a significant factor.

### 5.4.10 Rice Hull Briquettes

Briquettes have been in place for a long time as a cheap source of fuel for many applications. Growing environmental concerns have prompted people to look for alternate solutions for heating and ambiance fires that result in minimal environmental pollution. The economic aspects of alternate fuels to replace traditional fuels are also significant. Traditionally, petroleum-based fuels had taken precedence and this trend will probably continue for some time, especially where large industrial applications are concerned.
However, briquettes may be better suited for low-end applications. At present some briquettes are made from different materials, mostly wastes. In Asian and Far Eastern countries, briquettes made from rice hulls are very popular. China and Thailand are offering to produce briquettes having dimensions of 20–40 cm (length) and 5–7 cm (diameter) and these densified briquettes will have a heat content of 3,000–4,000 kcal/kg. Rice hulls in the densified state are difficult to ignite, so manufacturers may incorporate an igniting promoter in the mix. There will be a market for the ash that results from such procedures.

5.4.11 Rice Hull Ash

The ash produced after hulls have been burnt is high in silica. The list below shows some of the possibilities in which this material can be applied but a word of caution is called for. Irrespective of the process that results in the production of ash or the method employed directly to produce rice hull ash, a very fine ‘dust’ will be emitted into the air in addition to the deposits of ash at the bottom of a device. In general, this dust will emerge through a chimney and, if not grounded through a curved chimney, will cause air pollution and create problems for any buildings close by:

- Aggregate and filler for the production of concrete and board
- Economical substitute for micro-silica/silica fumes
- Absorbents for oil and chemical spills
- Soil ameliorants
- Source of silicone
- An insulation powder in steel mills
- Repellents in the form of ‘vinegar-tar’
- Release agent in the ceramics industry
- Insulation material for homes and refrigerants

5.4.12 Case in Point

I present a case in point for the benefit of readers of this book for the possibility of using rice hulls in the natural state as fuel for steam boilers on an industrial scale.
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On a contract received by a group of businessmen in the Philippines, I set up a complete manufacturing plant for three sizes of Styrofoam fish boxes to include project design, factory building, machinery, technology, and training. To save initial project costs and not delay the start of production, the supply of steam was taken from the neighbouring factory, which was manufacturing silk threads from silk worms. Interestingly, their steam boiler was fuelled by rice hulls in the natural state. This system was quite advanced and more or less automatic, with effective collection of ash to the ground.

During the second year of operation, the producer of Styrofoam fish boxes, on my recommendation, installed his own steam boiler system fired with rice hulls with automatic operation. Rice hulls were freely available locally, which enabled this producer to minimise fuel costs.

5.4.13 Rice Hulls in Building Construction

I present some polymeric composite products with rice hulls other than the number-one product: composite lumber in building construction. Over the years, people have used natural wood in all types of construction work: domestic, industrial or other. Natural wood has a very wide range of applications but, due to rising costs and particularly serious environmental concerns with deforestation on a global scale, it was merely a matter of time before people would find alternatives.

One such product is roof tiles. Mixtures of polymers (pure wastes or recycled), mixed with rice hull flour, a small percentage of cement, additives and colours, has led to production of roofing tiles with excellent properties and a wide range of finishes and shapes. The practice of using polyethylene or polyvinyl chloride as the polymer matrix will no doubt extend to other polymers. Another product is floor tiles based more or less on the same formulation mix. One big advantage is that wastes can be used, with probably the ideal being recycled wastes in pellet form for easy compounding. Using this same concept, strong roofing sheets in any colour or shape can also be produced and, according to reports, are already in use.

The possibilities of rice hulls and their ash have many exciting and challenging possibilities of applications, and even the producers of polymeric composites are coming up with interesting products. In fact, the actual producer is probably the most knowledgeable source with first-hand information to initiate practical new products.
5.4.14 Miscellaneous Uses

Rice hulls are also used in other applications:

- Fibre used in pet food
- To increase the lautering ability of a mash when brewing beer
- As fillers for fireworks
- For improving the extraction efficiency of fruit-juice pressing
- Stuffing pillows
- Insulation boards

This list shows the versatility of rice hulls and there is no doubt that as research and development takes place, newer applications will emerge. For most end processes, the inherent moisture content may be a concern and may have to be controlled by pre-drying before use.