Study on Coir Reinforced Polymer Matrix Composite Cured By Microwave and Compression Moulding Technique

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Abstract: In this research short fibre coir was used as a reinforcement and polypropylene as a matrix cured with microwave and compression moulding technique. In case of microwave moulding, fibre content and power output of the microwave was considered as the parameter. But in compression moulding fibre content was only considered as the parameter. Tensile strength and compressive strength were the mechanical properties which were tested after the experiment for both the moulding techniques. During the research coir was observed as a microwave absorber. Because of this property of coir, the time taken for processing reduced to a great extent. The mechanical properties of compression moulding was found to be better than that of microwave moulding. But the cost and time taken in microwave moulding was less. To find out the reason of failure of composites FESEM tests were conducted. Blow holes and improper bonding between the fibres and polypropylene was found in the test which were the reason for failure of composites. Further observations made are mentioned in the paper.

1. Introduction

The major priorities of the current manufacturing scenario is to achieve lower processing costs and efficient processing of materials. To achieve these priorities innovative ideas and research are developed which has lead us to better technologies in manufacturing which have low processing cost and less time taken than the older methods with enhanced quality.

The main purpose of microwaves was to cook food. But the technology of using microwaves for the processing of materials is a relatively new concept. The use of microwave for the processing of materials has many new approaches as the physical properties of the material improves; it is a substitute for processing materials which are not easy to process; material processing has less impact on the environment; reduction in cost as it requires less energy, area and time.

In conventional heat treatment, material attains energy through thermal conductivity, and heat radiation from the materials surface. However, the energy of microwaves is supplied directly to the material through a molecular interaction with the electromagnetic field. In heat transfer, thermal properties are the cause of transfer of energy, but in microwave heating electromagnetic energy is transmitted into thermal energy which is the conversion of energy instead of heat transfer.

This dissimilarity in the way of energy transfer has many advantages over the traditional method. Since microwave can get through materials and generate energy, it enables volumetric heating. Fast and constant heating of thick materials is achieved. Slow heating rate is chosen in traditional heating to minimize steep thermal gradient so processing time is large. This problem is overcome in microwave processing where volumetric heating takes place, therefore processing time is reduced to a large extent.

Along with volumetric heating there are other benefits such as energy transfer at molecular level. Selective heating is one advantage. Selective heating of materials is one benefit of using microwaves. The molecular structure of the material is responsible for the transfer of energy amongst the particles. When materials having different dielectric properties are connected, the microwaves can be selectively engageable with the material having a tendency to high losses.

In traditional method, ceramics and polymers took a considerable time and wastage of energy took place in heating the interface through the substrates by conduction. By microwaves, the joint compound can be heated by absorbing a higher loss of material at the interface.

In heterogeneous state material, some phases combine with microwaves more than other phases which enables selective heating of different phases to produce materials with different microstructures. Chemical reactions can be initiated through
microwaves which isn’t possible by selective heating of reactants in conventional processing. Creation of new materials takes place in microwave processing.

Even though there are many advantages by direct heating of the materials, there are some new processing challenges in microwave technology. In these type of processing the energy is transmitted by electromagnetic field so non uniform heating takes place as the electric field are non uniform as well as the materials encounter a bit physical and constructural transformation which affects their dielectric properties further affecting heat generation through microwaves.

The field of microwave processing of materials is complicated by the material’s chemical composition which is under process, electromagnetic field properties, microwave/material physics interactions, constitutional alterations that occur during processing, and the heated object’s size and shape.

1.1 Natural Fibres

Natural fibres can be easily found in the nature. These days a number of origins of natural fibres are used to make polymer composites. Natural fibres are acquired either from animals or from the plants. Compared to the synthetic fibres, natural fibres are cheaper and they are also biodegradable. Plant fibres are mainly applied in the composite factory. Cellulose, micro fibril angle and lignin are the main constiuents of a plant fibre. The fibre and the polymer matrix bond depends on the lignin constituent and the micro fibril angle of the fibre. Animal fibres generally consists of proteins. Plant fibres are much strong than the animal fibres, therefore plant fibres are more preferred for making composites. As per the fibre origin plant fibres can be classified as:

A. **Fruit and seed hairs** – Hairs around the seed or fruit like coconut.
B. **Leaf Fibre** – These are acquired from leaves. These run along the length of the leaves like abaca and sisal.
C. **Grass fibre** – These are achieved form the stem of the plant like bamboo and sugarcane.
D. **Bast fibres** – These are obtained from a stems inner bark which is also known as a plant’s phloem eg. Jute, hemp, flax etc.

1.2 Microwave and Material Interaction

The dielectric properties of the material are responsible for the processing of materials with microwave energy. There are two major aspect which are given below:

1) Dielectric constant
2) Loss factor

These two can be described internms of loss tangent and complex permittivity as shown by eqn. (1) and (2) respectively.

\[
\tan \delta = \frac{\varepsilon''}{\varepsilon'} \quad (1) \\
\varepsilon^* = \varepsilon' - i\varepsilon'' \quad (2)
\]

here $\varepsilon'$ is the dielectric constant representing the microwave penetration into the material, $\tan \delta$ represents the loss tangent which is the capacity of the material to obtain heat from the incoming microwave energy [2], and $\varepsilon''$ denotes loss factor which is the material’s capacity to store energy.

Eventually the effect of electromagnetic field on the material is determined by the dielectric properties. According to the dielectric properties, materials can be classified as given below:

1. **Opaque** – In this type of materials microwaves are reflected without any penetration into the material, these are normally the good conductors which have good conductivity, example metals.
2. **Transparent** – This type of materials allow the microwaves to pass through them without any losses. There is minimum energy loss inside the material as they are low dielectric loss materials, example Teflon.
(3) **Absorbing** – These type of materials have a moderate dielectric constant. The capacity to absorb microwaves is determined by their dielectric constant value, example water, SiC.

(4) **Mixed Absorber** – There are generally two phases present in this type of materials, and microwaves can be absorbed according to the dielectric properties of these phases, example Composites.

### 1.3 Microwave Heating Mechanism

Materials which are heated by microwave are different from the traditional heating. The dielectric and magnetic properties of materials under process are responsible for microwave heating.

Materials absorb microwave by the phenomenon of ionic conduction and polarization processes. Polarization comprises of short range shifting of charge through rotation and formation of electric dipoles (or magnetic dipoles). At the same time ionic conduction requires long range movement of charge. In certain frequency ranges, both have absorption losses. Ionic conduction are dominant at low frequencies because of which the dielectric and absorption losses, \( \epsilon'' \), are caused and at higher frequencies rotation of permanent dipoles are favourable. When the ions shift through the material and strike with other type ohmic losses occur which are responsible for ionic conduction losses. The transportation time allowed in the field’s direction decreases with increasing frequency, hence, ionic conduction decreases with increasing frequency. The kinetic energy of the dipoles increases as the temperature increases which makes quite simpler for them to acknowledge to the fluctuating field displacing the absorption curves to greater frequencies.

### 1.4 Compression Moulding

For producing plastics and polymer composite products, compression moulding technique is considered in the current time. Many types of products can be produced using the compression moulding technique starting form simpler structures like automotive parts, aircraft parts, electrical parts, pot handles etc. As compared to the transfer moulding and injection moulding process, the cost of processing in compression moulding process is much cheaper. In this process the plastic is in the molten state which is pressed into the mould with a very high pressure and temperature acquire the wanted shape.

### Working Principle

In this technique, firstly the exact amount of plastic required is heated and then it is placed in the bottom half of the heated mould before squeezing it into the mould. After that the moulding unit is enclosed with the upper portion of the mould and pressure is applied, so that the material can be squeezed into the mould cavity and the desired shape of the mould can be attained. The temperature of the mould varies from 130 – 300°C and the pressure applied by mould is 7 – 25 MPa. The mould is allowed to cool down and then the mould cavity is opened and a cooled plastic of the desired shape is taken out using the ejector pins.

### 1.5 Polymer Matrix Composites

A range of continuous and short fibres compelled together by an organic polymer matrix constitutes a polymer matrix composites (PMCs). The reinforcement gives excessive strength and firmness in a PMC whereas in ceramic matrix composite the reinforcement is used to enhance the fracture toughness. The fibres are linked together and the load transfer is carried out with the help of matrix. The arrangement of the PMC is such that the structure mechanical loads is supported by the reinforcement.

There are two categories of polymer matrix composites: advanced composites and reinforced plastics. The difference is based on the level of mechanical properties (basically toughness and strength). There is an absolute line dividing the two. As compared to advanced composites, reinforced composites are cheaper, it contains glass fibres having low firmness with which the polyester resins are made. Advanced composites, which have been used for almost 16 years, mainly in the aerospace manufactory acquire high stability and hardness, and comparably costly.

The major benefits of using a polymer matrix composite is they have less weight but high firmness and stability in the way of the reinforcement. The foundation of this arrangement is the effectiveness in automobiles, moving structures and aircrafts. Further necessary properties comprises rust and fatigue resistance related to metals. Since the matrix melts at elevated temperature, though the present polymer matrix composites are restricted to operating temperatures under 316°C.
2. Experimental Setup

2.1 Experimental setup and procedure of microwave moulding process:

STEP I - The mould volume is firstly measured using a Vernier calliper. The density of the Polypropylene which we are using is known. Now after finding out the specific volume of the mould the mass of the polypropylene can be found by using the following formula,

\[ \text{Volume} = \frac{\text{mass}}{\text{density}} \]

Or

\[ \text{Mass} = \text{volume} \times \text{density} \]

STEP II - Now from the total mass of the polypropylene, 5% (as per the research) is deducted. And in place of that withdrawn polypropylene 5% of fibre is placed. Short fibre coir is used as the natural fibre in this research.

STEP III - 95% Polypropylene and 5% fibre (coir) is mixed uniformly and transferred into the mould. Short fibre coir of length 4-5 mm is used.

STEP IV - Pressure is applied to the mixture in the mould from above by using floor tiles as the pressure plate. The dimension of the pressure must be same as that of the mould’s open side with approximately ±1 mm clearance. The clearance is provided so that the composite can be taken out easily after the solidification.

STEP V - Now the whole set up is put into a Teflon clamp and tightened using the screws of the Teflon clamp up to a level so that appropriate pressure can applied to the pressure plate and from there to the mixture of natural fibre and polypropylene.

STEP VI - The whole set up of the moulding mounted on the Teflon clamps are kept inside the microwave oven.

STEP VII - The power knob of the microwave is kept at 700 W initially as per the requirement. A timing of average 3 minutes is set as the composite get burnt after this timing and remains not melted before this.

STEP VIII - Now the temperature of the mould and the pressure plates are measured using an infrared thermometer. And then the composite is allowed to cool down.

STEP IX - After the solidification of the composite, it is taken out from the mould and checked whether the composite is perfect or not. If not time adjustment is made till a perfect composite is obtained. And then important observations are made accordingly.

STEP X - The procedure is repeated for 10% and 12% coir content in the composite. And then for 595 power output with the same composition of coir and PP as in 700 W.
2.2 Experimental procedure of compression moulding process

STEP I - Firstly the pellets are dispersed over the rolls and the pellets turn into their molten state. In this experiment the melting temperature is taken as 190°C and the rpm of the roll was 40.

STEP II - Now the required amount of natural fibre (5%, 10% and 12% coir) is added to the molten plastic to get a proper coupling between the polypropylene and the fibre (coir).

STEP III - The sample obtained is let to cool down which is a circular bulk of the composite which requires flattening for further tests.

STEP IV - The process used above is known as compounding which takes about 10 – 15 minutes depending upon the material of the sample.

STEP V - After acquiring circular masses of polymer matrix fibre composite, of various fibre composition these are taken forward for compression moulding. In this experiment a hand compression moulding machine is used.

STEP VI - There are two metal plates used in this technique which covers the mould from top and bottom. Silicon spray is applied on the mould for proper extraction of the sample.

STEP VII - Now the composites which were obtained after the compounding technique are put into a mould and a pressure of 50 kgf/cm² at a temperature of 190°C is applied for 30 seconds. This pressure is known as the breathing pressure at which the air is evacuated to prevent blow holes. After this the apparent pressure for compression is applied which fluctuates from 180 – 200 Kgf/cm². For proper forming of the composites this pressure is applied for 10 minutes.

STEP VIII - Now the compression pressure is released and the mould is allowed to cool down. After the sample is cooled, it is extracted out of the mould. Thus the final sample is achieved.

3. Results and Discussions

The real compressive strength of PP is 24 MPa.

The real tensile strength of PP is 28 MPa.

By microwave moulding technique the compressive strength and tensile strength at various power outputs are given below:

<table>
<thead>
<tr>
<th>Test parameters (595 Watt)</th>
<th>5% coir</th>
<th>10% coir</th>
<th>12% coir</th>
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</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>27.1</td>
<td>45.6</td>
<td>55.7</td>
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<tr>
<td>Compressive strength</td>
<td>20.6</td>
<td>42.5</td>
<td>48.2</td>
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<tr>
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<th>5% coir</th>
<th>10% coir</th>
<th>12% coir</th>
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</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>38</td>
<td>44.1</td>
<td>52.2</td>
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<tr>
<td>Compressive Strength</td>
<td>21</td>
<td>39.1</td>
<td>50.6</td>
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</table>

<table>
<thead>
<tr>
<th>Test parameters (compression moulding)</th>
<th>5% coir</th>
<th>10% coir</th>
<th>12% coir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>66.8</td>
<td>74.8</td>
<td>76.1</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>76.6</td>
<td>81.2</td>
<td>83.2</td>
</tr>
</tbody>
</table>
Fig. 6. Comparison between 595 watt and 700 watt of Coir based on tensile strength

Fig. 7. Comparison between 595 watt and 700 watt of Coir based on compressive strength

Fig. 8. Comparison between microwave moulding and compression moulding of Coir based on tensile strength

Fig. 9. Comparison between microwave moulding and compression moulding of Coir based on tensile strength

Fig. 10. Bonding between fibre and polypropylene in Microwave moulding

Fig. 11. Bonding between fibre and PP in microwave processing
Fig. 12. Fibre breakage in microwave moulding

Fig. 13. Blow holes in microwave moulding

Fig. 14. Cracks in microwave moulding

Fig. 15. Holes in compression moulding

Fig. 16. Bonding between fibres and PP in compression moulding

Fig. 17. Bonding between fibres and PP in Compression moulding
4. Conclusion

- By the addition of natural fibres in polypropylene and processing those in microwave enhanced the mechanical properties like tensile strength and compressive strength as compared to the Polypropylene.
- The mechanical properties increases as the fibre content increases.
- Coir was found to be a microwave absorber.
- As coir is a microwave absorber, there is no need of a susceptor.
- The processing time of polymer matrix composite reinforced with coir is very less as coir has the property of absorbing microwave which helps in rapid melting of the PP.
- The more is the power output, the lesser time of manufacturing takes place in microwave moulding.
- In case of compression moulding also the tensile strength and compressive strengths increases enormously.
- As compared to the microwave moulding, the composites produced by compression moulding process has better mechanical properties such as tensile strength and compressive strength.
- The presence of blow holes, cracks and other moulding defects were more in microwave processed composite.
- In case of compression moulding technique the power consumption is very high as composites in this process are produced using two machines, first a two roll mill for compounding and then in a compression moulding machine as both the machines consume power individually.

- As seen in both the processes the mechanical properties increases as the content of fibre increases.
- For producing a higher number of products at a much cheaper price, microwave moulding is considered.

4.1 Recommendations

- For mass production of products at a cheaper cost, microwave moulding is recommended, as the processing cost is very less as compared to compression moulding.
- For faster rate of production, microwave moulding is preferred as it takes lesser time than the compression moulding technique.
- After the accomplishment of the research, it is found that the overall mechanical properties of compression moulding technique was found to be better than microwave moulding technique, thus compression moulding is recommended.
- If the power output of the microwaves can be increased then samples of better mechanical properties can be achieved.
- As coir was found to be a microwave absorber, so using this saves a lot of time, therefore coir is recommended as a natural fibre.

4.2 Future Scope

- The length of the fibres can be varied and as long fibres and mat form fibres can be used for different research.
- This research can be used for various other natural fibres like hemp, gewia optiva, bagasse, sisal, abaca, bamboo etc.
- Research can be made on the microwave absorbing behaviour of coir.
- Different techniques can be used for comparison with microwave moulding such as injection moulding, extrusion moulding etc.
- Research can be made on a variety of fibre content in the composite.

5. References


