

## SYNTHESIS AND CHARACTERIZATION OF *CANNABIS INDICA* FIBER REINFORCED COMPOSITES

Amar S. Singha,<sup>a</sup> Balbir S. Kaith, and Aishwarya J. Khanna<sup>b,\*</sup>

This paper reports on the synthesis of *Cannabis indica* fiber-reinforced composites using Urea-Resorcinol-Formaldehyde (URF) as a novel matrix through compression molding technique. The polycondensation between urea, resorcinol, and formaldehyde in different molar ratios was applied to the synthesis of the URF polymer matrix. A thermosetting matrix based composite, reinforced with lignocellulose from *Cannabis indica* with different fiber loadings 10, 20, 30, 40, and 50% by weight, was obtained. The mechanical properties of randomly oriented intimately mixed fiber particle reinforced composites were determined. Effects of fiber loadings on mechanical properties such as tensile, compressive, flexural strength, and wear resistance were evaluated. Results showed that mechanical properties of URF resin matrix increased considerably when reinforced with particles of *Cannabis indica* fiber. Thermal (TGA/DTA/DTG) and morphological studies (SEM) of the resin, fiber and polymer composite thus synthesized were carried out.

*Keywords:* Biocomposites; Natural fiber; Mechanical strength; Thermal behavior; SEM; Optimization

*Contact information:* a: Department of Chemistry, National Institute of Technology, Hamirpur, 177 005 India; b: Department of Chemistry, National Institute of Technology, Hamirpur, 177 005 India; c: Department of chemistry, National Institute of Technology, Jalundhar, Punjab, India; \* Corresponding author: [aishwarya\\_khanna23@yahoo.com](mailto:aishwarya_khanna23@yahoo.com)

### INTRODUCTION

Growing environmental awareness and societal concern, a high rate of depletion of petroleum resources, the concept of sustainability, and new environmental regulations have triggered the search for new products that are compatible with the environment. Sustainability, 'cradle to grave' design, industrial ecology, eco-efficiency, and biocompatibility are the guiding principles of development of new generations of materials. Lignocellulosic reinforced composites are the materials of the new paradigm. The use of biodegradable and environment friendly plant-based fibers in the composites reduces waste disposal problems, environment pollution, and ecological concerns. Light weight, decreased wearing of machines, low abrasiveness, as well as an absence of health hazards during processing, application, and upon disposal are added advantages of these composites. Also these fibers can be incinerated, are CO<sub>2</sub> neutral (when they are burned), and because of their hollow and cellular structure, perform well as acoustic and thermal insulators.

Lignocelluloses fibers play an important role in developing high performance biocomposites. Mukherjee et al. (1986) reported structural aspects and properties of various natural fibers and different biodegradable polymers that are used for the development of biocomposites. It has been reported (Nabi Saheb et. al. 1999) that

cellulose microfibrils and cellulose nanocrystals can be used as a reinforcing phase in polymeric matrix. Introduction of biocomposites will reduce the waste disposal problems, especially in agricultural fields, environmental pollution, etc., and can find various applications in engineering, electronic, and automotive fields (Venkataswamy et al. 1987). Based upon the above concerns, many workers around the world are working on the development of natural fiber-based composites, in which ramie, hemp, jute, sisal, pine needles, *Saccharum cilliari*, and so on are used as reinforcements in place of synthetic fibers. Flax, kenaf, hemp, and wood flour are reported to be highly suitable for the preparation of load-bearing and impact-absorbing components of vehicles.

In our research laboratory comprehensive research on the utilization of natural fibers in polymer matrix composites had been carried out in the last few years. This research has involved pine needles (Singha et al. 2008c,d and 2009), *Saccharum cilliari* (Singha et al. 2002, 2007, 2008a,b), *Hibiscus sabdariffa* (Singha et al.2008e), and flax (Kaith et al. 2003, 2004) fibers as the reinforcing fillers in polymer matrix composites.

The present study focuses on the mechanical properties of the versatile natural fiber *Cannabis indica*. This plant is most widely found in the forests of Himachal Pradesh. This is also a most common weed plant. Hence, research has been started to utilize this waste biomass as reinforcing filler in polymer matrix-based green composites. *Cannabis* (hemp) is a bast fiber belonging to the family cannabicae commonly referred to as bhang. *Cannabis* is characterized by its high length and great strength as compared to cotton and silk. Its specific strength is comparable to those of glass fibers, and it shows higher elongation. This fiber is widely used in the textile industry due to its softness. This fiber is a good candidate for biocomposites.

The purpose of the study is thus to study the effect of the presence of fiber loadings on the mechanical properties of *Cannabis indica* fiber-based composites. URF, a thermosetting matrix, was used as the binder. First URF with varying amount of resorcinol was optimized with respect to mechanical properties such as tensile, compressive, flexural strength, and wear resistance. This optimized ratio was then used to prepare the biocomposites reinforced with lignocellulose from the *Cannabis indica* plant. Effects of fiber volume or loading on the mechanical properties of URF matrix were studied. Further thermal (TGA/DTA/DTG) and morphological (SEM) studies of these biocomposites were also carried out.

## **EXPERIMENTAL**

### **Materials**

Urea, resorcinol, formaldehyde solution, and sodium hydroxide were kindly supplied by Qualigens Chemicals Ltd. and were used as received. Urea-Resorcinol-Formaldehyde (URF) was used as matrix polymer. The lignocellulosic material used as the reinforcing filler in the composites was *Cannabis indica* fiber of micron size.

### **Instruments Used**

Weights of the samples were obtained with a Shimadzu make electronic balance (LIBROR AEG-220). Curing of samples was done on a compression molding machine

(Santech India Ltd.). Thermal studies were carried out with a Thermal analyzer (Perkin Elmer). SEM micrographs were taken with a LEO 435 VP.

### Synthesis of Urea-Resorcinol-Formaldehyde Resin

Urea-formaldehyde (UF) resin was synthesized by the standard method developed in our Applied Chemistry research laboratory (Singha et al. 2007, 2008). Urea and formaldehyde in the ratio 1.0:2.5 were taken by weight, in the reaction kettle, and were mixed with the varying molar ratios of resorcinol (0.5, 1.0, 1.5, 2.0, and 2.5) by weight with the help of a mechanical stirrer. The reaction was carried out in an alkaline medium. Since the reaction is exothermic, proper care was taken to maintain the temperature between 50 and 60 °C for an initial two hours. Then the temperature was increased to 80-85 °C at pH 5.5 to 6, and the mixture was heated at this temperature until the resinification started.

After the completion of resinification the resin was cooled, and ammonium chloride was added pinch-wise to increase the bonding between the molecules. It acts as the hardener to enhance crosslinking in the URF resin. This mixture was then poured into specially made molds. Resin sheets of 150 mm x 150 mm x 5.0 mm were prepared by closed mold method under the pressure (4.0 MPa) and 150 °C temperature. These samples were then post-cured at 120 °C for 7 hours.

### Preparation of Composites

Retted *Cannabis indica* fiber obtained from a local source was first thoroughly washed with detergent powder. After this these fibers were soaked in hot distilled water for 3 hours, dried for 48 hours in air at room temperature, followed by drying in a hot air oven at 105 to 110 °C for 12 hours. The dried fibers were then ground to a fine powder of size 200 microns. This powder was then mixed with URF resin using a mechanical stirrer with different loadings (10, 20, 30, 40, and 50%) in terms of weight.

This mixture was then poured into specially made molds. The surfaces of molds were coated with oleic acid to prevent adhesion of mix to the mold and to result in a glossy finish of the product. Composite sheets of size 150 mm x 150 mm x 5.0 mm were prepared in compression molding machine.

Compression molding was performed in a hot press using a mold preheated to 110 °C. The material first placed in a hot open mold was left for about 5 minutes and then the mold was closed. Composite sheets were prepared by hot pressing the mold at 150 °C for 30 minutes at a pressure of 3 to 4 MPa, depending on the fiber loading. All specimens then were post-cured at 120 °C for 12 hours.

### Mechanical Testing

#### *Tensile strength test*

The tensile strength test was conducted on a Computerized Universal Testing Machine (HOUNSFIELD H25KS). The tensile test was conducted in accordance with ASTM D 3039 method. The test was conducted at the constant strain rate of 10 mm/min. Force was applied till the failure of the sample and load – elongation curve was obtained. Each sample was tested for seven times.

### *Compressive strength test*

The compression strength of samples was tested on a Computerized Universal Testing Machine. The compression test was conducted in accordance with ASTM D 3410 method. The composite sample was held between the two platforms, and the strain rate was fixed at 10 mm/min, whereas the total compression range was 7.5 mm. The compression stress was applied up to the failure of the sample. The total compression strain per unit force was noted.

### *Flexural strength test*

Flexural strength of samples was also tested on a Computerized Universal Testing Machine. The three-point bend flexural test was conducted in accordance with ASTM D 790 method.

### *Wear test*

The wear test of the sample was conducted with a Wear & Friction Monitor (DUCOM- TR-20L). Wear resistance of composites was carried-out as per ASTM D 3702 method. The disc was cleaned with Emery paper and it was fixed at 500 rpm. The inner diameter of the steel disc was 80 mm. The initial weight of the sample was noted, and the sample pin was fixed in the jaws of wear testing machine. Then the machine was set to display zero wear and friction. The samples were tested with different loads varying from 1.0 to 3.0 kg. For each load the machine was allowed to run for 15 minutes, and the readings were recorded. After 15 minutes the sample was taken out from the machine and weighed again. Then loss in weight due to abrasion was calculated and this weight loss was used as the measure of wear.

## **Stress – Strain Analysis**

A stress-strain diagram expresses the relationship between a load applied to a material and the deformation of the material, caused by the load. Stress-strain diagrams were determined from tensile, compressive, and flexural tests. Stress was calculated as usual by dividing the applied load with the initial annular cross-sectional area, while strain is defined as the ratio of the displacement and the initial length.

## **Thermal Analysis of Samples**

Thermal analysis of natural fiber and synthetic polymer along with biocomposite was done on the thermal analyzer. These studies were carried out in nitrogen atmosphere at a constant heating rate of 10 °C/min in an aluminum crucible. The temperature range was 50 °C to 1000 °C. The combustion of the sample was continued for 100 minutes, and the results, Delta-M (mg), vs. temperature (°C) in case of TGA and DTA signal (μV) vs. temperature (°C) in case of DTA, were compiled automatically by the software.

## **SEM Analysis of Samples**

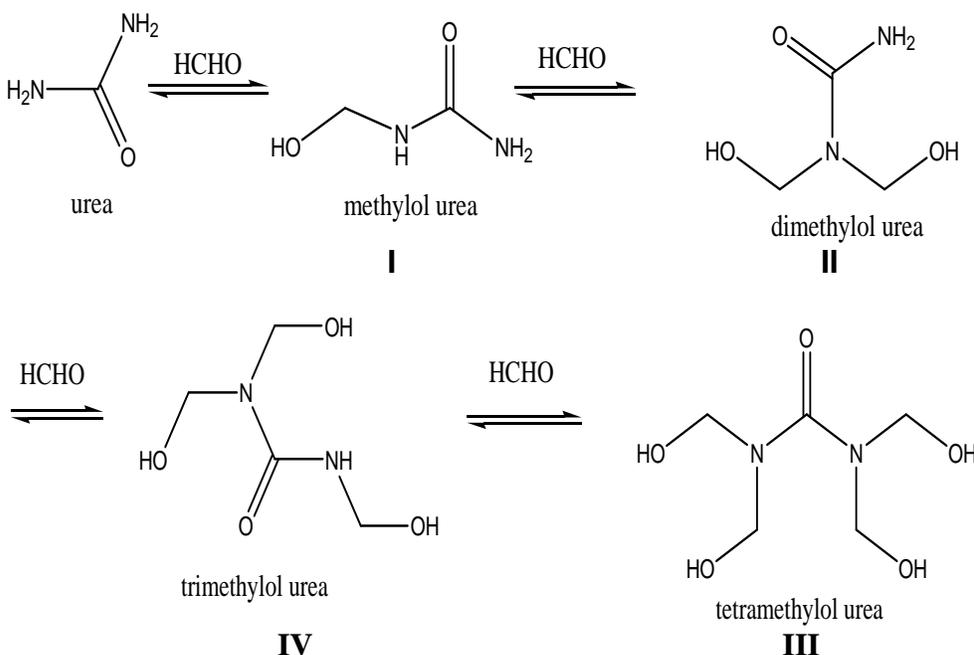
In order to evaluate the changes that occurred in the surfaces, the polymer matrix, fiber, and composite samples were analyzed by scanning electron microscopy (SEM). The excitation energy used was 5 keV. To achieve good electrical conductivity, all samples were first carbon-sputtered, followed by gold palladium sputtering before

examination. Then these samples were placed on the stub and inserted into the scanning barrel. The scanning was done in vacuum to prevent interference of the image by air. Scanning was synchronized with a microscopic beam in order to maintain the small size over a large distance relative to the specimen. SEM micrographs of all the samples show the surface morphology and changes that took place in the surfaces during the fabrication of composites.

## RESULTS AND DISCUSSION

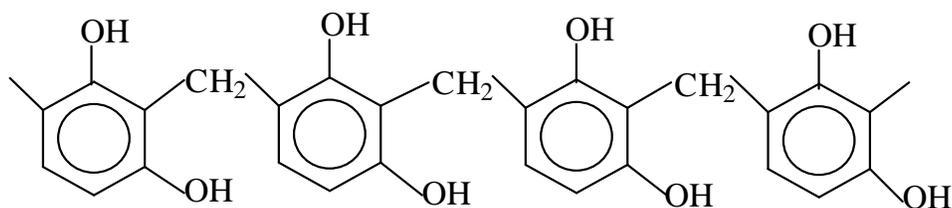
### Mechanism of Synthesis of Urea-Resorcinol-Formaldehyde Resin

The chemical reaction is supposed to take place in two steps. First step involves the reaction between urea and formaldehyde to form methylol urea. Since urea is tetra-functional, the initial reaction may lead to the formation of the tetra-methylol derivative of urea (as shown in Scheme 1). However slightly alkaline medium (pH of 7 to 8) controls the reaction and favours the formation of dimethylol urea. Since these methylol ureas are non-adhesive in nature, condensation does not take place. However, condensation takes place in acidic medium. Therefore the reaction is carried out at 80 to 90 °C, and the reaction speed is controlled by the acidity of the medium (pH 5.5 to 6). As the reaction proceeds, larger molecules with crosslinked structures are formed. At the required level the reaction is arrested by neutralization (pH 7.5 to 8). The condensation is closely watched and controlled at the stages of production, because if the reaction is allowed to continue, crosslinking leads to the gelation of the resin. Under acidic conditions methylol urea condenses by elimination of water between either of four steps (as shown in Scheme 2).



**Scheme 1.** Formation of methylol derivatives of urea





**Scheme 5.** One dimensional network of Resorcinol Formaldehyde polymer

## Optimization of Urea-Formaldehyde Resin

### *Tensile strength*

The load – extension curves for the different ratios of UF resin are shown in Fig-1(a). It was observed that with increasing amount of formaldehyde in the samples the tensile strength also increased. This could be due to the formation of a two- or three-dimensional network, which accounts for the increased tensile strength. The maximum tensile strength is shown by ratio 1.0:2.5 (106 N), followed by 1.0:2.0 (63.5 N), 1.0:3.0 (50.6 N), 1.0:1.5 (34.3 N), and 1.0:1.0 (10.1 N) with the percentage extension of 1.6(1.0:1.0), 2.0(1.0:1.5), 2.9 (1.0:2.0), 3.0(1.0:2.5), and 2.9(1.0:3.0), respectively.

### *Compressive strength*

The force versus compression curves of different ratios of UF resin are shown in Fig. 1(b). It is apparent from the curves that the UF ratio 1.0:2.5 yielded the highest compressive strength of 787 N, followed by 1.0:2.0 (675 N), 1.0:1.5 (370 N), 1.0:3.0 (289 N), and 1.0:1.0 (15.4 N).

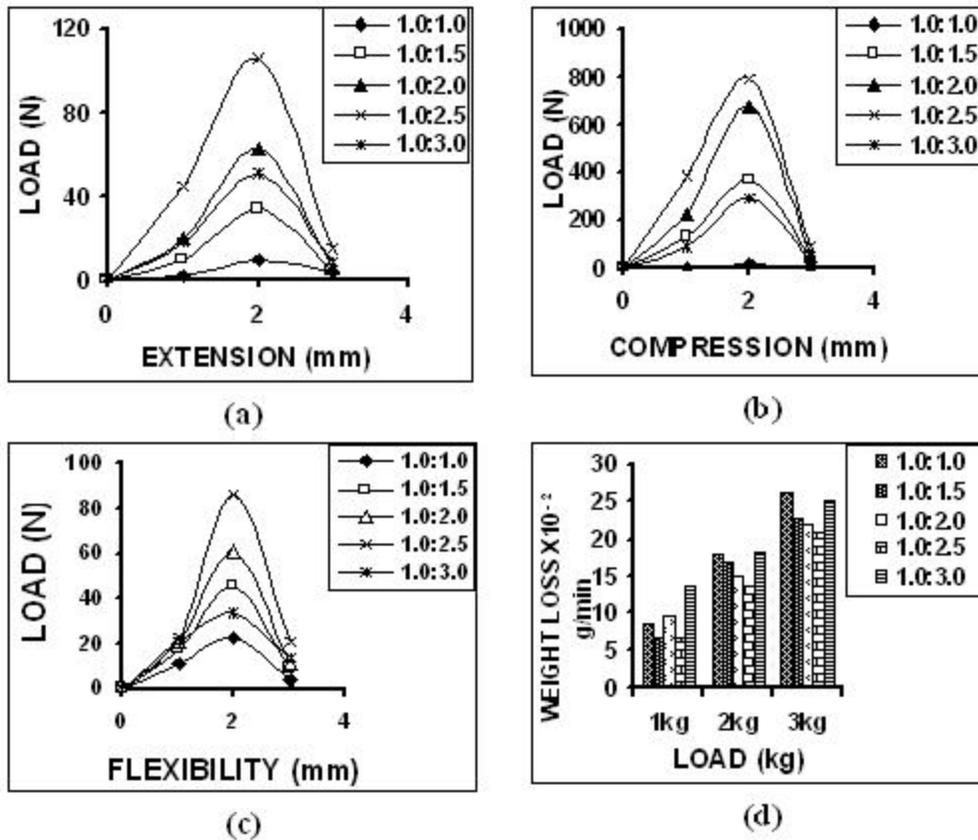
### *Flexural strength*

A similar trend was observed for flexural strength results. The flexural properties of samples as a function of force and flexibility are shown in Fig 1(c). The sample having a ratio of 1.0 :2.5 showed a maximum flexural strength of 48.1 N and flexibility of 1.614 mm.

### *Wear resistance*

It was observed that wear rate of samples of ratio 1.0:2.5 was less as compared to any other samples, as shown in Fig. 1(d). Loss of material was due to abrasion and friction of samples with the disc. The wear resistance results support the tensile, compressive, flexural, and hardness results, as brittle materials tend to have higher wear rate and low tensile, compressive and flexural strength. The samples with lower amount of formaldehyde had higher concentrations of dimethylol urea, which makes them amorphous in nature, but as the ratio of formalin increases, the concentration of dimethylol urea decreases due to the formation of ether linkages and two- or three-dimensional crosslinking.

Samples of ratio 1.0:2.5 showed maximum tensile, compressive, and flexural strength, and at this ratio the wear rate was greatly minimized. The hardness and impact strength of the samples of this ratio were found to be good compared to other ratios. Therefore, this ratio was taken as the optimized ratio for further preparation of urea resorcinol formaldehyde resin.



**Figure 1(a-d).** Tensile/ Compressive/ Flexural/ Wear resistance curves of Urea- Resorcinol- Formaldehyde resin

## Optimization of Urea-Resorcinol-Formaldehyde Resin

### Tensile strength

The tensile strength of U-R-F resin samples was found to be high relative to the samples of U-F resin, as shown in Fig. 2(a). The sample of ratio 1.0:1.0:2.5 showed maximum tensile strength at a force of 555 N, followed by 281 N (1.0:0.5:2.5), 205 N (1.0:1.5:2.5), 102 N (1.0:2.0:2.5), and 60 N (1.0:2.5:2.5). This could be due to the difference in the microstructures of URF and UF polymers. The tensile strength of URF polymer has been reported to be 5 times as that of UF resin (Singha et al. 2009).

### Compressive strength

The compressive strength of U-R-F samples is shown in Fig. 2(b). URF resin with ratio: 1.0:1.0: 2.5 was able to bear a maximum force of 1162 N, which is about 1.2 times more than that of the UF resin by itself.

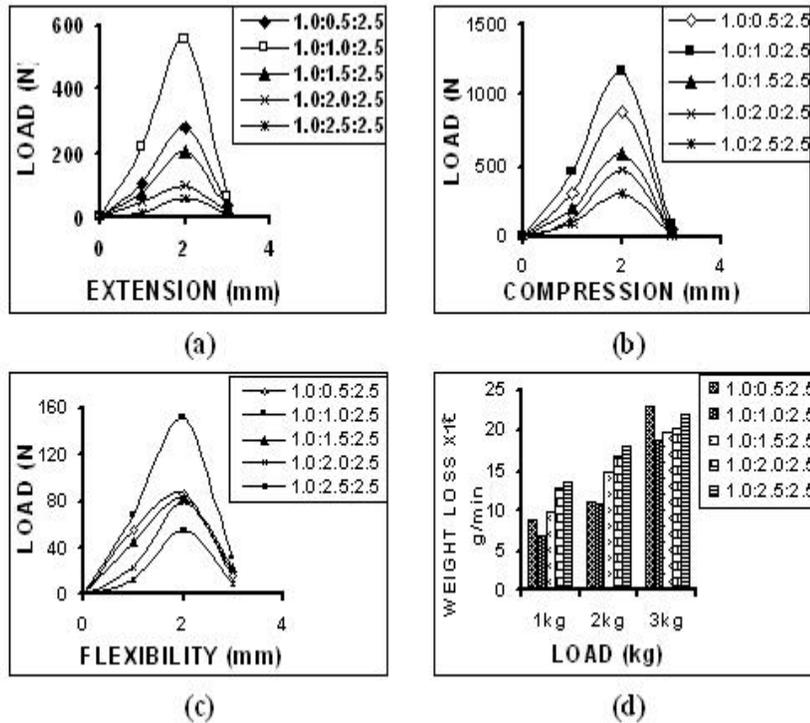
### Wear test

The wear rate of U-R-F resin samples of all ratios was found to be low relative to U-F resin. The sample of ratio 1.0:1.0:2.5 exhibited less wear rate at all loads as compared to other samples, as shown in Fig. 2(d).

### Flexural strength

The URF sample of ratio 1.0:1.0:2.5 could bear a flexural load of 151.6 N and had a flexibility of 1.78mm, which was more than other ratios Fig. 2(c).

Mechanical properties of U-R-F resin samples with ratio 1.0:1.0:2.5 were found to be good compared to other samples. So, this ratio was taken to prepare composites.



**Figure 2(a-d).** Tensile/ Compressive/ Flexural/ Wear resistance curves of Urea- Resorcinol- Formaldehyde resin

## Reinforcement vs. Mechanical Properties of URF Based Composites

### Tensile strength

It was observed that tensile strength of URF polymer resin increased on reinforcement with *Cannabis indica* fiber. The URF polymer composites when reinforced with the particles of *Cannabis indica* fiber could bear a maximum load of 677.5, 769.2, 945, 1093.6, and 730 N, and the corresponding extension values were 2.5, 2.8, 3.4, 3.6, and 3.2 mm for 10%, 20%, 30%, 40%, and 50% fiber loadings, respectively, as shown in Fig. 3(a).

### Compressive strength

Compressive strength of URF matrix was found to increase on reinforcement with *Cannabis indica* fiber. The compressive properties of the composites as the function of load and deformation are presented in Fig. 3(b). From the graph it is evident that the compressive force first increased with the increase in fiber content, but after 40% fiber content a significant decrease in compressive strength was observed.

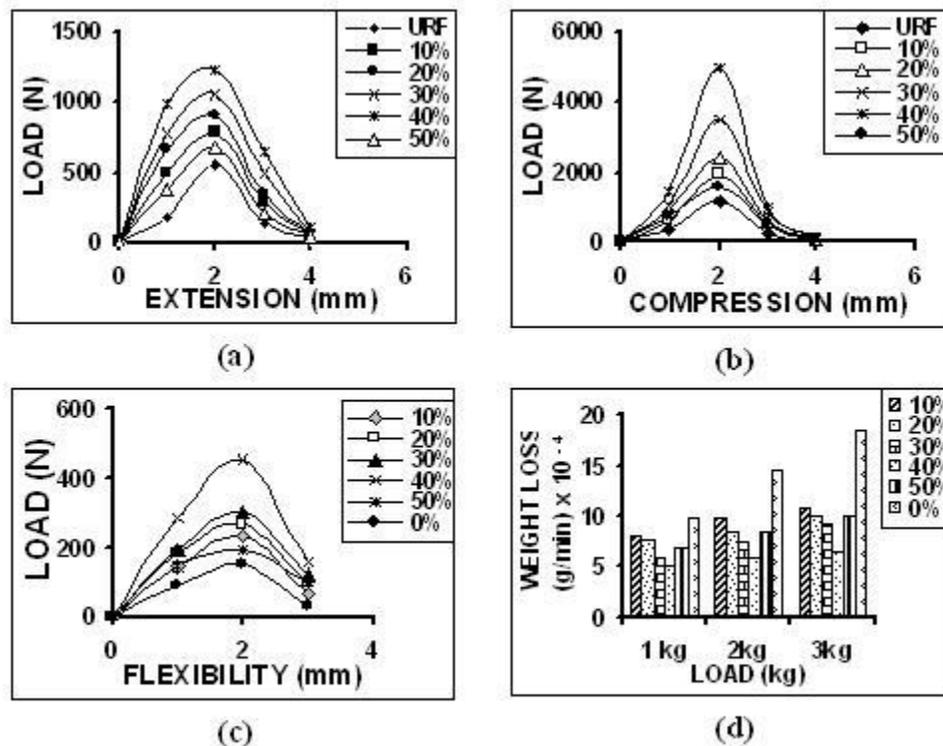
It is clear from the figure that URF polymer composites reinforced with the particles of *Cannabis indica* fiber could bear a maximum load of 1408, 2568, 3375, 4055, and 2143 N with a compression of 2.34, 2.57, 3.25, 3.7, and 3.2 mm respectively for 10%, 20%, 30%, 40%, and 50% fiber loadings.

#### Flexural strength

Similar trends as obtained in tensile strength and compressive strength tests were observed for flexural strength results. The flexural properties of samples as a function of force (in terms of load) and deflection are shown in Fig. 3(c). It is clear from the figure that URF polymer composites could bear a maximum load of 255, 334, 401, 476.6, and 315.1 N with the flexibility of 2.5, 2.87, 3.45, 3.67, and 3.23 mm for 10%, 20%, 30%, 40%, and 50% fiber loadings, respectively.

#### Wear test

As evident from Fig. 3d, the wear rate of UF matrix decreased appreciably as reinforcement with *Cannabis indica* fiber increased. It was observed that particle reinforcement decreased the wear rate by particle reinforcement to a much greater extent. Maximum wear resistance behavior was shown by a composite with 40% wt. loading, followed by 30, 20, 50, and 10% loadings.



**Figure 3(a-d).** Tensile/compressive/flexural/wear resistance curves of urea-resorcinol-formaldehyde resin based composites with different fiber loadings

### Stress-Strain Behaviour

Since both the stress and the strain are obtained by dividing the load and elongation by constant factors, the stress-strain curves have the same shape as the force-extension/compression/flexibility curves. From the curves it is clear that in the elastic region stress was linearly proportional to strain. When the load exceeded a value corresponding to the yield strength, the specimen underwent gross plastic deformation. It was permanently deformed if the load was subsequently released to zero. Different parameters derived from the stress-strain curves are shown in Tables 1 to 3.

**Table 1.** Various Stresses Calculated from Tensile Load/Extension Curves of URF- and URF-Based Biocomposites

| Sample Code | Ultimate Stress MPa | Working Stress MPa | Yield Stress MPa | Fracture Point MPa | Modulus MPa | S.D. $\pm$ |
|-------------|---------------------|--------------------|------------------|--------------------|-------------|------------|
| URF         | 21.3                | 12.5               | 15.85            | 17.5               | 756.9       | 1.23       |
| Prnf-10     | 22.2                | 16.9               | 16.14            | 21.29              | 778.6       | 1.20       |
| Prnf-20     | 27.6                | 19.2               | 23.4             | 23.22              | 823.1       | 1.38       |
| Prnf-30     | 31.8                | 20.3               | 27.54            | 24.96              | 876.4       | 1.49       |
| Prnf-40     | 44.3                | 21                 | 27.5             | 28.82              | 1234.9      | 1.99       |
| Prnf-50     | 26.7                | 14.5               | 18.9             | 18.22              | 800.8       | 2.01       |

**Table 2.** Various Stresses Calculated from Compressive Load/Compression Curves of URF- and URF-Based Biocomposites

| Sample Code | Ultimate Stress MPa | Working Stress MPa | Yield Stress MPa | Fracture Point MPa | Modulus MPa | S.D. $\pm$ |
|-------------|---------------------|--------------------|------------------|--------------------|-------------|------------|
| URF         | 46.48               | 29.8               | 34.5             | 38.9               | 1198.7      | 1.56       |
| Prnf-10     | 47.2                | 31.7               | 37.9             | 43.1               | 1205        | 1.78       |
| Prnf-20     | 85.92               | 56.9               | 64.5             | 78.9               | 2272        | 1.67       |
| Prnf-30     | 129                 | 89.45              | 103.4            | 113.5              | 3240        | 2.34       |
| Prnf-40     | 156                 | 123.4              | 146.8            | 137.9              | 3617        | 1.89       |
| Prnf-50     | 51.72               | 31.56              | 41.3             | 49.8               | 1566        | 2.13       |

**Table 3.** Various Stresses Calculated from Flexural Load/Flexibility Curves of URF- and URF-based Biocomposites

| Sample Code | Ultimate Stress MPa | Working Stress MPa | Yielding Stress MPa | Fracture Point MPa | Modulus MPa | S.D. $\pm$ |
|-------------|---------------------|--------------------|---------------------|--------------------|-------------|------------|
| URF         | 6.06                | 3.20               | 4.90                | 4.10               | 234.6       | 1.93       |
| Prnf-10     | 8.20                | 5.78               | 6.34                | 6.50               | 267.8       | 1.67       |
| Prnf-20     | 9.36                | 6.78               | 7.45                | 8.09               | 335.7       | 2.11       |
| Prnf-30     | 12.04               | 8.98               | 10.23               | 10.99              | 378.9       | 1.5        |
| Prnf-40     | 17.60               | 11.76              | 13.54               | 14.98              | 427.0       | 1.63       |
| Prnf-50     | 12.20               | 8.34               | 10.20               | 9.87               | 357.4       | 2.12       |

From these results it is clear that *Cannabis indica* fibers are efficient candidates as reinforcing materials in URF matrix-based composites. This may be due to larger surface area and more fiber/matrix interaction in the case of *Cannabis indica* fibers reinforced URF matrix-based composites. This also may be due to the different adhesion strength between matrices and fibers. The adhesion is usually the strongest in polar polymers capable of forming hydrogen bonds with hydroxyl groups available on the fiber surface. The chemical bonding accounts for the adhesion between URF resin and cellulose of *Cannabis indica* fiber. Still higher bond strength obtained for URF resin matrix can be attributed to the possible reaction between the methylol groups of the resin with the hydroxyl group of cellulose.

Further it has been observed that higher fiber loading (> 40%) resulted in a decrease in the mechanical properties of URF matrix-based composites. This behaviour can be explained as resulting from the formation of agglomeration or bundles of fibers within the matrix, such that stress is not effectively transferred to the matrix at higher fiber loading. Hence, lower results were obtained for 50% loading.

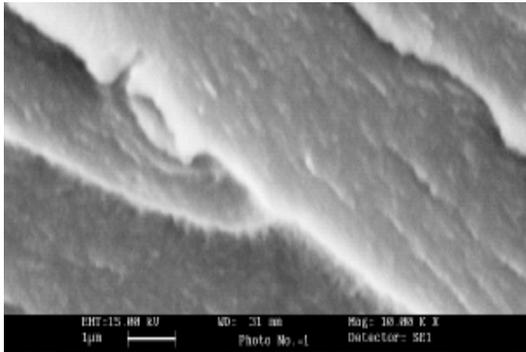
At low fiber volume fraction, a drastic decrease in tensile strength is usually observed. This has been explained with dilution of the matrix and introduction of flaws at the fiber ends where high stress concentrations occur, causing the bond between fiber and matrix to break. At high fiber volume fraction, the matrix is sufficiently restrained and the stress is more evenly distributed. This could be due to reinforcement effect outweighing the dilution effect. As the volume fraction of fibers is increased to a higher level, the tensile properties gradually improve to give strength higher than that of the matrix. The corresponding fiber volume fraction in which the strength properties of the composite cease to decline with fiber addition, and begin to again to improve, is known as the optimum or critical fiber volume fraction ( $V_{crit}$ ). For fiber reinforced composites to perform well during service, the matrix must be loaded with fibers beyond this critical value. At very high fiber volume fraction, the strength again decreases due to insufficient matrix material. Thomas *et al.* (1993, 1997) investigated the mechanical behavior of pineapple leaf fiber-reinforced polyester composites as a function of fiber loading, fiber length, and fiber surface modification. Tensile strength and modulus were found to increase linearly with fiber content. The impact strength was also found to follow the same trend. But in the case of flexural strength, there was a leveling off beyond 30% fiber content.

These results suggest that *Cannabis indica* fibers have immense scope in the fabrication of natural fiber reinforced polymer composites having vast number of industrial applications. Further this can provide employment to a number of villagers.

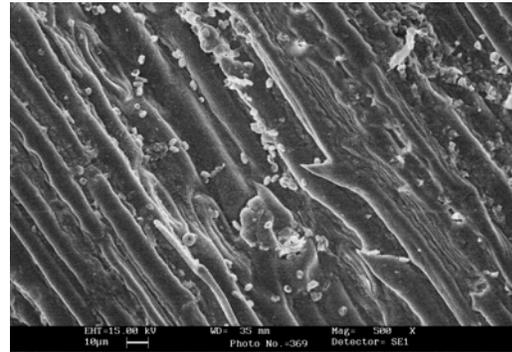
### Morphological Study of Composites

In order to evaluate the changes that occurred in the surface morphology of the reinforcing material and the resin matrix, these were subjected to scanning electron microscopic studies. SEM micrographs of *Cannabis indica*, URF, and URF-based composites reinforced with the *Canabis indica* fiber of particle size are presented in Fig. 4(c, e, g). SEM micrographs of *Canabis indica* reinforced URF composite samples clearly showed the difference in the morphology of polymer matrix, i.e. URF resin and the *Canabis indica* plant fiber separately. These results showed that when the polymer

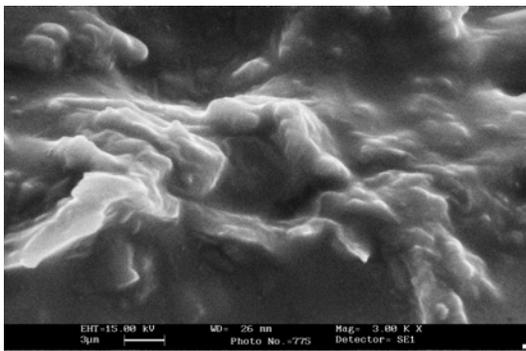
matrix was reinforced with fiber, changes evidently had taken place in the morphology. These results also showed differences in the morphology of composite samples and the resin itself. These results clearly showed that in case of composite samples there was intimate mixing of fiber and matrix. The SEM images of fractured samples are shown in Fig. 4(d, f, h). The SEM results supported the tensile, compressive, flexural strength, and wear resistance results.



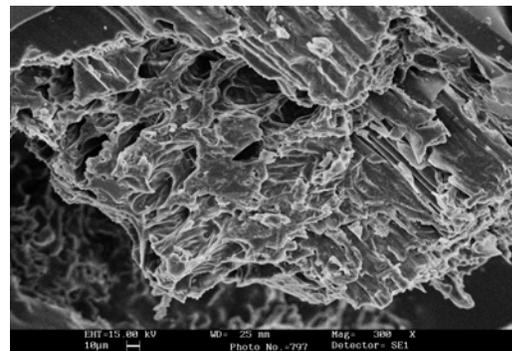
(a)



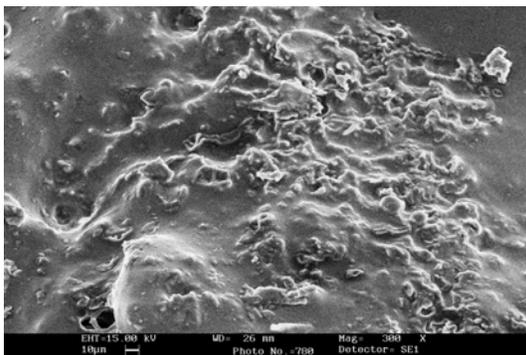
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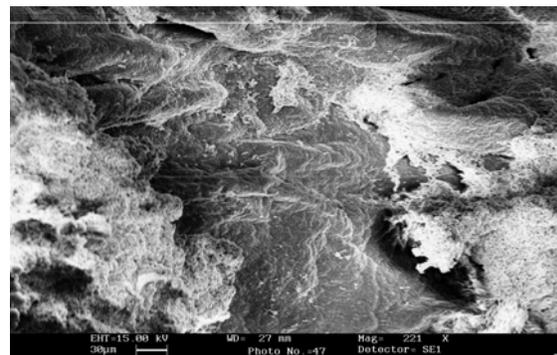
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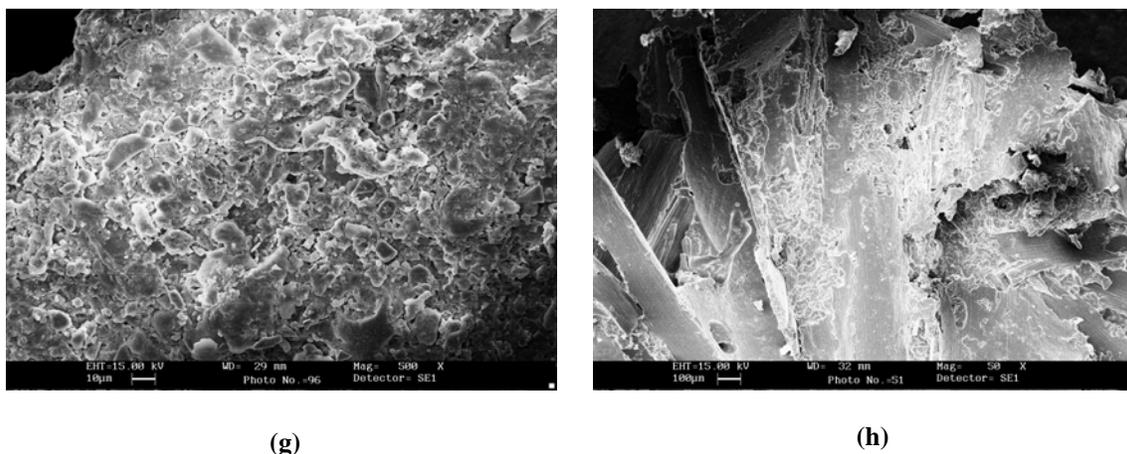
(d)



(e)



(f)



**Figure 4 (a-h).** SEM micrographs of URF, *Cannabis indica* and URF based composite samples with 10, 40 and 50% fiber loadings (c, e, g) and fractured surface of these composites (d, f, h)

### Thermal Behaviour of URF Resin and its Composites

Thermal (TGA) studies of samples were carried out in a nitrogen atmosphere on a thermal analyzer (Perkin Elmer) at a heating rate of 10 °C/min. The objective of the thermal study was to study the effect of heating on the stability of materials, which can be important for its applications in different sectors. Thermogravimetric analysis of raw fiber, URF resin, and biocomposite with 40% fiber loading was studied as a function of percent weight loss with the increase in temperature. In case of raw fiber, in the beginning depolymerisation, dehydration, and glucosan formation took place between the temperatures of 26.0 and 201.0 °C, followed by cleavage of C-H, C-C, and C-O bonds. The initial decomposition temperature was 201 °C, and the final decomposition temperature was 507 °C. The TG thermogram (Fig. 5) of URF resin shows that the initial decomposition started at 192 °C and ended at 700 °C. Subsequently, slow decomposition took place up to 996 °C. For the polymer composite the initial decomposition temperature was 199.0 °C and final decomposition took place at 600 °C, which indicates that the presence of natural fiber affects the thermal properties of the composite, as is shown in Fig. 5. The initial decomposition temperature of polymer composite has been found to be more than polymer matrix but less than natural fiber. This was consistent with results reported earlier (Singha et al. 2009).

TGA thermograms and char yield of various samples are shown in Fig. 5 and Table 4. The char yield of natural fiber and composite was found to be clearly larger than that for the URF matrix. The char yields of natural fiber, URF, and composite sample (40% fiber) were found to be 27.5%, 12.3%, and 22.6%, respectively. These results reveal that the addition of natural fiber to URF would effectively raise the char yield of the sample. As reported earlier (Shih 2007), the char yield is directly correlated to the potency of flame retardancy for the polymers. Increasing char yield can limit the formation of combustible gases, decrease the exothermicity of the pyrolysis reaction, and inhibit the thermal conductivity of the burning materials. Therefore, the addition of natural fiber would raise the level of flame retardancy relative to the URF polymer matrix by itself.

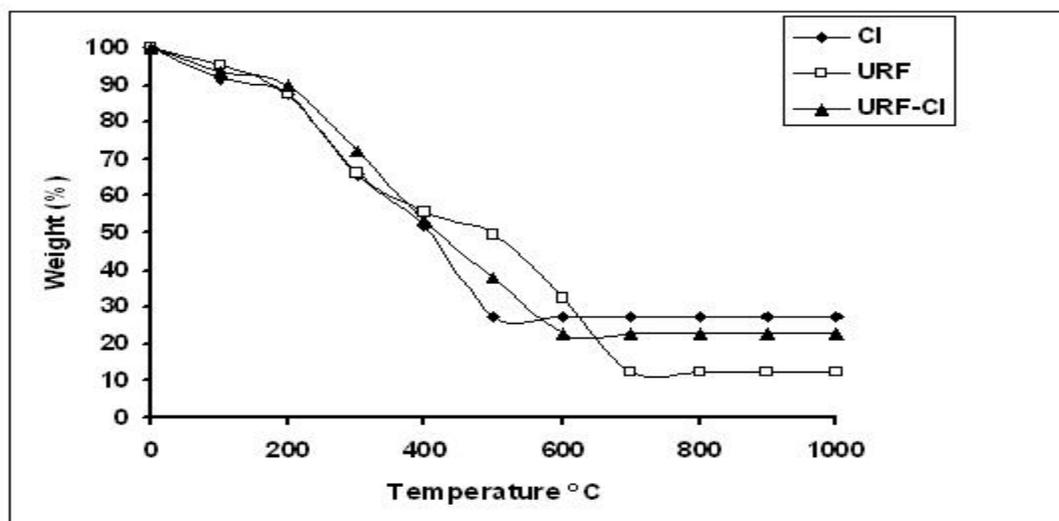


Figure 5. TGA thermograms of various samples

Table 4. TGA Analysis and Char Yield Results of *Cannabis indica* Fiber, and URF- and URF-based Biocomposites

| Sample Code            | IDT °C | FDT °C | % Char Yield |
|------------------------|--------|--------|--------------|
| <i>Cannabis indica</i> | 201    | 507    | 27.5         |
| URF                    | 192    | 700    | 12.3         |
| Composite Sample       | 199    | 600    | 22.6         |

## CONCLUSIONS

The mechanical properties of *Cannabis indica* reinforced polymer composites have been investigated as a function of the chemical nature of matrix polymer and the content of the reinforcing material. From the results obtained we can conclude:

- The Urea-Resorcinol-Formaldehyde resin was found to be mechanically stronger when compared with Urea-Formaldehyde resin.
- The mechanical properties of URF resin-based composites were found to be many times higher as compared to URF resin alone. Mechanical properties of composites increased with increase in fiber loading up to 40%wt. loading and then decreased.
- Thermal studies of these composites showed that the thermal degradation of polymer matrix was affected by the addition of fiber. The polymer composites were found to be more thermally stable when compared to polymer matrix.
- SEM micrographs showed distinctions between the surface morphology of composites and polymer matrix.
- These composites showed potential to be future materials for the production of eco-friendly products.

## ACKNOWLEDGEMENTS

We express our sincere thanks to Director, National Institute of Technology Hamirpur (H.P.) INDIA for providing the basic laboratory facilities.

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Article submitted: April 23, 2010; Peer review completed: January 24, 2011; Revised version received and accepted: April 8, 2011; Published: April 25, 2011.