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Effects of Reactive Dyeand Chemicalson the Performance of Jute Fabrics Polypropylene Composites

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Abstract: *Jute fabrics modified by Indosol E-50 with or without reactive dye in the presence and absence of salt and soda ash were considered to incorporate into polypropylene for composite fabrication. Conventional sodium hydroxide (NaOH) was also used for chemical modification of jute fabrics. Besides, untreated jute fabrics were treated with reactive dye by normal dyeing method to observe the nature of modification. The effects of treated jute fabrics on mechanical properties, Scanning Electron Microscopy (SEM), thermal behavior (TG/DTA), and water absorption properties of their resulting composites were evaluated. The composites of treated jute fabrics with Indosol E-50 plus Drimarene Red K8b had shown the highest mechanical performance such as tensile strength and modulus, which were 53 and 69% more than that of untreated jute fabrics reinforced composites. The higher tensile strength was attributed to the strong interfacial adhesion as a result of surface modification of jute fabrics which was confirmed by SEM results. Also, it confirms the best thermal stability among all other treatments including the control composites. Again, water absorption test revealed that the composites of this treated jute fabrics had 45% less water uptake than that of composites of untreated jute fabrics.*

Keywords: *Polymer composites, Chemical modification, Mechanical properties, Thermal behavior.*

I. Introduction

Among the natural fibers, jute fiber occupies the second place in terms of world production levels of cellulosic fibers. One of the major countries of jute production is Bangladesh, due to its natural fertile soil. Jute fiber is a lignocellulosic fiber containing three main categories of chemical compounds, namely cellulose (58–63%), hemicellulose (20–24%), and lignin (12–15%), and some other small quantities of constituents such as fats, pectin, and aqueous extract. Owing to its eco-friendly and biodegradable nature, the demand for jute fiber is raising day by day. Nearly, 75% of jute goods are used as packaging materials, burlap, gunny cloth, (hessian), and sacks. Therefore, it is particular interestto use jute fiber as reinforcement in polymer matrix (JRPCs). Natural fiber reinforced composites have been used in several applications for several years and the market is continuously growing. This market was estimated at 0.36 million metric ton in 2007 and it is expected to reach 3.45 million metric ton in 2020 [1]. However, the hydrophilic nature of natural fibers is a major drawback for their application as reinforcement for hydrophobic polymer matrix. The poor moisture resistance of natural fibers leads to incompatibility and poor wettability with hydrophobic polymers and this causes poor fiber/matrix interface bonding. Chemical or physical modifications are, therefore, usually carried out to improve bonding and adhesionaffinity to polymeric matrices and ensure dimensional stability. Many researchers [2-4] have tried to modify jute fibers by using alkali or other chemicals, the use of compatibilizers [5], coupling agents, such as maleic-anhydride-polypropylene co-polymer (MAH-PP) [6], have been reported to overcome the problem of incompatible surface polarities between the natural fibers and polymer matrix.

Reactive dyes are anionic dyes which are mostly used to dye cellulosic fibers. . These dyes have a low utilization degree compared to other types of dyestuff, since the functional group also bonds to water, creating hydrolysis. When alkalinity is introduced in the dye bath in order to facilitate the formation of covalent bond between the fiber and the functional groups of the reactive dye, the only 60-65% dye utilization is attainable even with the use of salt in the normal dyeing systems [7]. In the discipline of textile dyeing, most of the researchers focus on introducing cationic sites into the cellulosic fibers for interaction with anionic dyes to improve the dyeing performance [8-9]. Many studies [10-11] had been done to improve the dyeabilities of jute fiber also. Glytac and sodium hydroxide treated jute fibers [12] were dyed with reactive dyes in combination with common salt and soda ash. Khan [13] explained in his paper that the grafted fiber shows greater tensile strength and possesses better color fastness than that of bleached fiber. Bonding and adhesion characteristics of these treated jute fibers [12 and 13] with polymer were not analyzed. Hence, it is found that detail studies of dye treatments of jute fabric composites with PP are still lacking in the literature. Therefore, the present study is intended to focus on these aspects in an attempt to evaluate different physical, thermal, and mechanical properties of jute fabric reinforced PP composites.

II. Experimental

Materials

Jute fabrics

Jute fabrics were used without further treatment (scoured and bleached). Plain woven structured fabrics of untreated jute yarn were collected from Bangladesh Jute Research Institute (BJRI). Specification of woven fabrics was – number of yarn per inch (both directions): 10-12, number of twist per inch: 4-5, yarn count: 241 tex, fabric strength: about 20MPa. Same yarns were used in both (warp and weft) direction of the fabrics.

Chemicals

Indosol E-50 liquid (polyethylene polyamine in aqueous solution) and Drimarene Red K-8b (reactive dye) Clariant, Switzerland were used in this study. Sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3), and sodium chloride (NaCl) from BDH, (UK) were also used in the present study.

Methods

Chemical treatment of jute fabrics

To observe the effects of chemical treatment, five different techniques (I1 to I5) as shown in Table 1 were followed to treat the jute fabrics. In all the cases, the concentration of different chemicals was- Indosol E-50: 4 g/l, NaCl: 40g/l, and Na_2CO_3: 10g/l. Also, 1% Drimarene Red K-8b was used in every case. Besides these samples raw jute fabric was treated with normal dyeing method, i.e. jute fabric was treated with the mixture of 1% Drimarene Red K8b, sodium chloride (40g/l), and sodium carbonate (10g/l). Again, raw jute fabric was treated with 4% sodium hydroxide. All the treatments shown in Table 1 were carried out in a sealed steel container in a laboratory dyeing machine Rota Dyer with the material to liquor ratio of 1:15 and at the temperature of 60^oC for 60 minutes. The samples were then taken out and washed with water at least three times in order to remove any residual chemical so that a final pH value of 7 was maintained and then dried in an open air. I1 to I5 treated jute fabrics/PP composites are denoted here as CI1 to CI5and composites reinforced with NaOH treated, normal dyed, and untreated (raw) jute fabric are denoted here as CS, CN, and CUn, respectively. CN, CS, and CUn composite samples were considered here as a control sample.

Preparation of composites

Granules of polypropylene (PP) were used to prepare thin sheets (0.1-0.4mm thickness) using an extruder, Lab Tech Engineering Company Ltd. (USA).The PP sheets were cut into small pieces (18×18cm) and kept in the polyethylene bag until composite fabrication. Jute fabrics were cut into pieces of equal dimension (18×18cm) as PP sheets andplaced between two steel plates under normal pressure at90^oC temperature to remove moisture. Composites weremanufactured by sandwiching one layer of jute fabrics (55±1%) between two layers of pre-weighted PP sheets and pressing at 5 metric ton pressure and 190^oC temperature for 10 minutes between two steel plates of Carver laboratory press machine [14]. Then the composites with the steel mold was cooled to room temperature using another press (Carver, USA) and released from the mold. The composites were then cut to obtain specimens of desired size.

Table no 1: Different treatment procedures

Sample	Treatment procedure
S	Treatment with NaOH
N	Treatment with Drimarene Red K8b+ NaCl + Na_2CO_3(normal dyed sample)
I1	Treatment with Indosol E-50
I2	Treatment with Indosol E-50 + Drimarene Red K8b
I3	Treatment with Indosol E-50 + Drimarene Red K8b+ NaCl + Na_2CO_3
I4	Treatment of I-1 sample with Drimarene Red K8b
I5	Treatment of I-1 sample with Drimarene Red K8b + NaCl + Na_2CO_3

Characterization

Mechanical Properties

The tensile and flexural properties of composite samples were determined according to ASTM D 638 and ASTM D 790-00 standard methods, respectively, by a universal testing machine (model H50 KS-0404, Hounsfield Series S, UK). The crosshead speed was 5 mm/min. Impact strength was measured by an impact tester (HT – 8041B Izod, Pendulum type, Hung Ta Instrument Co. Ltd.) according to IS0 179/1fU standard in the flat wise, unnotched mode. All the results correspond to average values of at least five samples. In this study, mechanical properties of the composites were measured in the longitudinal direction in all the cases.

Scanning Electron Microscopy

The fiber matrix adhesion of the tensile fracture surface of the composites was examined by using a Field Emission Scanning Electron Microscope (model no: JEOL JSM -7600F, serial no: SM1761001050105) at BUET. The micrographs taken at a magnification of 1000X are presented in Section 3.

Thermogravimetric Analysis (TGA)

Thermo gravimetric analysis was carried out on 8-10 mg of composites at heating rate of 20^{O}C/min in a nitrogen atmosphere using a thermo-gravimetric analyzer, Seiko instruments Inc. (TG/DTA 6300). Raw and treated samples were subjected to TG/DTA in pure nitrogen gas under constant flow rate of 50 ml/min. Thermal decomposition of each sample occurred in a programmed temperature range of 30^{O}C - 550^{O}C.

Water absorption

Water absorption properties were evaluated according to ASTM D 570-99 standard. The specimens were first dried in a vacuum oven at 70^{O}C until a constant weight was attained. The weight of the dry specimens was measured carefully with an accuracy of ±0.01 g. Then, the specimens were immersed in distilled water for 24 h at room temperature. After that, the specimens were taken out and wiped with filter paper. The wet weight of the specimens was again measured and the water absorption was calculated as a percent.

III. Results and Discussion

As mentioned in a preceding section, seven different treatment procedures were employed for the modification of jute fabrics. The effects of these treatment procedures on the resulting composites are discussed in the sequel.

Tensile properties

The variation of tensile strength against different treated jute fabrics (J1 to J5) is shown in Figure1. It shows that all the composites of treated fabrics had higher tensile strength than that of untreated jute fabrics/PP composites. Specifically, the tensile strength of the composites CI1 and CS (corresponding to treatments of jute fabrics in absence of dye) was increased by 46.14% and 20.62% respectively, compared with that of the untreated jute fabrics/PP composites. Whereas, the tensile strength of the composites CI2, CI3, CI4, CI5, and CN (corresponding to treatments of jute fabrics in presence of dye) was increased by 53.34, 44.02, 30.13, 16.43, and 30.08% respectively, compared with that of the untreated jute fabrics/PP composites. Among all the composites as shown in Figure 1, CI2 composites gave the highest tensile strength value (32.57MPa), which was 27% higher than that of the CS composites. Tensile modulus of composites of treated jute fabrics is shown in Figure 2. It is found that all the composites reinforced with treated jute fabrics had the higher modulus than that of composites reinforced with untreated jute fabrics. Further, CI2 composites reinforced with I2 treated jute fabrics exhibited the highest tensile modulus (3.54 GPa), which was 69.38% higher than that of composites of untreated fabrics. This reveals that there might be some mechanical interlocking or chemical bonding that was formed between fiber and matrix. Figure 3 shows the effects of chemical modification of jute fabrics on the elongation at break ofdifferent treated and

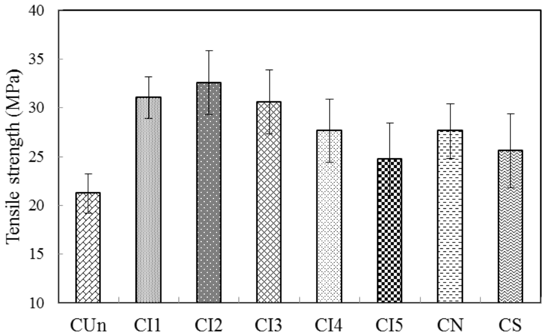


Fig. 1: Tensile strength of different composites

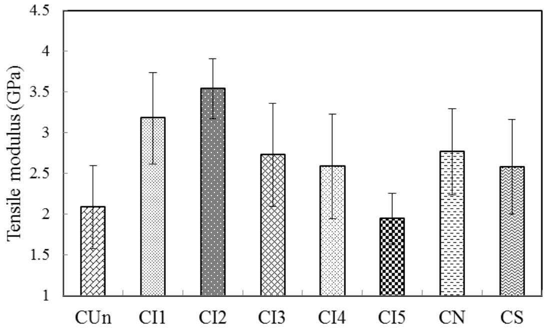


Fig. 2: Tensile modulus of different composites

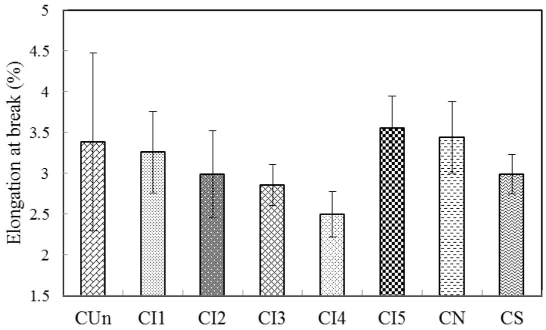


Fig. 3: Elongation percent of different composites

control JRPCs. It is observed that apart from CI5 composites, all the treated jute fabrics/PP composites show lower values of elongation than that of composites of untreated jute fabrics. However, the elongation percent of CI4 composites gave the lowest value (2.5%) among all the samples including control samples, which is 26% lower than CUn composites. The possible reason is the brittleness of jute fabrics after treatment with the chemicals corresponding to I4 treatment.

Flexural properties

Among all the dye treated jute fabrics/PP composites (CI2 to CI5 and CN), CI2 composites had the highest tensile strength value. Therefore, to observe the effects of I2 treatment on flexural properties of composites, CI1 (composite reinforced with Indosol E-50 treated jute fabrics) and CI2 (composite reinforced with Indosol E-50 plus dye treated jute fabrics) composites were selected for this purpose. Flexural strength of treated and control JRPCs are shown in Figure 4. The highest value of flexural strength (54.05 Mpa) was observed for CI2 composite and the second highest value of flexural strength (52.66 MPa) was observed for the composites of Indosol E-50 treated jute fabric (CI1), which was little bit higher than the flexural strength value (52.38MPa) of CN jute fabrics/PP composites. The flexural strength of CI2 and CI1 composites were increased by 20.83% and 17.73% than that of the composites of untreated jute fabrics,respectively. It was observed from Figure 5 that the flexural modulus of CI2 jute fabrics/PP

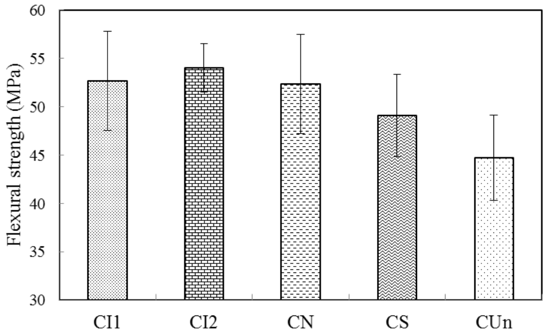


Fig. 4: Flexural strength of different composites

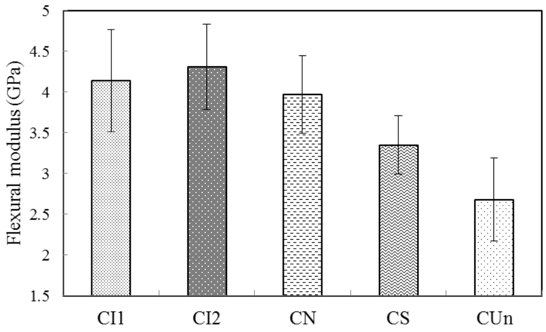


Fig. 5: Flexural modulus of different composites

composites was found to be maximum value (4.31 GPa), which was 60.82% higher than that of CUn composites and also, 28.66% higher thanthat of CS composites. Thus, this result shows that CI2 composites exhibited better flexural strength and modulus compared with other treated including control composites. So, it can be referred that Drimarene Red K-8b (reactive dye) and Indosol E-50 had a higher degree of influence on mechanical behavior of jute fabrics/PP composites.

Impact properties

The Charpy impact test determines the amount of energy absorbed by a material during fracture. Considering the above mentioned test results, CI2 and CI2 composites were selected for this purpose. Impact strength of treated and control JRPCs are shown in Figure 6. It is observed that the impact strength of CI1 and CI2 composites found to be 15.78% and 30.24% higher than that of the composites of untreated jute fabrics, respectively. The treated fiber had more solid content phase than that of the untreated fiber which may be the reason of higher impact strength of treated fabrics composites compared with that of untreated jute fabrics composites.

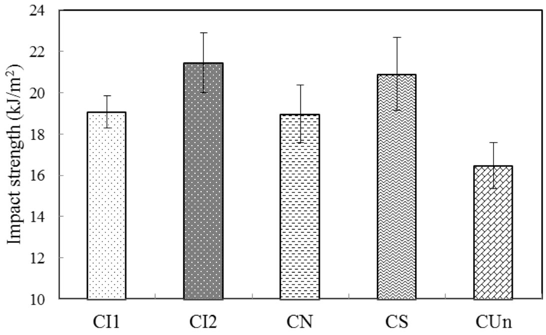
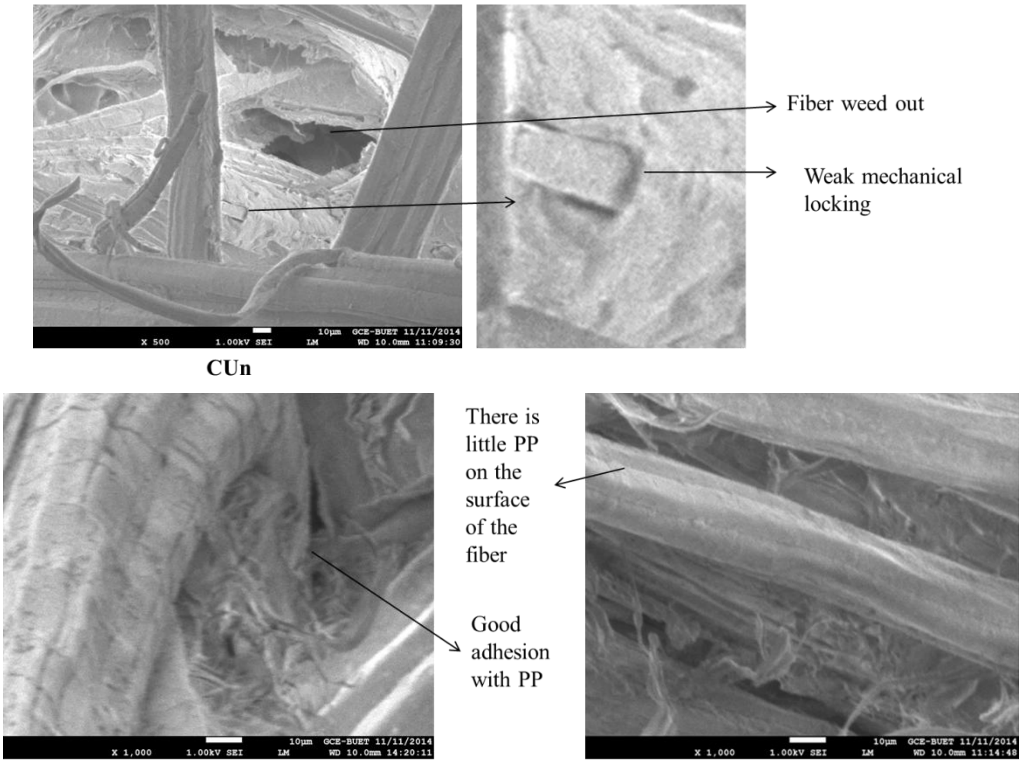


Fig. 6: Variation of impact strength of different composites

Scanning Electron Microscopy (SEM) indentations

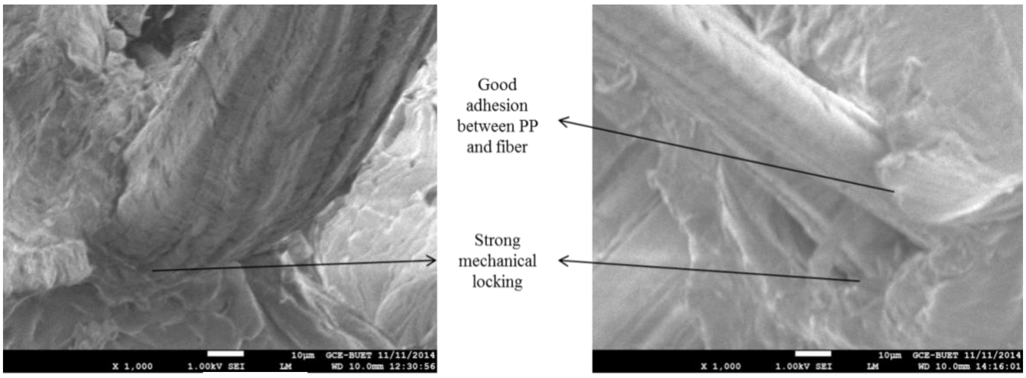
The SEM micrographs of the tensile fracture surfaces of all the control composites (CUn, CN, and CS) are shown in Figure 7. Figure 8 shows the SEM micrographs of tensile fracture surfaces of the composites (CI1 and CI2) corresponding to the fabrics treated in the presence of Indosol E-50. It is clearly shown in the SEM micrographs of the composites of untreated fabrics (CUn) that the jute fibers were pulled out from the PP matrix during the fracture process and there is little trace of PP on the surface of the NaOH treated fabrics (CS), which indicates no or poor adhesion between fibers and matrix. On the other hand, the composites (CI1 and CI2) of treated jute fabrics have different fracture surfaces, considerable amount of PP matrix remained and adhered to the surface of the jute fibers. It is also observed that the jute fibers failed by tearing, but no complete interfacial failure occurred in these treated fabrics PP composites. This indicates that the adhesion between the treated jute fibers and PP matrix was strong enough as shown in the micrographs of the treated jute fabrics/PP composites (Figure 8). Similar observations of SEM of tensile fracture surfaces of JRPCs were reported in the previous researches [15]. Thus, the Indosol treatments of Table 1 of the jute fabrics improved its surface properties and strengthened the fiber matrix interaction as shown in Figure 8. This finding conforms to the results for tensile strength of these composites in Figure 1.



CUn

CN CS

Fig. 7:SEM micrographs of tensile fracture surfaces of CUn, CN, and CS composites



C CI1 CI2

Fig. 8:SEM micrographs of tensile fracture surface of CI1 and CI2 composites

TGA study of composites

The results of all thermograms were summarised in Table2 which shows that mass percentage residue at 450^{o}C had significantly increased for all the treated jute fabrics/PP composites, compared with the untreated jute fabrics/PP composites. It was increased noticeable from 8% to 52% in the case of composite of I2 treated jute fabrics compared with composites of untreated fabrics. It can also be mentioned from Table 2 that 50% weight loss temperature was much higher in case of all treated jute fabrics/PP composites than that of the untreated jute fabrics/PP composites. This is as expected results for flame retardant materials since untreated cellulose undergoes decomposition vigorously to volatiles with little char formation, whereas flame retardant cellulosic retard decomposition to volatiles to some extent and increase char formation [16]. These results said the higher thermal stability of the composites of treated jute fabrics compared with composites of untreated fabrics and particularly I2

Table no 2: TG analysis of treated and control jute fabrics/PP composites

Samples	DTG peak, ^{o}C			10% mass loss temp. ^{o}C	50% mass loss temp. ^{o}C	Residue% at 450^{o}C	DTA
	Initiation	1st Peak	Final peak				(µV) at max temp.
CUn	308	374	437	293	390	8	0.6

CS	296	364	443	292	407	21	-3
CN	282	348	432	284	399	14	1
CI1	293	381	464	316	437	41	-10
CI2	**331**	**381**	**472**	**326**	**453**	**52**	**-9**
CI3	223	366	454	310	427	31	-10
CI4	248	380	447	298	405	19	-9
CI5	275	347	441	283	401	19	-4

treated jute fabric/PP composites confirms the highest thermal stability among all the composites including control composites. This indicates that jute fiber chemically bonded with matrix which required more energy to break the bond between fiber and PP matrix which confirms in the DTA data in each treated fabrics reinforced composites in Table 2. Hence the thermal stability of different treated and control jute fabrics/PP composites can be summarized in the order of: CUn<CN <CI5 <CS < CI4/CI3 <CI1 <CI2.

Water up take of composites

Water uptake characteristics at 24 hours of the jute fabrics/PP composites are shown in Table 3. It is observed from Table 3 that all the composites of treated jute fabrics (except CI3) had lower water uptake percent compared with that of the untreated jute fabrics/PP composites. Also, it is noticed that the composites of I3 treated jute fabrics had the highest and CI2 composite had the lowest percent of water uptake among all the composites including control composites. CI1, CI2, CI4, CI5, CS, and CN reduced 19.25, 45.25, 30.73, 30.32, 20.62, and 35.91% lower water uptake percent than that of the untreated jute fabrics/PP composites, accordingly. The overall reduced water uptake properties of the composites reinforced with treated fabrics is due to the fact that Indosol E-50 alone or with other chemicals react with the OH group of cellulose, which reduces the hydrophilic nature of the fiber and the polymer fills the void space of the treated fiber [14].

Table no 3: Water uptake at 24 hours of different composites

Sample	Water uptake % at 24 hours
CUn	19.69
CS	15.63
CN	12.62
CI1	15.90
CI2	10.78
CI3	31.58
CI4	13.64
CI5	13.71

IV. Conclusion

Mechanical and physical properties of chemically modified jute fabrics reinforced PP composites are investigated and analyzed in this study. The tensile properties of the jute fabrics/PP composites are influenced by the treatments (I1 to I5) in which, Indosol E-50 and Drimarene Red K-8b was specially included. The composites of treated jute fabrics with Indosol E-50 plus Drimarene Red K8b (I2) had shown the highest mechanical performance such as tensile strength and modulus, which were 53 and 69%; flexural strength and modulus, which were 21 and 61%; and impact strength, which was 30% more than that of untreated jute fabrics reinforced composites. Again, CI2 composite confirms the best thermal stability and lowest water absorption, which was 45% lower than that of the composites reinforced with untreated jute fabrics. Therefore, chemical modification of jute fabrics with the mixture of Indosol E-50 and Drimarene Red K8b (I2) increased the performance of resulting composites greatly.

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