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Effect of Water Absorption on the Mechanical Properties of Wheat Straw Fibre Reinforced Polystyrene Composites

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The present work deals with the effect of water absorption on the mechanical properties of alkali plus silane treated wheat straw reinforced polystyrene composites. Wheat straw polystyrene composite was prepared with different fibre loading (5%, 10%, 15%, 20%, 25%) by compounding process using twin screw extruder. Samples were prepared by the compression moulding process. There was a decrease in the tensile strength initially at 5% fibre loading followed by an increase in it with higher fibre loading. There is an increase in flexural strength up to 15% fibre loading followed by decrease in it with higher fibre loading. There is an increase in the hardness initially at 5% fibre loading followed by decrease in it with higher fibre loading. There is an increase in water absorption with percentage increase in fibre loading. Tensile strength, flexural strength, and hardness of alkali plus silane treated wheat straw reinforced polystyrene composites with water absorption is always less than alkali plus silane treated wheat straw reinforced polystyrene composites without water absorption.

Keywords: Polystyrene; wheat straw; Water absorption; silane; mechanical properties; composites

I. INTRODUCTION

Natural fibre composites are gaining attention due to its number of advantages such as environmentally friendly (Joshi *et. al.*, 2004; Banik, Dey & Sastry, 2017; Zwawi, 2021), low density (Sherman, 1999; Sgriccia, Hawley & Misra, 2008) and low cost (Pickering, Efendy & Le, 2016). However, poor compatibility and moisture absorption are the major drawbacks of natural fibre composites (Li, Tabil & Panigrahi, 2007). Various chemical treatments are used to overcome these problems. Silane compounds having bifunctional structure are recognised as an effective coupling agent for natural fibre composites (Herrera-Franco & Valadez-González, 2004; Sgriccia, Hawley & Misra, 2008; Xie *et al.*, 2010). Alkali treatment of natural fibres results in improved compatibility of fibre-matrix, due to enhancement in surface roughness of fibres (Zin *et. al.*, 2018; Lakshmi Narayana & Bhaskara Rao, 2021). There is an enhancement in mechanical properties of natural fibre composite with silane and alkali treatment (Asim *et. al.*, 2016; Sahai & Pardeshi, 2021).

Natural fibres have the tendency of water absorption due to cellulose, which results in swelling of the fibres and affecting its mechanical and dimensional properties (Alamri & Low, 2012; Muñoz & García-Manrique, 2015). There is an increase in water absorption with increase in natural fibre loading which results in decrease in mechanical properties of natural fibre composites (Deo & Acharya, 2010; Upadhyaya *et. al.*, 2012; Zhu, Zhu & Njuguna, 2013; Singh & Palsule, 2014; Huner, 2015; Widiastuti, Pratiwi & Cahyo, 2020). Improvement in the mechanical properties have been observed with the addition of wheat straw fibre in polymer matrix (Panthapulakkal, Zereshkian & Sain, 2006; Kim *et. al.*, 2012; M & R, 2016). Treatment with coupling agent improves the properties of wheat straw reinforced polymer composites (Mengeloglu & Karakus, 2008; Pan, Zhang & Zhou, 2010; Sahai, Pardeshi & Biswas, 2021). There was a

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reduction in mechanical properties of wheat straw reinforced epoxy composite with water absorption (Mittal & Sinha, 2017). An increase in mechanical properties of polystyrene matrix with the addition of natural fibres (Manikandan Nair, Diwan & Thomas, 1996; Haneefa *et. al.*, 2008; Singha & Rana, 2012).

In the present work, an attempt has been made to treat the wheat straw fibre with alkali as well as silane to make the surface less vulnerable to moisture that leads to decrease in strength. The treated fibres have been incorporated in polystyrene to make composite and their mechanical and other properties have been studied.

II. EXPERIMENTAL

A. Materials

Supreme Petrochemical Limited, Mumbai, India supplied polystyrene (SC 203 EL) which was used as matrix material for this experiment. Wheat straw fibre is obtained from Ujjain farmland, Madhya Pradesh. Which was used for reinforcement. Sodium Hydroxide (NaOH) and Silane (3-Aminopropyltriethoxy) was obtained from Vara Synthesis private Ltd.

B. Surface Treatment of Wheat Straw

The pre-dried fibres are soaked in the solution made of NaOH 20% (w/v). The fibres were immersed in the solution for a duration of 12 h. After treatment, fibres were cleaned with water to remove any traces of alkali on the fibre surface and cleaned carefully with distilled water. The treated fibres were then dried at room temperature. A solution of 1 percent silane [3-aminopropyltriethoxy] in acetone was prepared. It was used to encourage hydrolysis with moisture on the surface of the fibres rather than within the carrier. Acetone also encourages fibre swelling and thus raises the fibre surface area that is subjected to treatment. The fibres were then immersed in the solution for 12 hours. Fibres were removed from the solution after treatment. The treated fibres were dried at room temperature.

C. Compounding

Before compounding, the batches of different weight percent of fibre with batch size of 400gm were prepared. Compunding was carried out using twin screw extruder and RPM for the extruder screw was 40-70 and temperature range was 170-210 ^{o}C.

D. Compression Moulding

The granules of the extrudate were compression moulded for preparing specimen to test for tensile properties, hardness, and water absorption. Test specimens were prepared as per ASTM standards. Wet samples were prepared by keeping them in water till saturation stage is reached.

Figure 1. Wheat straw

III. RESULTS AND DISCUSSION

A. Tensile Strength

Figure 2 shows the change in tensile strength with percentage variation in fibre loading with and without water absorption. Initially, there is a decrease in the tensile strength of the wheat straw reinforced polystyrene composites up to 5% fibre loading without water absorption. With initial addition of straw, there is possibility of decrease of chain packing in polystyrene resulting in decrease of strength and at lower volume reinforcing effect of fibre is not significant. There is an increase in the tensile strength with higher fibre loading, indicating reinforcing effect of wheat straw fibre. Alkali treatment provides better fibre matrix compatibility, promoting the efficiency of silane coupling agent, resulting in better matrix/fibre interaction. Initially, there is a decrease in tensile strength for alkali plus silane treated wheat straw fibre reinforced polystyrene composites at 5 % fibre loading indicating predominance of effect of water absorption in reducing mechanical properties compared to reinforcing effects of fibres in enhancing mechanical properties.

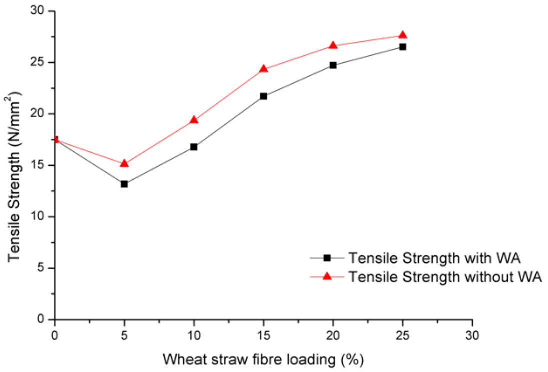

Figure 2. Tensile strength of alkali plus silane treated wheat straw reinforced polystyrene composites with and without water absorption

There is an increase in the tensile strength with further increase in fibre loading, indicating dominating effect of fibre reinforcement on the mechanical properties. Absorption of water causes swelling, plasticising (Upadhyaya *et. al.,* 2012; Zhu, Zhu & Njuguna, 2013) and weakening of the fibre/matrix interface (Costa & D'Almeida, 1999; Assarar *et al.,* 2011) resulting in decrease in mechanical properties (Meenalochani & Vijayasimha, 2017). The tensile strength of wheat straw reinforced polyester composites without water absorption is always higher compared to the tensile strength of strength of wheat straw reinforced polyester composites with water absorption at any given fibre loading.

B. Flexural Strength

Figure 3 shows the variation in the flexural strength for wheat straw reinforced polystyrene composites with and without water absorption. Initially, there is a decrease in the flexural strength for alkali plus silane treated wheat straw reinforced polystyrene composites without water absorption up to 5% fibre loading followed by an increase in it up to 15% fibre loading. Again, the initial decrease can be attributed to possibility of decrease of chain packing in polystyrene resulting in decrease of strength and at lower volume reinforcing effect of fibre is not significant. Increase in the flexural strength with further increase in fibre loading can be attributed to the possibility of effect of treatment as silane and alkali treatment increases flexural strength as they provide higher aspect ratio resulting in better fibre matrix interface (Sood & Dwivedi, 2018). There is a decrease in the flexural strength with higher fibre loading. This decrease in the flexural strength can be attributed to poor dispersion of fibre, as at higher loading fibre tend to aggregate (Ngo *et al.,* 2014). The flexural strength of wheat straw reinforced polyester composites without water absorption is always higher compared to the flexural strength of strength of wheat straw reinforced polyester composites with water absorption at any given fibre loading.

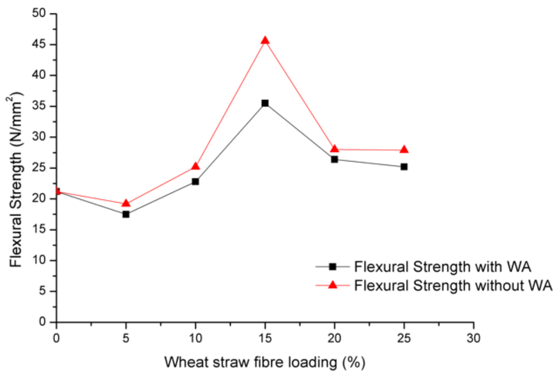

Figure 3. Flexural strength of alkali plus silane treated wheat straw reinforced polystyrene composites with and without water absorption

C. Hardness

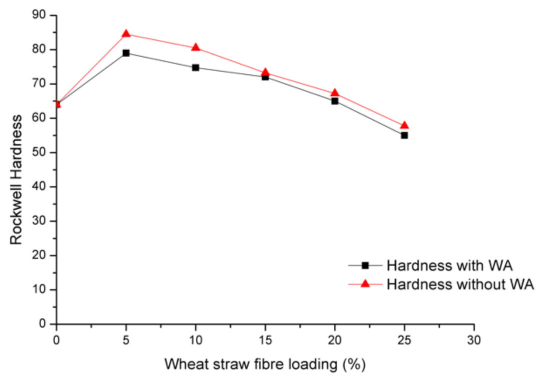

Figure 4. Hardness of alkali plus silane treated wheat straw reinforced polystyrene composites with and without water absorption

Figure 4 shows the variation in the hardness for wheat straw reinforced polystyrene composites with and without water absorption. Initially, there is an increase in the hardness with an increase in fibre loading at 5% percent, followed by decrease in it with higher fibre loading for alkali plus silane treated wheat straw reinforced polystyrene composites with and without water absorption. Hardness for alkali plus silane treated wheat straw reinforced polystyrene composites without water absorption is always higher than hardness for alkali plus silane treated wheat straw reinforced polystyrene composites with water absorption. Water absorption results in the weakening of fibre matrix interface, resulting in the reduction of mechanical properties (Meenalochani & Vijayasimha, 2017).

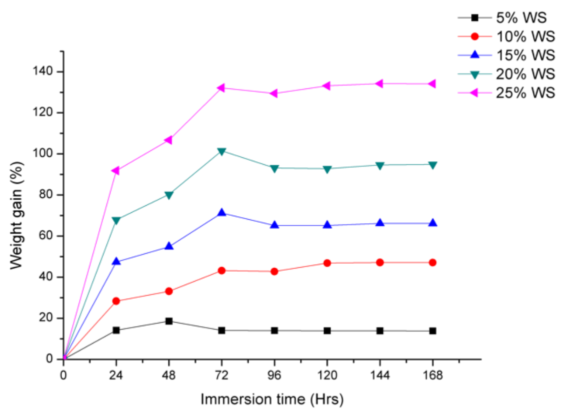

Figure 5. Water absorption of alkali plus silane treated wheat straw reinforced polystyrene composites

Figure 5 shows variation in water absorption for alkali plus silane treated wheat straw reinforced polystyrene composites. There is an increase in water absorption with percentage increase in fibre loading. The rate of increase is maximum for 25% fibre loading and increase in water absorption can be attributed to higher diffusion coefficients of samples with higher fibre loading, because of higher cellulose content (Muñoz & García-Manrique, 2015) and increase in diffusion transport of water due to fibre swelling and microcracks (Marom, 1985). With increase in immersion time, saturation takes place. Water absorption in natural fibre composites follows Fickian behaviour (Espert, Vilaplana & Karlsson, 2004).

D. FTIR Analysis

The composite samples with and without water adsorption were studied by FTIR. The FTIR spectrum of the composite samples are shown in Figure 6 and Figure 7.

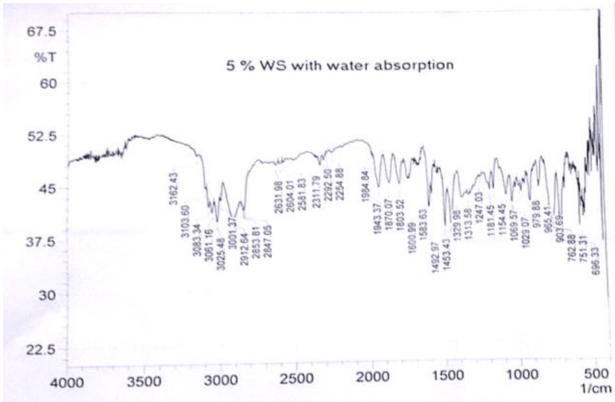

Figure 6. FTIR of 5% wheat straw reinforced polystyrene composite with water absorption

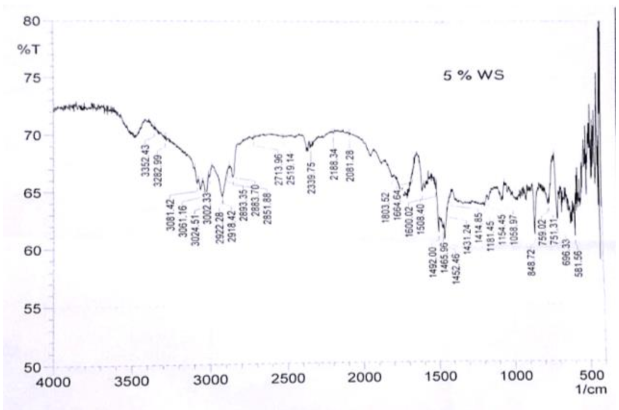

Figure 7. FTIR of 5% wheat straw reinforced polystyrene composite without water absorption

From the spectra of the sample before water adsorption, a small peak is noticed at 3500 cm^{-1} that indicates the presence of negligible amount of hydrogen bonded crystalline zone hydroxyl group, which decreases further after absorbing H_2O molecules. The peaks at 3002-3081 cm^{-1} are due to aromatic –CH stretching vibration. The aliphatic –CH & -CH_2 stretching vibration peaks are located around 2912-2922 cm^{-1}. The peaks around 1583-1600 cm^{-1} indicate –NH vibrations present in aminosilane moiety. The peaks at 1492, 1465 cm^{-1} are characteristics of aromatic C=C stretching vibration. The crystalline absorption at 1430 cm^{-1} of cellulose is practically negligible due to NaOH treatment (Oh *et al.,* 2005).

The peaks in the range of 1069-1154 cm^{-1} represent -Si-O-Si and Si-O-C bonds. Peaks at 698, 756 cm^{-1} belong to styrene unit (---CH out of plane bending vibration).

It appears that there is not much change in the major peaks after absorption of water as the –OH groups are modified with silane.

Table 1. Mechanical properties of alkali plus silane treated wheat straw fibre reinforced polystyrene composites with and without water absorption

Wheat straw fibre loading	Tensile Strength		Flexural Strength		Rockwell Hardness	
%	N/mm^2 with WA	N/mm^2 without WA	N/mm^2 with WA	N/mm^2 without WA	with WA	without WA
0	17.50	17.50	21.20	21.20	64.00	64.00
5	13.18	15.13	17.50	19.20	79.00	84.50
10	16.78	19.37	22.80	25.20	74.75	80.50
15	21.71	24.34	35.50	45.60	72.00	73.25
20	24.73	26.62	26.40	28.00	65.00	67.25
25	26.51	27.63	25.20	27.90	55.00	57.75

Table 2. Water absorption of alkali plus silane treated wheat straw reinforced polystyrene composites

Immersion time (Hrs)	Weight gain (%)				
	5% WS	10% WS	15% WS	20% WS	25% WS
0	0	0	0	0	0
24	14.15	28.35	47.41	67.96	91.88
48	18.58	33.15	54.83	80.24	106.77
72	14.04	43.19	71.22	101.49	132.14
96	13.99	42.76	65.13	93.21	129.46
120	13.93	46.82	65.19	92.79	133.15
144	13.88	47.14	66.20	94.60	134.22
168	13.83	47.09	66.15	94.92	134.16

IV. CONCLUSION

Initially, there is a decrease in the tensile strength of the wheat straw reinforced polystyrene composites up to 5% fibre loading followed by an increase in the tensile strength with higher fibre loading for alkali plus silane treated wheat straw reinforced polystyrene composites with and without water absorption. There is an increase in flexural strength up 15% fibre loading followed by decrease in it with higher fibre loading for alkali plus silane treated wheat straw reinforced polystyrene composites with and without water absorption. Initially, there is an increase in the hardness with an increase in fibre loading at 5% percent, followed by decrease in it with higher fibre loading for alkali plus silane treated wheat straw reinforced polystyrene composites with and without water absorption. There is an increase in water absorption with percentage increase in fibre loading. The rate of increase is maximum for 25% fibre loading. Tensile strength, flexural strength, and hardness of alkali plus silane treated wheat straw reinforced polystyrene composites with water absorption is always less than alkali plus silane treated wheat straw reinforced polystyrene composites without water absorption.

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