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Effect of Silane Coupling Agent on Flexural Strength and Hardness of Wheat Straw Polystyrene Composites

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In the present research work, the effect of silane treatment along with alkali treatment on flexural strength, flexural modulus, and hardness investigated. Wheat straw as a filler was added (5%, 10%, 15% and 20%) to polystyrene matrix to prepare wheat straw polystyrene composite. The wheat straw fibre was first treated with 20% NaOH and 1% silane coupling agent to prepare wheat straw polystyrene composite. The compounding process was carried out in twin-screw extruder and samples were prepared by the compression moulding process. There was an increase in flexural modulus (214%), flexural strength (44%), and hardness (28%) of composite with the addition of alkali and silane treated wheat straw fibre.

Keywords: Polystyrene; wheat straw; silane coupling agent; alkali treatment

I. INTRODUCTION

Natural fibre polymer composites are getting increasingly attention in the polymer composite research area because of distinctive properties such as low density, high specific properties, and eco-friendly as mentioned (Nabi Saheb & Jog, 1999; Pickering, Efendy & Le, 2016; Atmakuri *et. al.*, 2020; Gholampour & Ozbakkaloglu, 2020). The incorporation of natural fibre has resulted in improved mechanical properties of polymer composites (Mishra & Naik, 2005).

The effect of different types of natural fibre along with its various factors such as fibre dimensions and source of natural fibre on performance of natural fibre polymer composites has been reported (Singha and Rana, 2012; Mohammed *et al.*, 2015). The incorporation of rice husk fibre as filler resulted in the higher tensile modulus of the composite (Park *et al.*, 2016). The addition of jute fibre and agave fibre as filler in the polymer matrix provided polymer composite with superior mechanical properties was highlighted by (Sinha & Panigrahi, 2009; Singha & Rana, 2013; Kumar & Srivastava, 2017). The addition of wheat straw as filler in natural fibre polymer composites resulted in superior mechanical properties of polymer composites (Bisanda, 2000; Panthapulakkal, Zereshkian & Sain, 2006; Kellersztein & Dotan, 2016). Incorporation of wheat straw shows better results compared to other fillers such as wood flour and others for wheat straw reinforced HDPE polymer composites (Panthapulakkal & Sain, 2007). There is an increase in Young's modulus with increase in filler loading of plantain peel reinforced polystyrene composites (Adeniyi *et al.*, 2020).

Poor compatibility between the natural fibre and polymer matrix is a great challenge (Westman *et al.*, 2010). Various chemical treatments of fibres are carried out in order to improve the compatibility of natural fibre with polymer matrix (Panthapulakkal, Zereshkian & Sain, 2006) to obtain the better performance of natural fibre polymer composites (Li, Tabil & Panigrahi, 2007). Silanes are prominently used as coupling agent in natural fibre composite. Because hydrolyzed silane solutions have an enhance affinity for the hydroxyl sites of natural fibre, it improves compatibility between natural fibre and polymer matrix (Abdelmouleh *et. al.*, 2002; Sahai & Pardeshi, 2019). Silane has been used for various polymer matrix such as polyethylene, polystyrene, epoxy, PVC etc. (Valadez-Gonzalez *et. al.*, 1999; Rong *et. al.*,

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2001; Xie *et al.*, 2010). The application of the silane coupling agent increased the tribological properties of polymer composites (Goriparthi, Suman & Mohan Rao, 2012; Nishitani, Kajiyama & Yamanaka, 2017; Milosevic, Valášek & Ruggiero, 2020). Higher compatibility between polymer matrix and natural fibre with the application of silane as the coupling agent has been reported (Yoon *et al.*, 2020).

Alkali treatment of natural fibres results in removal of hemicellulose and lignin resulting in increased surface area for better mechanical interlocking and enhancing possible reaction sites (Li, Tabil & Panigrahi, 2007; Sgriccia, Hawley & Misra, 2008; Sahai & Pardeshi, 2019; Alhijazi *et al.*, 2020). Alkali treatment improves the degradation temperature of wheat straw fibre (Mittal & Sinha, 2017). The degradation temperature of wheat straw was increased to 264ºC on alkali treatment which is higher than processing temperature of polystyrene (Sahai & Pardeshi, 2019). The alkali treatment of fibres resulted in better mechanical properties of polymer composites (Ray *et. al.*, 2001; Nam *et. al.*, 2011; Oushabi *et al.*, 2017). The application of silane coupling agent along with alkali treatment resulted in polymer composites with superior mechanical properties were reported in (Srisuwan, Jarukumjorn & Suppakarn, 2018; Sahai & Pardeshi, 2019).

The application of maleic anhydride resulted in better performance of natural fibre polymer composites was reported in previous studies (Mishra & Naik, 2005; Mengeloglu & Karakus, 2008; Yoon *et al.*, 2020).

This study aims to develop a wheat straw polystyrene composite with superior mechanical properties and environment friendly.

II. MATERIALS AND METHOD

A. Raw Materials

In this research work, polystyrene being used as polymer matrix material. Polystyrene (GPPS Grade) (SC 206) with an MFI 12 gm/10 minutes was obtained from Supreme Petrochem Limited, Mumbai, India. Wheat straw fibres were procured from the farmland of Ujjain, Madhya Pradesh. Silane was obtained from Avra Synthesis Pvt. Ltd.

The wheat straw fibre was chopped (4-6 mm) and washed and dried properly. The fibres were initially dried to remove excess water and impurities and soaked in 20% (w/v) sodium hydroxide solution (liquor ratio 20:1, for 30 minutes). After the treatment process, these were neutralized with a dilute acetic acid solution, and further it is washed thoroughly with distilled water and finally dried.

About 1% silane solution, i.e. 3-aminopropyltriethoxy was prepared using acetone. The pH of the solution was adjusted to 4.0 with acetic-acid and was stirred for 5 minutes. The wheat straw fibres were placed in the solution for a duration of 1 hour. The fibres were later removed from the solution and were dried in the oven maintaining a constant temperature of 100°C for a duration of 12 hours.

Compounding of wheat straw polystyrene composite was carried out in twin-screw extruders. (RPM 80-100). Processing temperature of Zone 1,2,3,4 and dies were 180ºC, 200ºC, 220ºC, 230ºC and 250ºC. Pelletizing was carried out after compounding in a twin-screw extruder. Sheets were prepared using compression moulding at a temperature of 220ºC. Samples were prepared using ASTM D790 for flexural test and ASTM D785.

Figure 1. Wheat straw fibre

III. RESULT AND DISCUSSION

A. Flexural Strength

Figure 3 represents the change in flexural strength of wheat straw polystyrene composites with variation in wheat straw fibre loading. From the figure we can observe that as we increase the wheat straw fibre loading, there is a substantial increase in the flexural strength of the material. Flexural strength is obtained maximum at 5% fibre loading which decreases with an increase in fibre loading up to 20%. However, the value of flexural strength even at 20% fibre loading is higher than the flexural strength of polystyrene without filler. There is an improved interaction of polymer matrix with fibre because of increased surface roughness of fibre on alkali treatment and higher possible mechanical interlocking and chemical bonding (Bisanda, 2000).

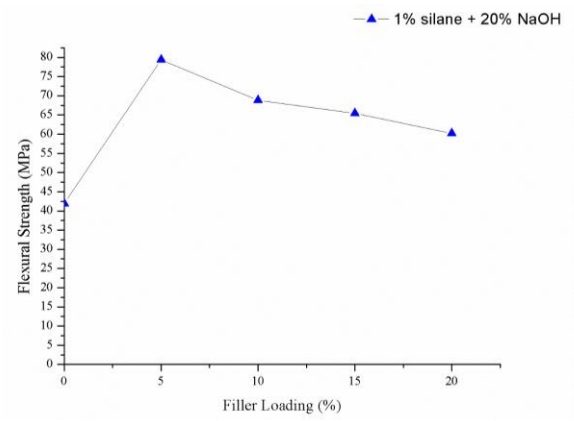

Figure 3. Flexural strength of polystyrene wheat straw composites

The silane coupling agent is more effective in enhancing the mechanical properties of wheat straw polystyrene composites because of better fibre-matrix compatibility (Sood & Dwivedi, 2018; Sahai & Pardeshi, 2019). The decrease in flexural strength can be attributed to the possible rise of fibre defects due to an increase in fibre concentration which acts as a source of stress concentration (Sawpan, Pickering & Fernyhough, 2012). However, the influence of better interfacial adhesion between alkali and silane treated fibre with polymer matrix overcomes this decline, resulting in a higher value of flexural strength compared to virgin polystyrene even at 20% of fiber loading.

B. Flexural Modulus

Figure 4 represents the change in flexural modulus of wheat straw polystyrene composites with variation in wheat straw fibre loading. It is observed that there is an increase in flexural modulus with an increase in wheat straw fibre loading. There is a significant rise in flexural modulus for 5% fibre loading which then decreases with an increase in further fibre loading up to 20%. However, the value of flexural modulus even at 20% fiber loading is much higher than the flexural modulus of polystyrene without filler. There is an improved interaction of polymer matrix with fibre because of increased surface roughness of fiber on alkali treatment and higher possible mechanical interlocking and chemical bonding.

The silane coupling agent is more effective in enhancing the mechanical properties of wheat straw polystyrene composites again due to better fibre-matrix compatibility as a result of alkali treatment. The rise in flexural modulus can be again attributed to higher interfacial bonding between alkali and silane treated wheat straw fibre and polystyrene composite (Webo, Masu & Maringa, 2018).

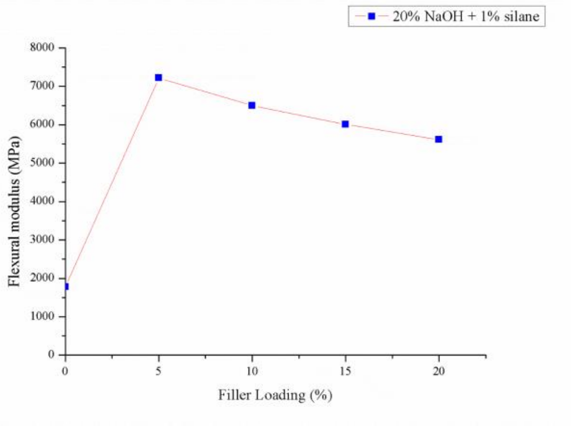

Figure 4. Flexural modulus of polystyrene wheat straw composites

C. Hardness

Figure 5 represents the change in Rockwell hardness of wheat straw polystyrene composites with variation in wheat straw fibre loading. There is an increase in Rockwell hardness for a direct increase in wheat straw fibre loading. Rockwell hardness is maximum at 5% fibre loading which decreases for an increase in further fibre loading up to 20%. For an increase in fibre loading from 5% to 10%, the rate of decrease is minimum as compared to a higher rate of decrease for fibre loading for 10% to 15% and 20%. However, the value of Rockwell hardness even at 20% fiber loading is higher than Rockwell's hardness of polystyrene without filler. The rise in hardness can be attributed to improving interfacial bonding between the wheat straw fibre and polystyrene matrix (Webo, Masu & Maringa, 2018).

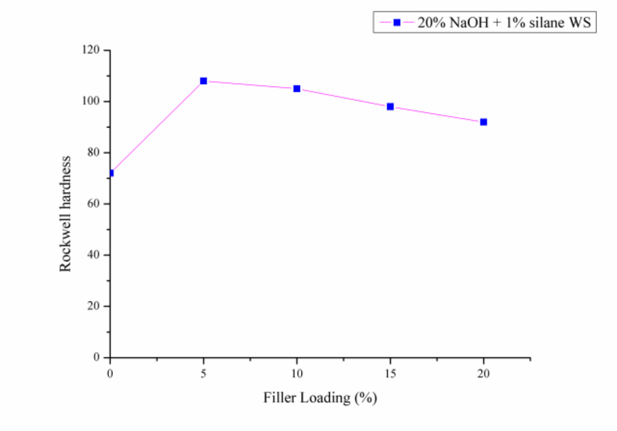

Figure 5. Hardness of polystyrene wheat straw composites

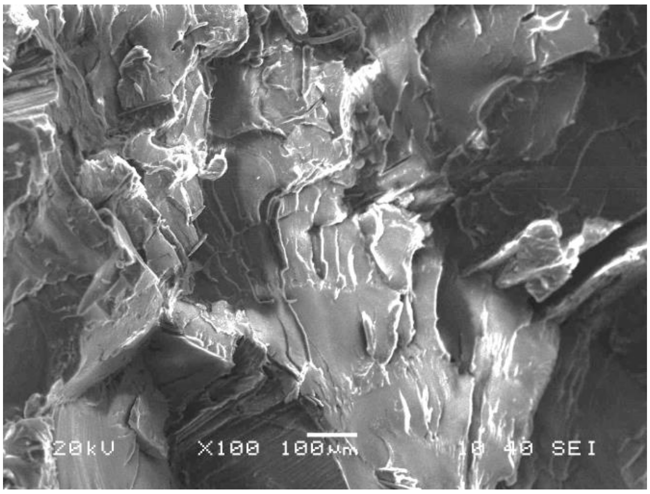

Figure 6. SEM of alkali and silane treated wheat straw-filled polystyrene composite

Figure 6 shows a scanning electron microscopic (SEM) image of alkali and silane treated wheat straw reinforced polystyrene composites. Alkali treatment along with the silane coupling agent is very effective in improving interfacial adhesion between fiber and polymer matrix because of higher surface roughness resulting in superior flexural strength.

IV. CONCLUSION

There is an increase in flexural strength, flexural modulus, and hardness of wheat straw polystyrene composites with the addition of filler loading. The flexural strength, flexural modulus, and hardness of wheat straw polystyrene composites are maximum at 5% fiber loading.

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