

## Characterization of Plastic Composite Based on HIPS Loaded with Bagasse

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**T**HE AVAILABILITY of natural fibers in Egypt such as bagasse, rice straw, corn husk, etc attracted the researcher interests to reutilize this agricultural biomass for the development of natural fiber reinforced composites for diversity valuable applications. Recently the utilization of bio-fillers in thermoplastics composites has increased. Polystyrene is a thermoplastic polymer that is commercially available with a wide range of high impact polystyrene (HIPS) applications in various fields because of its mechanical properties. So natural fiber reinforced thermoplastic polystyrene composites can be used as natural wood substitutes in housing, and constructions purposes. Herein we used sugarcane bagasse as a natural filler for HIPS. Where HIPS was melted and mixing with sugarcane bagasse at different ratios using screw extruder, then the fiber/polymer mixture was molded into standard test samples under pressure and heating. The effect of external effectors such as slight aqueous acidic, alkaline solutions, engine oil treatments or UV exposure on the mechanical properties of the prepared composites was investigated. Additionally, the impact of filler content on polystyrene thermal stability and morphological characteristics, water absorption, and swelling capacity were studied.

**Keywords:** Composite, Sugarcane bagasse, Polystyrene, Thermal stability, Water absorption

### Introduction

Sugarcane bagasse is an agro-industrial by-product of sugarcane after its crushing and juice extraction; it is produced in massive amounts annually in Egypt. Several strategies have been suggested to maximize the economic utility of sugarcane bagasse in an eco-friendly manner [1]. Among these strategies is the modification of bagasse for metal chelation [2], its use for the production of biofuel and ethanol for industrial purposes [3-5] or as raw material in cogeneration plants to produce electric power in Brazil [6,7]. On the other hand, the value of sugarcane bagasse wastes was expanded to its utility as filler in cement [8], or as fiber rich additives in many thermoplastic or thermosetting petroleum polymers based composites including phenol-formaldehyde resins, polyethylene, polypropylene, and polyethylene-co-vinyl acetate [9-12].

The growing interest in the use of agricultural and industrial biomass such as rice straw, sawdust, sugar cane bagasse, and cotton stalk, flax, hemp,

jute and sisal, wool as fibrous fillers in many polymers based composite materials, showed a great impact in improving the mechanical properties of the polymers. Since this biomass is characterized by their abundance, low cost, low density, in addition to their biodegradability, and high specific strength compared to the more expensive synthetic fillers, such as glass, carbon, or steel [13-16]. Natural fiber-reinforced composites are used in the manufacturing of plastics, automotive, packaging, civil engineering, and construction industries to reduce the products costs [17,18]. Nonetheless, the main drawback of natural fibers is the weak interfacial adhesion between hydrophilic lignocellulosic fibers and hydrophobic polymer matrix resulting in poor mechanical properties [15, 19]. Some Coupling additives such as maleate and organosilane, acylating, benzoylation agents or Acrylonitrile grafting, have been investigated to improve the interfacial adhesion between the fibrous component and the composite matrices [20-23]. Furthermore, several studies reported the effect

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of dioctyl phthalate (DOP) addition as a plasticizer to the polymer matrix. Although DOP decrease the crystallinity of the polymer matrix due to the increasing of macromolecule movement [24], it improves its thermal stability of the polymer and enhances the adhesion ability between the hydrophilic fibrous filler and the hydrophobic polymer in composite fabrication [22-24]. Polystyrene (PS) is a thermoplastic transparent nondegradable polymer, that is present either as a solid plastic or in the form of a rigid foam material. It is produced by the free radical polymerization of the styrene monomer [25]. HIPS is extensively used in a variety of products such as food packaging, molds, and bowls, printing, paints, glue, fixtures, as well as medical device applications like test tubes or Petri dishes [26,27]. However, its abundant as a production and disposal of HIPS commodities results in critical environmental anxiety. Therefore, the reinforcement of thermoplastic polymers with biodegradable natural fiber represents a practical solution to overcome the environmental claims [13,16-18].

The objective of the present work was to evaluate the impact of utilization of sugarcane bagasse, as a natural biodegradable inexpensive agro-industrial by-product for reinforcement of HIPS polymer. The thermal stability, mechanical properties, and their water absorption behavior will be investigated taking into our consideration the influence of fiber content in the reinforced HIPS composite.

## **Experimental**

### *Materials*

Bagasse was kindly provided by IDFO Company, Egypt. Bagasse was dried, grounded and sieved to be in part size 125  $\mu$ . High impact polystyrene (HIPS), used as a polymeric matrix, was procured from M/s Indian Petrochemical Corp., Ltd. (Baroda, India), and it has a melt index of 2 g/10 min and a density of 0.92 g/cm<sup>3</sup>.

### *Preparation of sugarcane bagasse*

The sugarcane bagasse fibers were washed thoroughly with steaming water to remove the adhered contaminants, and dried in an air oven at 100°C for 24 hours. The dried sugarcane bagasse fibers were ground and then sieved to obtain bagasse fiber with the size of  $\leq 75\mu\text{m}$ .

### *Compounding and compression molding*

Prior to blending, all fibers were dried to 1-2%

moisture content at 80 °C. HIPS was blended with various weight ratios of bagasse fibers (10%, 20%, 30%, 40% and 50%) introduced into a laboratory single screw extruder maintained at maximum temperature of 175°C for 10 min at a roller speed of 200 rpm (Haake RheomexTW100, twin screw extruder with intermeshing screws, USA). The extrudate was cooled, passed through a pelletiser, then cut into small pieces suitable for feeding four-piece stainless steel compression molds to make 3-4 mm thick test sample plates. After the thermoplastic matrix melted, the fiber powders were added and the mixing maintained for additional 10 min. Compression molding was done using compression molding at 175 °C and 5 MPa for 5 min. Each sample was then cooled to room temperature under the pressure before being removed from the press.

### *Fourier Transfer Infrared Spectroscopy FT-IR spectroscopy.*

Fourier transform infrared (FT-IR) spectroscopy was performed for the neat fiber neat polymer, and loaded polymer using IR spectra for this part was carried out on JASCO FT/IR 6100 Japan spectrometer at National Research Center Cairo, Egypt using KBr disc (USA).

### *Thermogravimetric Analysis (TGA)*

The thermal stability of sugarcane bagasse, HIPS, and sugarcane bagasse /HIPS composite specimens was studied using (TGA, Shimadzu DTG-60, Japan) at a heating rate of 10 °C/min from 25 to 700 °C under a nitrogen atmosphere.

### *Scanning electron microscopy (SEM)*

The morphology of the composite specimens and the neat sugarcane bagasse fiber, and HIPS, were investigated by SEM using JEOL JXA-840A electron probe microanalyzer (Tokyo, Japan). The samples were coated with a thin layer of gold before SEM with an S1SoA Edward, sputter coater (Crawley, UK).

### *Composite property testing*

The mechanical properties and water absorption and swelling behavior of the composite specimens were carried out in replicate.

#### *Composite thickness*

The composite thickness was measured using a dial micrometer.

#### *Composite swelling*

The procedure described by Abdelmouleh

*et al* [28] was used to evaluate the water absorption of the prepared composites. Pieces of the prepared films were cut into small samples with dimensions of  $6 \times 6 \text{ cm}^2 \times 0.5 \text{ mm}$ . The samples were weighed and then soaked in distilled water at  $25^\circ\text{C}$  for different periods. Next, the samples were removed, blotted to remove the excess water on the surface and then immediately weighed. The difference between the mass after a given time of immersion and the initial mass is used to determine the water absorption. The samples weight and dimensions were measured using dial micrometer dried after drying the composite film between two filter sheets. The percentage weight gain (PWG) was calculated according to the equation [28].

$$\text{PWG (\%)} = (W_f - W_o) / W_o \times 100$$

Where  $W_o$  is the weight of the sample before soaking in water and  $W_f$  is the weight of the sample after soaking in water. The percentage of swellability was calculated according to the equation. [28]

$$\text{Swellability (\%)} = (x - y) / y \times 100$$

Where  $x$  is the volume of the sample after soaking in water and  $y$  is the volume of the sample before soaking in water.

#### *Mechanical properties of the prepared composites*

The prepared composites were subjected to the following measurements:

The tensile strength, Young's modulus, and a composite maximum load of the resulted composites at different fiber feed ratios were tested in accordance with ASTM D638-91 standard using a universal testing machine LK10k (Hants, UK) fitted with a 5 kN load cell, and operated at a rate of 5 mm/min.

### **Results and Discussion**

Sugarcane bagasse fibers were employed as filler for HIPS which serve as a thermoplastic polymer. The fiber was blended with HIPS at weight ratios of (10%, 20%, 30%, 40% and 50%). The composites structure and morphology and mechanical properties were evaluated as follow.

#### *Characterization of the composites by FT-IR*

The FT-IR of the composite specimen with fiber feed (20%) and HIPS was compared to the IR of sugarcane bagasse. Since the IR for the two samples demonstrated the presence of strong absorption bands at  $3439 \text{ cm}^{-1}$  and  $3433 \text{ cm}^{-1}$  due to the stretching vibrational band of O-H groups form of the fibers, while the absorption bands for stretching C-H of the lignocellulose fibers and polystyrene backbone appeared at  $2925 \text{ cm}^{-1}$  and  $2823 \text{ cm}^{-1}$ . The absorption bands at  $1633 \text{ cm}^{-1}$ ,  $1425 \text{ cm}^{-1}$ , and  $1376 \text{ cm}^{-1}$  are characteristic to the stretching C-C, symmetric bending of C-H respectively. The band at  $1029$  in the composite sample is attributed to the stretching C-O in the lignocellulosic fibers [10-12, 28], as displayed in Fig. 1.

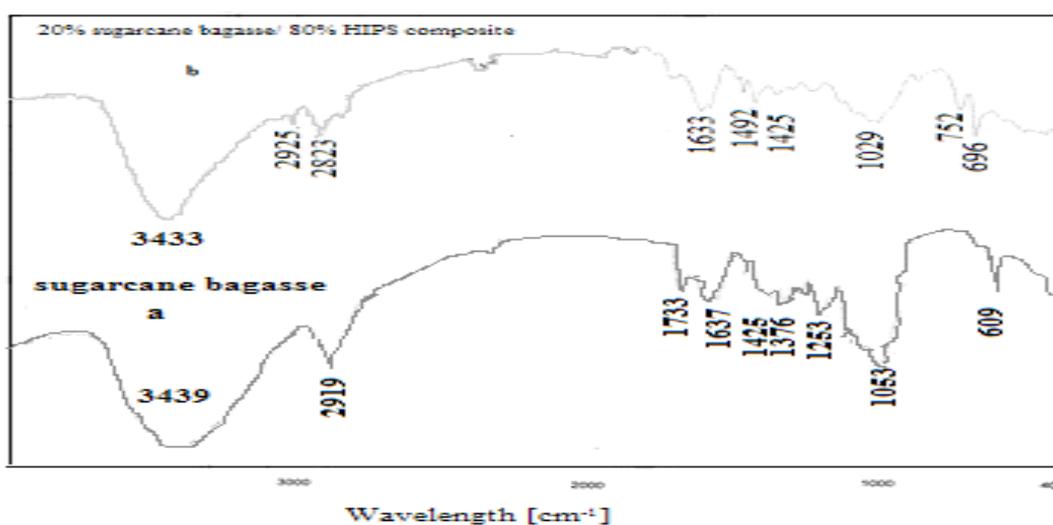


Fig.1. FT-IR for sugarcane bagasse and sugarcane bagasse (20%)/HIPS (80%).

### Composite thermal stability by TGA

TGA is usually used to study the thermal degradation behavior and thermal stability trend of HIPS, sugarcane bagasse and composites with and without DOP are presented in Figure 2a, b. The TGA curve of HIPS showed only one stage of weight loss that began at 350°C and ends at 420°C losing  $\approx 99\%$  of its weight as shown in Fig. 2 and this is very close to the reported one [29,30]. On the other side, the thermal decomposition behavior of sugarcane bagasse comprises showed two degradation stages. The first stage started at 25-100° C losing about 7% of its weight due to the vaporization of moisture content from the fibers [31]. The second stage of weight loss occurred at temperature range 200-400°C, with a transition peak at 350°C due to the decomposition of cellulose [32]. The final products from the degradation of bagasse under an inert atmosphere are carbonaceous residues plus ungraded fibers since they did not remain after heating [33].

The TGA curves of bagasse/HIPS with and without DOP exhibited three thermal degradation stages as shown in Fig. (2a, b). The first stage was at 25 –250 °C with a weight loss of 2% due to moisture vaporization. The second stage was from 250 to 400 °C with 20% weight loss which is due to the decomposition of cellulose and PS. Finally, the third stage occurred at 400-450°C with 8% residual. It is clear from TGA curves of composites that, the addition of small amount DOP did not affect the thermal stability

of bagasse/HIPS composite. We can conclude that the thermal stability of the prepared composites was in between HIPS and sugarcane bagasse.

### Morphological studies

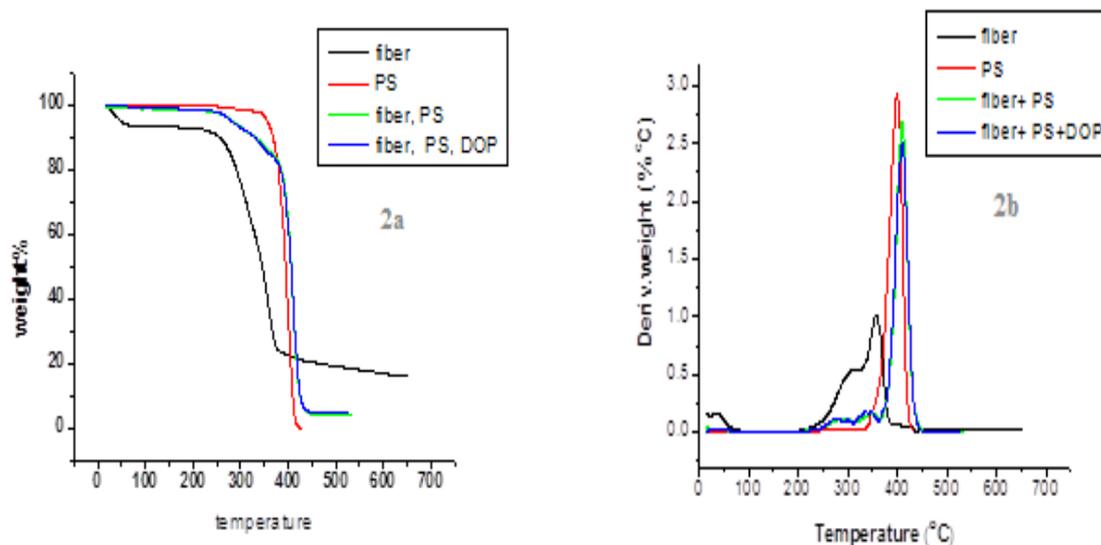
The surface morphology of sugarcane bagasse, HIPS, and their composites were studied using scanning electron microscope.

It was clear from the images that, the compatibility between the sugarcane bagasse fibers and high impact polystyrene were found to be fairly good. As shown in the Fig. (3a-c), the homogeneity of the composite material was demonstrated even in the presence or absence of DOP, where the good dispersion and strong interfacial adhesion were clear. This homogeneity can also be justified by the absence of holes or cracks inside the composite materials.

Figure (3a-c) Micrographs of the composites surface prepared with high impact polystyrene: a) sugarcane bagasse fibers, b) 20% fiber with HIPS, c) 20% fibers with HIPS in presence of DOP

### Mechanical properties of the composites

The impact of exposing sugarcane bagasse fiber/HIPS composites to different aqueous, acidic, alkaline aqueous solutions, engine oil, and UV on the composites' mechanical properties were studied.



holes or cracks inside the composite materials.  
 Fig. (2a, b). The TGA of sugarcane bagasse, HIPS, and bagasse/HIPS composite with/without DOP.

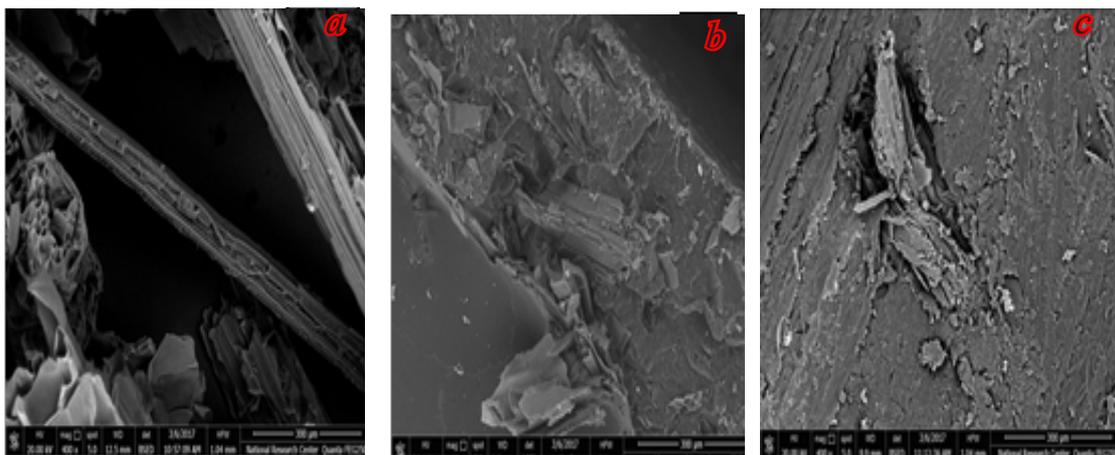


Fig. (3a-c). Micrographs of the composites surface prepared with high impact polystyrene: a) sugarcane bagasse fibers, b) 20% fiber with HIPS, c) 20% fibers with HIPS in presence of DOP.

#### *Effect of water soaking on the composites' mechanical properties*

The samples at different ratios of bagasse fiber/HIPS composite were soaked in water for 7 days, we found that both maximum load and tensile strength slightly decreased by increasing the fiber load from 10 to 20 %. Meanwhile, the moderate decrease in maximum load and tensile strength was observed in the composites with the fiber ratios 30% and 40 % Wt/Wt. But, the dramatic decrease was noticed at fiber ratio 50 % as shown in Fig. (4a, b). On the other side, fiber-reinforced HIPS composites had relatively higher Young's modulus compared to HIPS alone [33]. Since the natural fibers have higher Young's modulus than the thermoplastic polymers. Therefore, increasing the ratio of loaded fiber and soaking the composite in water increased the composite the flexural modulus.

#### *Effect of chemical treatment on the composites' mechanical properties*

The composite specimens were soaked in 5% HCl, 5% NaOH, and engine oil for 24 hours at room temperature. We found that the treatment of composites with either 5% HCl, 5 % NaOH increased the composites Young's modulus as shown in Fig.5a. The improvement of Young's modulus may be due to the high disaggregation of fibers with elevated elastic modulus. Meanwhile soaking the composite in oil for 24 h did not show any notable effect on the composite elasticity [33, 34] as in Fig. 5a. Generally, soaking the samples in 5% HCl, 5 % NaOH aqueous solutions or oil reduced their mechanical load and strength as demonstrated from Fig. (5 a,b). Additionally; the Maximum load and tensile strength decreased upon treatment the composites samples with slightly acidic, alkaline aqueous solutions or engine oil.

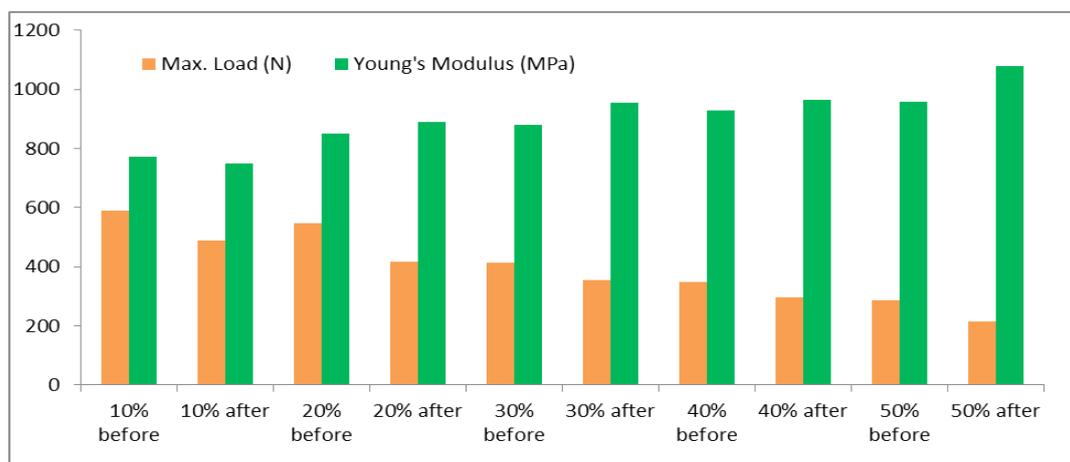


Fig. 4a. Max. load and Young's Modulus of composites before and after dipping in water.

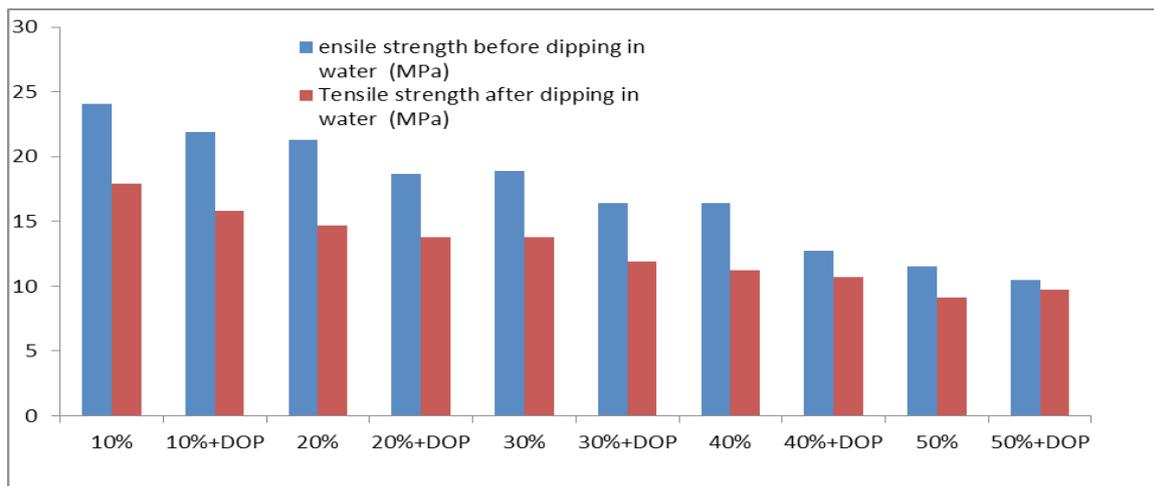


Fig. 4b. Tensile strength of composites before and after dipping in water

#### *Effect of UV exposure on the composite mechanical properties*

Furthermore, The exposure of the sugarcane bagasse/HIPS composites to UV radiation had a negative impact on the mechanical properties of the composite since the maximum load, tensile strength, and Young's modulus decreased upon their exposure to UV lighting, as shown in Fig. 5c.

#### *Water absorption and swelling behavior of the composites*

We studied the water absorption and the swellability behavior of the composites after soaking in water for 7 days. Increasing the fiber loading in the composite samples from 10-50 % Wt/Wt increased the water absorption capacity

of the composite as indicated from Fig. 6a. This is due to the hydrophobicity of the bagasse fibers which have a high tendency to water absorption compared to the hydrophobic nature of HIPS. Furthermore, the swelling rate for the five samples of the composite increased by increasing the ratio of bagasse fiber and the soaking time as well the same trend was reported when sugarcane bagasse was used for the preparation of sugarcane bagasse/polyester composites [35], Fig. 6b. Where the lower swelling rate was recorded after soaking the composite with fiber content 10 % for 1 day which increased by three folds at the 7<sup>th</sup> day. Meanwhile, the maximum swelling and water absorption were gained by the composite with the fiber feed ratio of 50 % after 7 days.

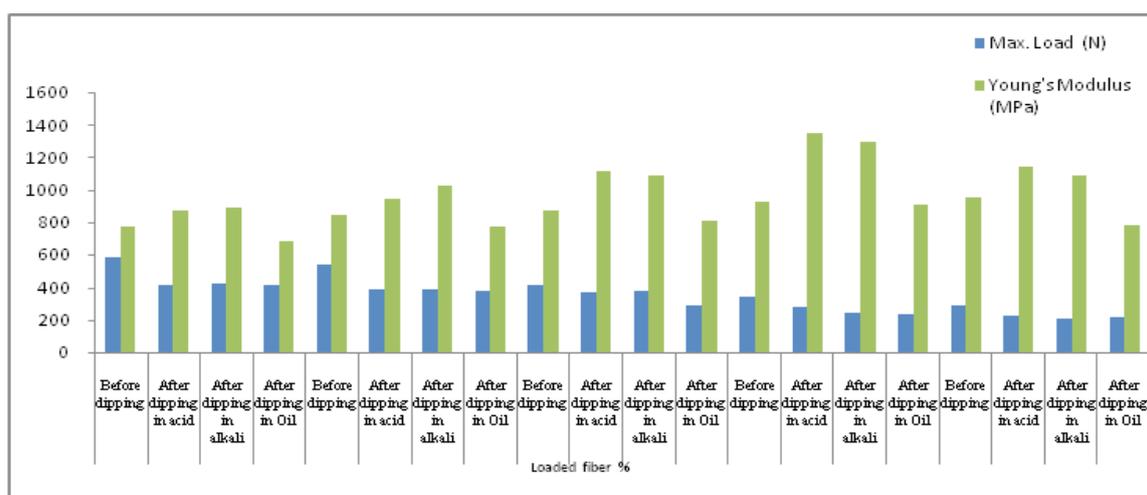


Fig.5a. Maximum load and Young's Modulus of composites before and after dipping in different chemicals.

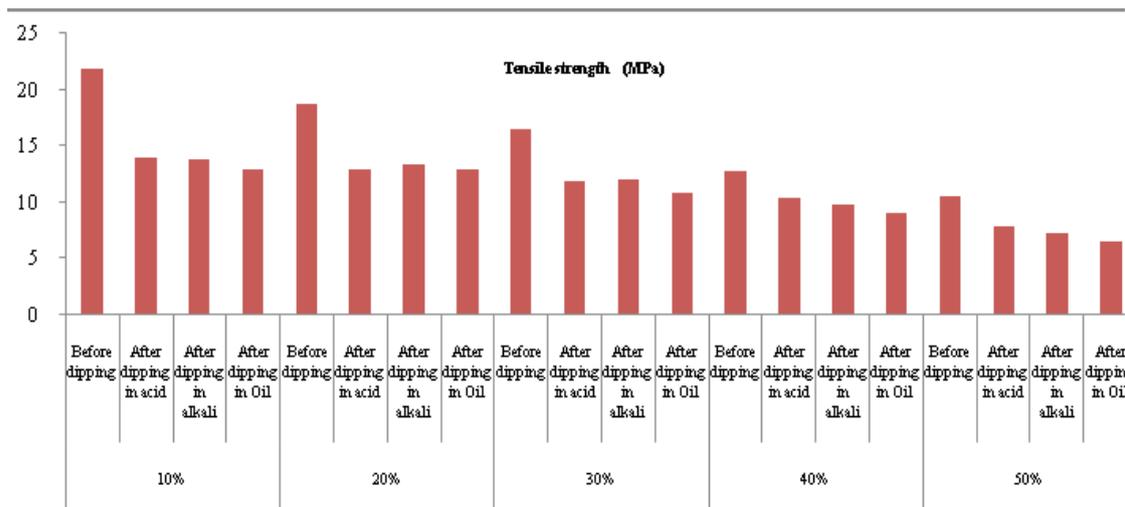


Fig.5b. Tensile strength of composites before and after dipping in different chemicals.

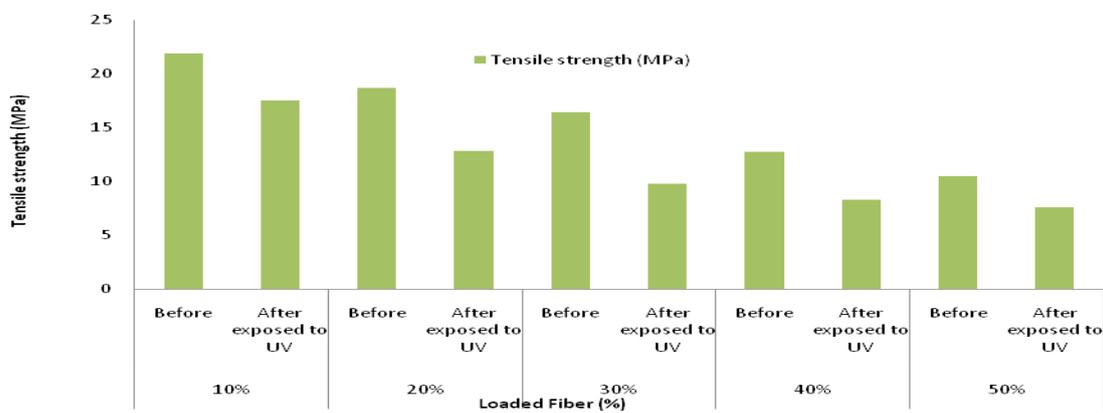


Fig. 5c. Mechanical properties of composites in presence of DOP before and after exposed to UV.

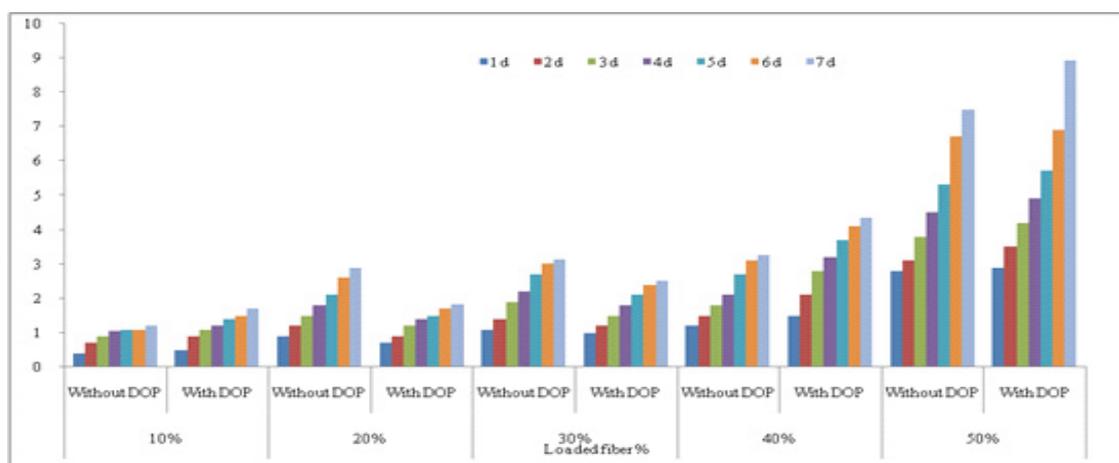


Fig.6a. Water absorption value of bagasse fiber composites during 7 days.

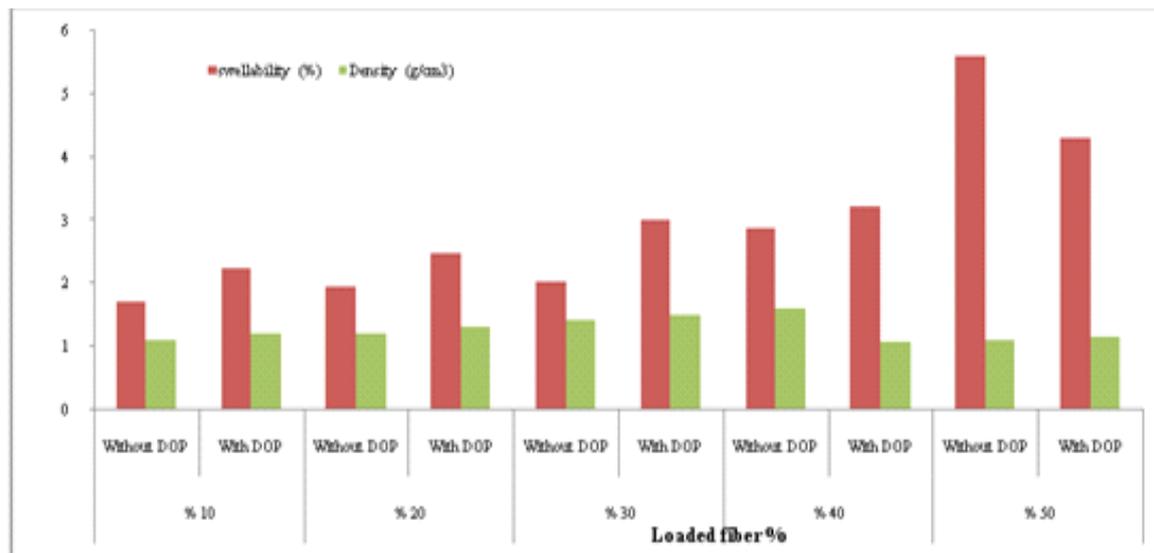


Fig.6b. Density and swellability of bagasse fiber composites after 7 days with and without DOP.

### Conclusion

Sugarcane bagasse fiber was used as filler for the reinforcement of HIPS polymer. Sugarcane bagasse/HIPS polymer composites were prepared at different fiber feed ratios (10, 20, 30, 40, and 50). The composite structure and morphology were characterized by FT-IR and SEM. The thermal stability of the prepared composites was meaningfully enhanced with the addition of sugarcane bagasse fiber to HIPS. With increasing the fiber ratio, soaking the films in water, 5% HCl, 5 % NaOH solution and petroleum oil, the maximum load and the tensile strength decrease while Young's modulus increase except when the composite films were soaked in oil. The water absorption and swelling behavior increased by increasing sugarcane bagasse fiber loading.

### Acknowledgement

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### توصيف و دراسة الخواصة الميكانيكية لمتراكبات بوليمر البولى استيرين ومصاصة قصب السكر

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<sup>١</sup>قسم السليلوز،<sup>٢</sup>قسم البوليمرات والأصباغ - المركز القومي للبحوث، ٣٣ البحوث. ص.ب. ١٢٦٢٢، الدقى الجيزة، مصر.

ان توافر الألياف الطبيعية في مصر مثل مخلفات قصب السكر، قش الأرز، قشر الذرة جذبت اهتمامات الكثير من الباحثين لاجاد طرق صديقه للبيئة لاعادة استخدام المخلفات الزراعية من أجل تطوير متراكبات مقواة بالألياف الطبيعية للتطبيقات المتنوعة. و في الآونة الأخيرة هناك اهتمام متزايد لاستخدام الالياف الحيوي كمادة مألته لمتراكبات البولى استيرين التى تستخدم على نطاق واسع في مختلف المجالات بسبب خصائصه الميكانيكي و الحراريه. حيث تستخدم متراكبات البوليسترين الحراريه كبديل رخيصة الثمن للخشب الطبيعي.

فى هذا البحث تم استخدام مصاص القصب كمادة مألته لتحضير متراكبات البولى استيرين. حيث تم اذابة بوليمر البولى استيرين وخلطه مع مصاصة قصب السكر بنسب مختلفة ، ثم اختبار التركيب البنائى تقييم الخواص. والمورفولوجى للمتراكبات الناتجة و دراسة الثبات الحراري للمتراكبات الناتجة كما تم ايضا الميكانيكيه للمتراكبات قبل وبعد تعرضها لبعض المؤثرات الخارجية مثل المحاليل الحمضية الطفيفة، المحاليل القلوية، و زيت المحرك أو التعرض للأشعة البنفسجية. واخيرا تم تقييم قدرة المتراكبات على امتصاص المياه و بغمز المتراكبات المختلفه التمدد حتى ٧ ايام متواصله، وجد انه بزيادة نسبة مصاصة القصب تزداد قدرة المتراكبات الناتج على امتصاص الماء والتمدد بينما تقل الخواص الميكانيكيه عند التعرض للماء , المحاليل الحمضيه و القلويه الأشعة فوق البنفسجية.