Chemical Resistance, Physical Properties and Biodegradability of palm fiber with cotton fiber in poly styrene matrix biocomposite

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Abstract

Growing environmental concern over synthetic materials and other sustainability issues related to depletion of natural fossil fuel resources have made remarkable progress in the development of green products like biocomposites. In order to widen the scope and application of biocomposites, there is need to overcome the limitations of bio fiber reinforced composite such as less durability, poor chemical resistance and hydrophilicity. The present study is focussed on the hybridisation of palm fiber with cotton fiber in poly styrene matrix biocomposite and compares the effect of hybridisation on physical, chemical and biodegradability properties. Physical (void content, solvent absorption), chemical resistant and biodegradability properties of pure cotton fiber and hybrid cotton-palm fiber poly styrene biocomposites are analysed. The void content of hybrid composite decreased due to well bonding of fiber and matrix. The chemical resistance of biocomposite enhanced on hybridising palm fiber with cotton fiber. Biodegradability of both pure and hybrid biocomposites are almost comparably equal. Biodegradability test also reveals that there is no negative impact on biodegradability which normally occurs on hybridizing natural fiber with synthetic fiber. The incorporation of palm fiber with cotton fiber in a polystyrene matrix produced hybrid biocomposite with improved properties competitive to synthetic composites.

Key words: Chemical resistance, Fibers, Hybrid biocomposites, Physical properties, Void content.

1. Introduction

Recently, ecological concerns, environmental safety, renewability, recyclability and other economic factors serve as the fundamental driving force to increase the use of bio-based materials [1,2]. Renewable and sustainable biomaterial's usage as an alternative to petroleum based synthetic products is among the potential part of bio-economy [3-6]. Natural fiber reinforced biocomposites offer great advantages over their competent synthetic fiber reinforcement such as light weight, large availability, renewability, low density, biodegradability and low cost [5,6,7]. Despite having these fascinating characteristics, the use of natural fiber reinforced biocomposites have been restricted due to its hydrophilic nature, poor chemical and environmental weathering resistance[8,9,10].Most of the drawbacks of biocomposites can be overcome by effective hybridisation of natural fiber with natural or synthetic fiber. There are many studies reporting about the effectiveness of hybridisation which enable biocomposites to meet the needs of many application fields [11-14].

The characteristics of the hybrid composite are weighed sum of individual components with a more favourable balance between advantages and disadvantages. Hybrid biocomposites revealed that they possess long fatigue life, better mechanical properties, thermal stability, chemical resistance and water resistivity compared to single fibre reinforced composites [15-20].There are several studies reported on the hybridization of natural fibers which are plenty available, for improvement in composite properties such as coir/oil palm , banana/flax [21,22]. Boopalan et al. [23] reported that hybridisation of banana fiber with jute fiber in the composites enhanced most of its mechanical properties, thermal stability and reduced moisture absorption. The Chemical resistance of silk/sisal hybrid fibre-reinforced composites are analyzed by Raghu et al [24] and found that hybrid composites were strongly resistant to most of the chemicals.

The present study focuses on the chemical resistance, physical and biodegradability properties of the biocomposites. These are significant characteristics of the material for finding suitable field of application. Biocomposites applied in packaging, automotives and other light weight application sectors can come across occasional or continuous exposure to chemicals such as cleaning agents, acids, alkalis or corrosive environment. The enhancement in physical barrier and chemical resistant properties of biocomposite without having negative effect on biodegradability can be achieved through incorporating more than one type of natural fiber.

The properties of pure woven cotton fiber (WCF) and hybrid woven palm-cotton fiber (WPCF) reinforced polystyrene biocomposite are compared and analyzed for evaluating the effect of hybridising cotton fiber with palm fiber. This study explores potential utilization of locally available palm fibers with cotton fiber in polystyrene matrix. The main aim of the study is to provide a cost effective, biodegradable eco-friendly material that has improved physical and chemical resistant properties.

2. Materials and Method

2.1 Materials

H_2SO_4, HCl, HNO_3, NaOH pellets, KOH pellets, NH_4OH, Methanol, Carbon tetra chloride purchased from Nice Chemicals Pvt. Ltd (India) are used as received. The samples were prepared with Woven cotton/cotton (both the wrap and weft) material and woven palm-cotton (cotton in the wrap and palm in weft) material reinforced in processed expanded polystyrene matrix. The prepared biocomposite samples of pure WCF materialwith20% polystyrene and samples of hybrid WPCF material with20% PS are taken for tests.

2.2 Chemical Resistance Test

Chemical resistance of the samples were tested with three acids (H_2SO_4, HNO_3, HCl) and three alkalis (NaOH, KOH, NH_4OH) The effect of these chemicals was studied on pure WCF/PS and hybrid WPCF/PS biocomposite. In each case, four pre-weighed samples were immersed in 25 ml of respective reagents taken in a container at room temperature. Each sample was removed after 1, 5, 10, 20, and 30 days of the time period. They are first drained by pressing with tissue paper to remove excess reagent and then by keeping in a vacuum oven. Their final weight (W2) was noted. The percentage chemical resistance was calculated in terms of weight loss/gain using the following equation.

$$Weight\ loss\% = \frac{\text{Initial Weight(W1)} - \text{Finalweight(W2)}}{\text{Initial Weight (W1)}} (x)\ 100 \qquad \text{(Eqn. 1)}$$

2.3 Physical barrier properties - Void content

The void content in the composites was determined using ASTM D 2734 method. It was calculated from theoretical and experimental density of the composites by using following equation.

$$\text{Void content} = \frac{[\text{Theoretical Density}]-[\text{Experimental Density}]}{\text{Theoretical Density}} \text{ (x) } 100 \qquad \text{(Eqn. 2)}$$

Theoretical density of both pure and hybrid biocomposite samples are calculated by Agarwal and Broutman Equation (25)

$$\text{Theoretical density} = \frac{1}{\left[\frac{\text{Fiber Weightfraction}}{\text{Fiber Density}}\right]+\left[\frac{\text{Matrix Weight fraction}}{\text{Matrix Density}}\right]} \qquad \text{(Eqn. 3)}$$

2.4 Solvent Absorption

Physical barrier properties are analyzed by immersing the pre weighed samples in three solvents such as water, methanol and carbon tetra chloride. Solvent absorption rate is found out by the weight gain method and is used to get an idea about surface properties, void content and barrier properties of the composite. Samples were

(both pure and hybrid) immersed in 25 ml of respective solvents taken in a container at room temperature. They were taken out after 1,5,10,20 and 30 days of the time period. They were drained by pressing with tissues and the final weight (W2) is noted. From the initial (W1) and final weight (W2), weight gain % can be found out by the following equation

$$\text{Weight Gain } \% = \frac{\text{Final Weight(W2)}-\text{Initial Weight (W1)}}{\text{Initial Weight (W1)}} \text{ (x) } 100 \qquad \text{(Eqn. 4)}$$

2.5 Biodegradability

Biodegradability of both pure and hybrid biocomposite samples were analysed by soil burial method. The biocomposite samples were dried in oven and pre-weighed (W1). Each sample was buried in biologically active soil taken in plastic bags. They were kept open to ensure air and natural environment for degradation. Samples were removed systematicallyafter1, 10, 20, 30, 40, 50, 60, 75 and 90 days of burial period. They were washed well with distilled water and dried for 24 h in a vacuum oven (60°C, 700 mm of Hg) and weighed (W2). From the initial and final weight, weight loss percentage and thereby biodegradability can be calculated by the equation given below

$$Weight\ loss\% = \frac{\text{Initial Weight(W1)}-Finalweight(W2)}{\text{Initial } Weight\,(W1)} \text{ (x) } 100 \qquad \text{(Eqn. 5)}$$

3. Results and Discussions

3.1 Chemical Resistance

Biocomposites can be applied in many fields where they may get continuous or occasional contact with chemicals. Resistance of the material is very important before suggesting them for applications. Chemical resistance test of pure WCF/PS and hybrid WPCF/PS samples indicated that hybridisation of comparatively tough palm fiber with cotton fiber improved their resistivity for both acid and alkaline reagents. Weight loss % of both pure and hybrid sample in strong acid is given in table-1. Among acids, maximum weight loss occurred in H_2SO_4 (Fig-1). The % weight loss of both pure and hybrid samples in HNO_3 (Fig-2) and HCl (Fig-3) is comparatively less than that of H_2SO_4. The trend of losing weight in all the three acids is same and hybridization resulted in improved chemical resistance towards strong acids on account of tight and compact fiber reinforcement in the PS matrix. Pure WCF/PS biocomposite sample exhibited 14.61%, 15.4% and 14.13% more weight loss in H_2SO_4, HNO_3 and HCl respectively in comparison with hybrid WPCF/PS sample. Alkalis such as NaOH, KOH and NH_4OH have not much impact on the weight reduction of composite. They are almost resistant to alkalis. Weight loss % of the samples is given in table-2. Hybridisation of palm fiber with cotton fiber increased their chemical resistance and durability. Fig-4 shows the weight loss % of both samples in NaOH. It is clear that pure sample has more impact in NaOH and almost 15.45% more weight loss occurred than hybrid sample. The weight loss% of both samples in KOH and NH4OH are given in Fig-5 and 6 respectively. Among alkalis, more weight loss of the samples occurred in NH_4OH.

Chemical resistance tests conducted with acids and alkalis for a maximum period of 30 days revealed that there is a remarkable increase in chemical resistance on hybridizing palm fiber with cotton fiber.

3.2 Physical Barrier Properties - Void Content

The void content % of pure WCF/PS and hybrid WPCF/PS biocomposites are given in Table-3. It is clear from the results that pure cotton fiber reinforced PS biocomposite samples have more void content which arised due to comparatively poor fiber matrix bonding. Fiber –matrix compatibility, tight packing of fibers and well processing of composite is very important to decrease void content. Void presence in composites decreases its density and many other properties which include lowering of impact resistance, greater prone to solvent absorption, less durability and changes in mechanical properties.

3.3 Solvent Absorption

Physical barrier properties were analysed by solvent absorption method (table-4) using water, methanol and Carbon tetra chloride. The results show that maximum weight gain occurred in water. Pure WCF/PS biocomposite sample absorb more solvent than hybrid sample. Fig-7 shows % weight gain of samples in water. The hydrophilic and polar groups present in natural fiber constituent absorb water. The tight and compactly packed woven hybrid reinforcement, produce composite with good consistency and less void content. This will lead to a decrease in absorption rate and thereby improvement in properties. The solvent absorption trend is almost same in methanol (Fig-8).The analysis reveals that hybridization of palm fiber with cotton fiber has a positive effect on the barrier properties of the composite.

3.4. Biodegradability

Biodegradability of the material is the prime factor for selecting natural fibers for reinforcement in composite over synthetic materials. Most of the time biodegradability could be affected when we try to improve other properties. Analysis of biodegradability of pure and hybrid samples given in Fig-9 reveal that, both samples have relatively equal biodegradability.

Conclusion

Hybrid WPCF/PS biocomposite and pure WCF/PS biocomposite samples are taken for analysing chemical resistance, physical barrier properties and biodegradability. Chemical resistance tested with acids and alkalis showed that hybridization has improved their chemical resistance. Physical barrier properties are analyzed by a solvent immersion method using water, Methanol and Carbon tetra chloride. Solvent absorption is measured by the %weight gain method and the absorption pattern is almost same in all solvents. Maximum absorption occurred in water. Hybrid sample has less weight gain % in all solvents. The void content of the hybrid sample is less than pure WCF/PS biocomposite. Less void content in the composite improves its physical barrier properties and chemical resistance. Biodegradability of the samples are analyzed by soil burial method. The % weight loss of the pure cotton and hybrid palm-cotton fiber reinforced biocomposite samples calculated systematically over a period of 90 days. The results show that both pure and hybrid samples have relatively equal biodegradability. This study sheds light on the positive effect of hybridization of natural cotton fiber with palm fiber for the production of biocomposite with innovative application possibility.

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References

1. Safak Yıldızhan, Ahmet Çalık, Mustafa Ozcanl, Hasan Serin Bio-composite materials: a short review of recent trends, mechanical and chemical properties, and applications European Mechanical Science, September 2018; 2(3): 83-91
2. Mohsen Bahrami, Juana Abenojar, Miguel Angel Martinez, Recent progress in hybrid biocomposite; mechanical properties, water absorption and flame retardancy Materials (2020)13,5145
3. L.Yan, S,Su, N,Chouw, Microstructure, flexural properties and durability of coir fiber reinforced concrete beams externally strengthened with flax FRP composites. Compos. Part B 80(2015)343-354.
4. L.CoDyre, K. Mak, A.Fam, Flexural and axial behaviour of sandwich panels with biobased flax fiber-reinforced polymer skins and various foam core densities. J. Sandwich Struct. Mater. (00)(2016)1-22.
5. K. Mak, M.ASCE, A. Fam, C. MacDougall, Flexural behavior of sandwich panels with bio-FRP skins made of flax fibers and epoxidized pine-oil resin, J. Compos. Constr (2015). 04015005-1 to 13.
6. L. Yan, N. Chouw, L. Huang, B. Kasal, Effect of alkali treatment on microstructure and mechanical properties of coir fibres, coir fibre reinforced-polymer composites and reinforced-cementitious composites, Constr. Build. Mater. 112 (2016) 168–182.
7. Keya, K. N., Kona, N. A., Koly, F. A., Maraz, K. M., Islam, M. N., & Khan, R. A. (2019). Natural fiber reinforced polymer composites: history, types, advantages and applications. *Materials Engineering Research*, *1*(2), 69-85.
8. C. Ealy, How green are celluose-reinforced composites?, Materials today 18 (10) (2015) 531
9. A. Vinod, M.R. Sanjay, Siengchin Suchart, Parameswaran pillai Jyotish kumar, Renewable and sustainable bio-based materials: An assessment on biofibers, biofilms, biopolymers and biocomposites, 258, 10 June 2020, 120978
10. Arnab Sengupta, Sarojrani Pattnaik and Mihir Kumar Sutar, Biocomposites: An Overview, International Journal of Engineering Technology Science and Research Vol 4 (2017) 649-653.
11. Cristiano Fragassa, et al., Improving performance and applicability of green composite *materials;* Contemporary Materials, VI−1 (2015) Page 35 of 43.
12. Nirupama Prasad, Vijay Kumar Agarwal and Shishir Sinha; Hybridization effect of coir fiber on physico-mechanical properties of polyethylene-banana/coir fiber hybrid composites Science and Engineering of Composite Materials

13. Ridwan Yahaya, S.M. Sapun, Mohammad jawal, Review of kenaf reinforced hybrid biocomposites; potential for defence applications. Current analytical chemistry, 13(3) Nov2017
14. Seyed Meysam Khoshnava, Science Direct Construction and Building Materials, 154 (2017) 55–166
15. Abdul Khalil HPS, Hanida S, Kang CW, Nik Fuaad NA. Agro-hybrid composite: the effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyester composites. J Reinf Plast Compos 2007;26(2):203–18.
16. Abdul Khalil HPS, Kang CW, Khairul A, Ridzuan R, Adawi TO, The effect of different laminations on mechanical and physical properties of hybrid composites. J Reinf Plast Compos 2009;28(9):1123–37
17. Abu Bakar A, Hariharan, Abdul Khalil HPS. Lignocellulose-based hybrid bilayerlaminate composite: part I – Studies on tensile and impact behavior of oil palm fiber–glass fiber-reinforced epoxy resin. J Compos Mater 2005;39(8):663–84.
18. De Carvalho LH, Moraes GS, D'Almeida JRM. Influence of water absorption and pre-drying conditions on the tensile mechanical properties of hybrid lingo-cellulosic fiber/polyester composites. J Reinf Plast Compos 2009;28(16):1921–32.
19. Shahzad A. Impact and fatigue properties of hemp-glass fiber hybrid bio-composites. J Reinforced Plast Compos 2011; 30(16): 1389–1398
20. Zainudin ES, Yan LH, Haniffah WH, et al. Effect of coir fiber loading on mechanical and morphological properties of oil palm fibers reinforced polypropylene composites. Polymer Compos 2014; 35: 1418–1425.
21. Srinivasan S V, Rajendra Boopathy, D.Sangeetha, Evaluation of mechanical and thermal properties of banana-flax based natural fibre composite. Mater Des 2014;60:620-627
22. M.Boopalan, M.Niranjanaa and M.J.Umapathy. Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites. composites Part B Engineering 2013;51:54-57
23. Raghu K, Noorunnisa Khanam P and Venkata Naidu S. Chemical resistance studies of silk/sisal fiber-reinforced unsaturated polyester-based hybrid composites. J Reinf Plast Compos 2010; 29(3): 343–345.
24. Agarwal BD, Broutman LJ, Chandrashekhara K ;2006 John Wiley and sons inc.3rd edn.

Table-1: Weight loss% of pure WCF/PS and hybrid WPCF/PS in Acids

Immersion time in Days	WPCF/PS			Pure WCF/PS		
	H_2SO_4	HNO_3	HCl	H_2SO_4	HNO_3	HCl
1	12.8	2.4	1.43	14.01	2.76	1.59
5	13.21	2.6	1.56	15.89	2.845	1.78
10	13.58	2.83	1.77	15.99	3.32	1.91
20	14.53	2.98	1.84	16.56	3.45	2.04
30	16.08	3.18	1.91	18.42	3.67	2.18

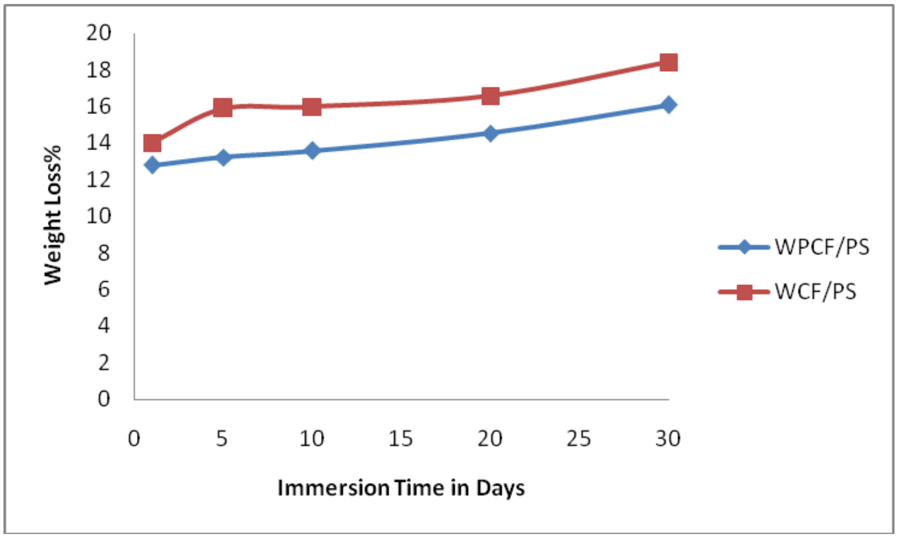

Fig-1: Weight loss% of pure WCF/PS and hybrid WPCF/PS in H_2SO_4

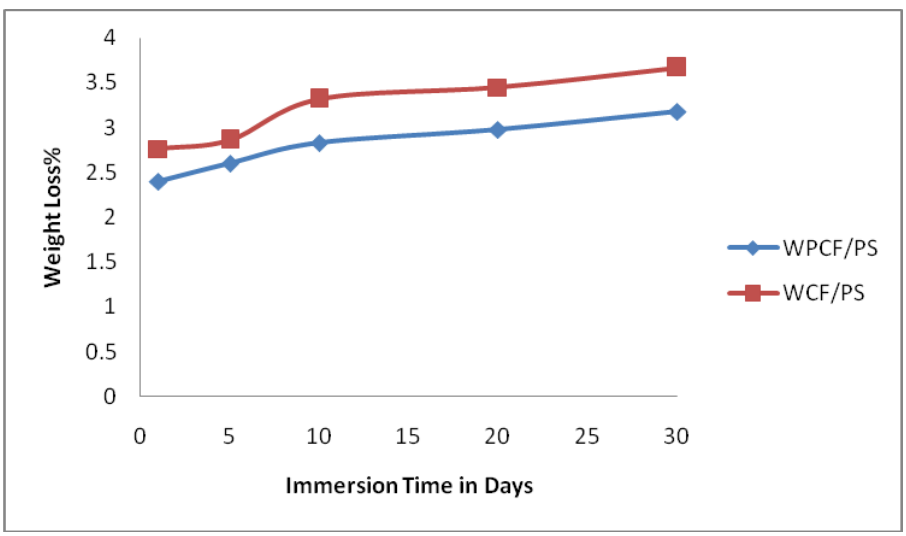

Fig-2: Weight loss% of pure WCF/PS and hybrid WPCF/PS in HNO_3

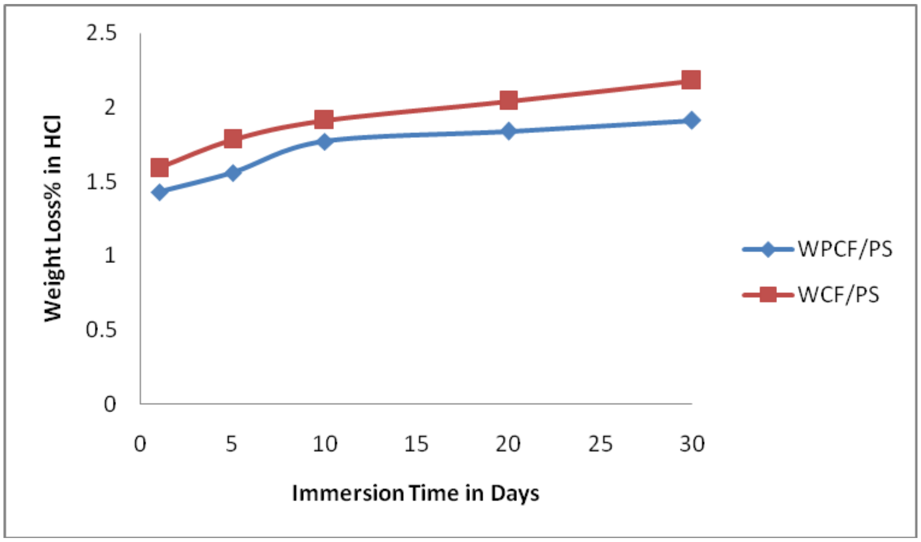

Fig-3: Weight loss% of pure WCF/PS and hybrid WPCF/PS in HCl

Table-2: Weight loss% of pure WCF/PS and hybrid WCF/PS in Alkali

Immersion time in days	Weight Loss % of WPCF /PS			Weight Loss % of pure WCF/PS		
	NH_4OH	NaOH	KOH	NH_4OH	NaOH	KOH
1	2.1	1.62	1.43	3.8	2.114	1.811
5	3.2	1.78	1.56	5.3	2.211	1.842
10	4.8	1.93	1.77	7.4	2.389	2.186
20	5.92	2.05	1.84	7.9	2.401	2.192
30	7.11	2.22	1.98	8.2	2.552	2.221

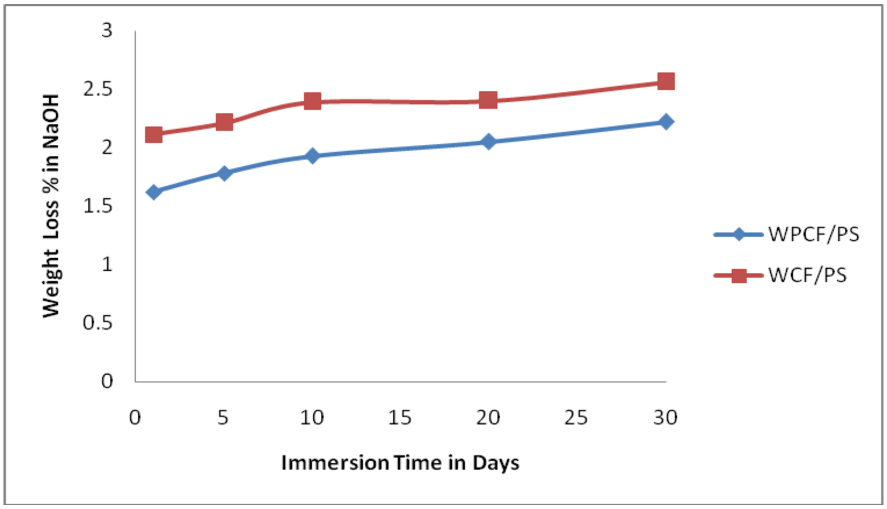

Fig-4: Weight loss% of pure WCF/PS and hybrid WCF/PS in NaOH

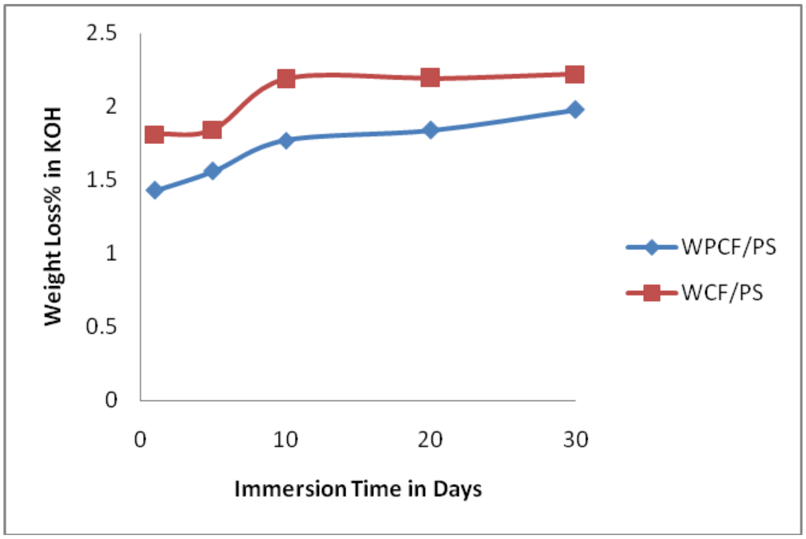

Fig-5: Weight loss% of WCF/PS and hybrid WPCF/PS biocomposite samples in KOH

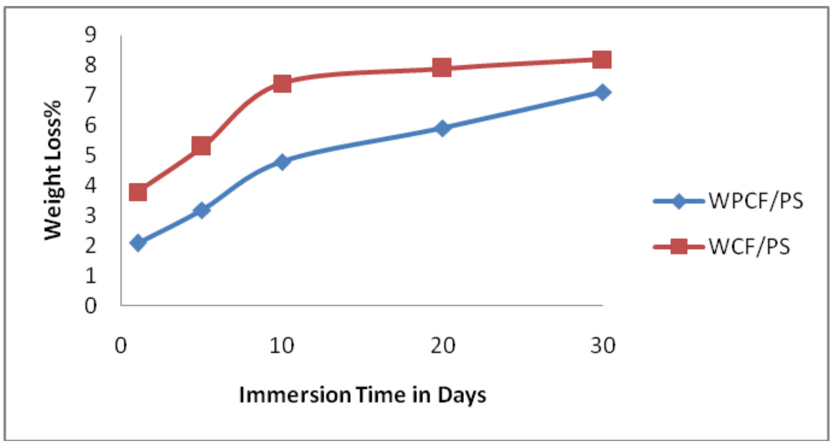

Fig-6: Weight loss% of pure WCF/PS and hybrid WPCF/PS biocomposite samples in NH_4OH

Table-3: The void content % of pure WCF/PS and hybrid WPCF/PS biocomposites

Composite	Theoretical Density	Experimental Density	Void Content (%)
WCF/PS	1.126	1.051	6.66
WPCF/PS	1.131	1.079	4.59

Table-4: Solvent absorption % of pure WCF/PS and hybrid WPCF/PS

Immersion time in Days	WPCF/PS			Pure WCF/PS		
	Methanol	CCl_4	Water	CH_3OH	CCl_4	Water
1	1.132	0.963	1.112	1.342	0.9891	1.241
5	1.76	0.997	2.436	1.953	1.124	2.611
10	2.35	1.647	2.675	2.673	1.987	2.94
20	2.761	1.9882	2.881	2.997	2.213	3.102
30	2.78	2.362	2.89	3.251	2.764	3.43

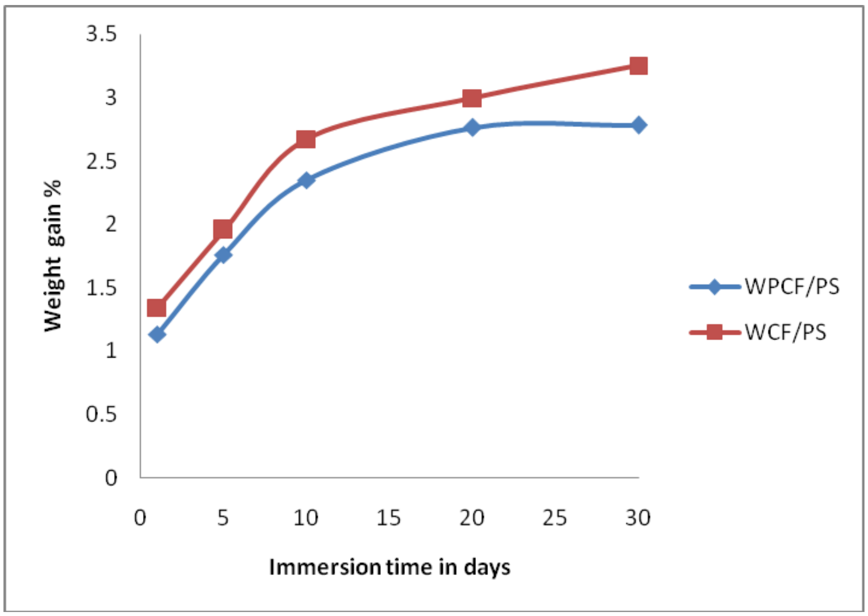

Fig-7: Weight gain% of pure WCF/PS and hybrid WPCF/PS biocomposite samples in Water

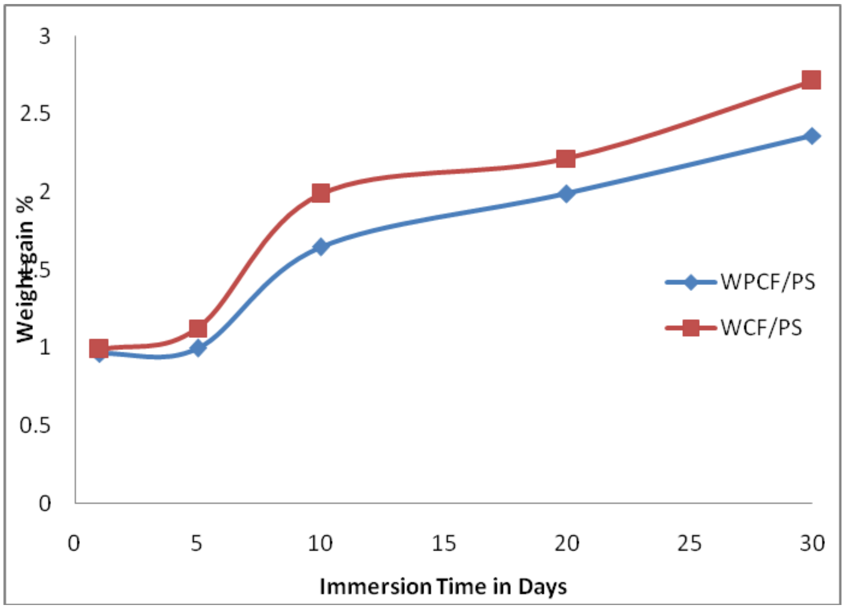

Fig-8: Weight gain% of pure WCF/PS and hybrid WPCF/PS biocomposite samples in Methanol

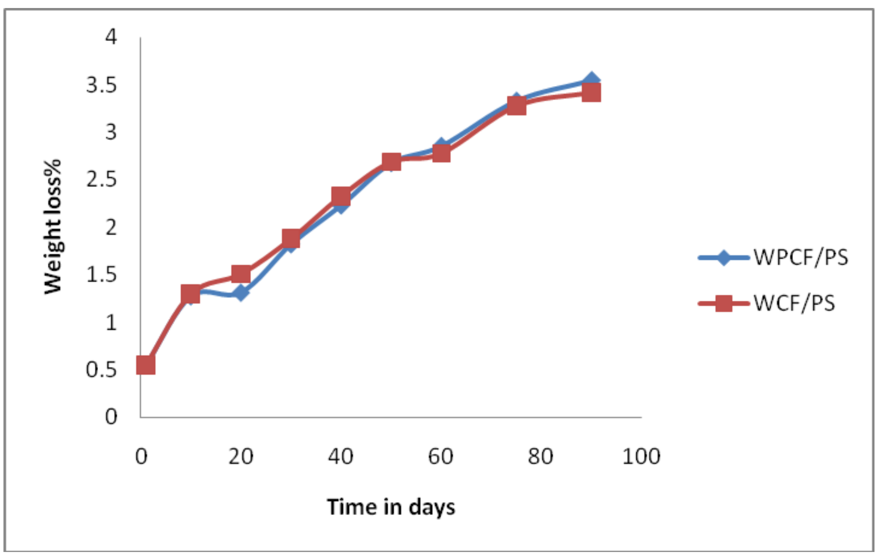

Fig-9: Biodegradability of WCF/PS and hybrid WPCF/PS biocomposite samples in Soil