

VEGETABLE FIBERS AS MULTIPURPOSE MATERIALS.

Sandro C. Amico^{1*}

*1** - Universidade Federal do Rio Grande do Sul - UFRGS, Campus do Vale, Porto Alegre – RS – amico@ufrgs.br

Abstract: Environmental concerns related to the ever-growing use of non-renewable raw-materials by modern society is driving the interest of the academic and scientific sectors for a new concept of material, which takes into account not only properties, cost and availability, but also environmentally-related issues, such as biodegradability, renewability and energy use, along with the promotion of social and economical development of the economically-challenged segment of the population. Vegetable fibers have been used in many home-made objects, such as ropes and artcraft, for perhaps as long as humanity exists. However, these fibers present a combination of interesting properties which enables their use in a wide variety of sectors. This invited paper will review the work recently carried out in collaboration with various researchers from UFRGS, UFPR and UCS, and it will be divided into two case studies, focusing on the use of vegetable fibers for oil sorption and as infiltration (flow) medium for RTM molded polymer composites, promoting their use in more demanding and rewarding applications.

Keywords: *Vegetable fibers; Oil sorption; Flow enhancement; Hybrid composites.*

Introduction

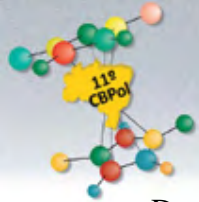
Environmental concerns related to the ever-growing use of non-renewable raw-materials by modern society is driving the interest of the academic and scientific sectors for a new concept of material, which takes into account not only properties, cost and availability, but also environmentally-related issues, such as biodegradability, renewability and energy use, along with the promotion of social and economical development of the economically-challenged segment of the population.

Vegetable fibers have been used in many home-made objects, such as ropes, textiles and artcraft, for perhaps as long as humanity exists. However, these fibers present a combination of interesting properties [1] which enables their use in a wider variety of sectors, among them: (a) Twines, ropes, cords [2]; (b) Textiles, non-woven, cellulose for papers, biomass for energy [3]; (c) Brooms, fancy articles (lady's bags, purses, table mats), carpets, scouring pads, palm sole, inner soles for shoes, bolters, leather straps, hats, car seats, gardening, mattress/sofa bed, for hammock and fishing lines, floor-furnishing, fertilizers, foot rugs, raw material for plastics [4, 5]; (d) Cones of speakers [6]; (e) Filler for cementitious composites; (f) Filler or reinforcement for polymer composites [7]; (g) Wood-plastic composites [8]; (h) Biocomposites [2], among many others.

This invited paper will revisit the work recently carried out by the author in collaboration with various researchers from UFRGS, UFPR and UCS, and will be divided into two case studies.

Case Study 1 – Sorption of Crude Oil [9, 10, 11]

Oil spills are a global concern due to their environmental and economical impact. Pollution by petroleum affects sea life, economy, tourism and leisure activities. Various commercial systems have been developed to control these spills, including the use of fibers as sorbents.



Despite the fact that synthetic polymers are usually regarded as ideal materials for marine oil-spill recovery due to their low density, low water uptake and excellent physical and chemical resistance, these sorbents are neither renewable nor biodegradable. Some vegetable fibers, which are environmentally friendly materials, were investigated as sorbent for oil. In sorption experiments, crude oil was poured into a beaker containing deionized water. After that, the fibrous material was placed onto the oil surface (Fig. 1a). The material was later removed and placed on a filter paper, being allowed drainage under vacuum for 5 min before weighing to determine sorption capacity. Other sorption conditions were experimentally simulated: (a) Dynamic system (Fig. 1b): Tests carried out under constant agitation (c.a. 500 rpm); (b) Dry system (Fig. 1c): Without water in the beaker; and (c) Marine conditions: Use of a substitute ocean (salty) water (ASTM D1141) instead of deionized water. Distillation of the sorbent after sorption (ASTM D95) was conducted to evaluate water uptake. Buoyancy and hydrophilicity were also evaluated.

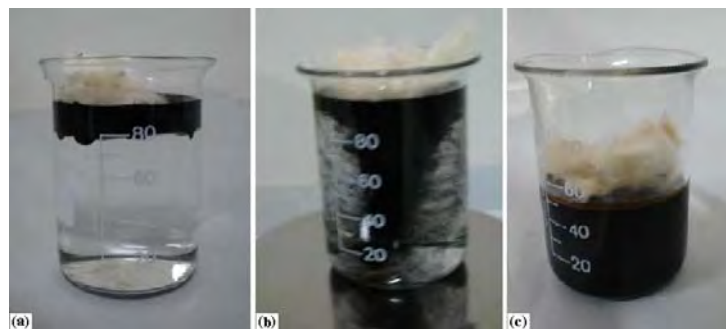
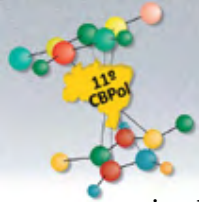


Figure 1 - Sorption systems just after fiber placement: (a) Static, (b) Dynamic, and (c) Dry system [9].

The results of the various sorption tests showed the following general trends: (i) Higher sorption for all fibers as the sorption time increased; (ii) Sorption capacity of the fibers followed: Silk-floss > Sisal > Sawdust > Coir fiber > Sponge gourd > Leaves residues (Fig. 2), and (iii) A much higher sorption for the silk-floss. Not all weight gain shown in Fig. 2 refers to oil sorption, since water is also incorporated into the fibers to an extent dependent on the particular fiber. Water uptake was higher for sponge gourd and coir fibers (42-51%), whereas sisal, leaves residues and sawdust showed intermediate (21-33%) values, and silk floss (3-5%) sorbed little water. Besides, the silk-floss reached around 98% hydrophobicity and 100% buoyancy, much higher than all other fibers, under the experimental conditions used.

Irrespective of the sorption conditions, the 24-hour oil sorption of the silk-floss reached approximately 85 g of oil/g sorbent. This sorption capacity is much higher than the reported values



in the literature for other vegetable fibers, including commercial vegetable sorbents of peat sorb. The performance of silk-floss is even comparable to that of synthetic materials, e.g. Witka-Jezewska [12] reported 30 g oil/g viscose rayon, 40 g oil/g polypropylene and 100 g oil/g polyurethane foam.

In all, the potential of silk-floss to be used as sorbent was evidenced by its rapid oil sorption and a very high sorption capacity of approximately 85 g oil/g sorbent (in 24 h), high degree of hydrophobicity and buoyancy and low water uptake. Indeed, the sorption capacity was much higher than that of two analyzed commercial products composed of peat sorb (5-10 g oil/g sorbent, dry system, 20°C, 60 min). The silk floss tree is abundant in various states of Brazil and the estimated cost (R\$ 60.00/kg) is approximately half that of the commercial product used for this aim. Mats and barriers produced with silk floss may show the same performance of commercial products and this has led the authors to deposit a patent [13].

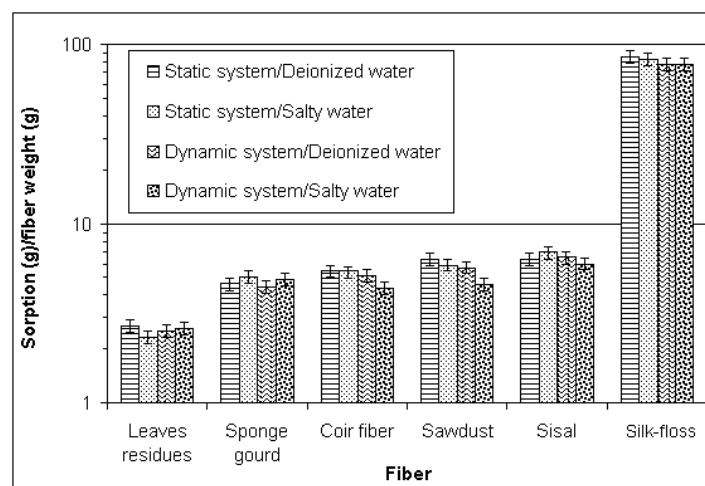


Figure 2 - Sorption of the different materials for a 60-minute sorption period under various conditions [9].

Case Study 2 - Infiltration (Flow) Medium for Resin Transfer Molding [14]

Resin transfer molding (RTM) is a process that is being increasingly used to manufacture fiber reinforced polymeric composites, including high-performance parts, such as automotive and aerospace structural components. The RTM process comprises the injection of a liquid resin into a closed mould cavity containing the fiber reinforcement and subsequent resin curing, producing a rigid composite part. Flow during RTM is usually modeled with Darcy's law and permeability (K) is the key property that determines how easy it is for a fluid to flow through the open pores.

Components of large in-plane dimensions and/or with high fiber content can be more rapidly infused when a high-permeability distribution medium, also called flow-enhancement fabric or flow



media, is integrated into the mid-plane of the reinforcement. The currently commercially available flow media are typically produced from synthetic fibers, e.g. polypropylene.

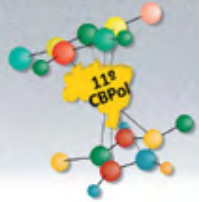
The performance of natural fiber mats as flow media in comparison with commercial flow media was investigated. The following materials were used: Commercial soybean oil; orthophthalic polyester resin UC 2080 (Elekeiroz) and methyl P-MEK; E-glass fiber mat - 300 g/m² (Owens Corning); polypropylene non-woven commercial flow medium - 200-250 g/m². The sisal fibers were chopped (40 mm) from ropes, washed with distilled water for 1 h and dried in an oven at 105°C for 30 min under low pressure to produce sisal mats. The overall fiber volume fraction (% V_f = 20.2%) was selected based on available commercial products for usual RTM light applications.

The studied porous systems were: (a) 6-7 glass mats (called GLASS); (b) PP core (called PP CORE); (c) Sisal mats (called SISAL); (d) (4 glass mats/1 PP core) hybrid reinforcement (13.7 and 6.5%, respectively), called GGPPG, where “G” represents a glass layer and “P” a PP layer; (e) 4 glass mats/1 sisal mat) hybrid reinforcement (13.7 and 6.5%, respectively), called GGSGG, where “S” represents a sisal layer.

Soybean oil was injected at constant pre-set pressure (10 kPa) into the different dry porous systems in rectilinear (unidirectional) RTM flow experiments (at 19-21 °C). Photographs of the position of the fluid flow-front and synchronized pressure readings were used to determine *K*. In addition, polyester was mixed with P-MEK (1% v/v), degassed and injected into the mould with the hybrid reinforcement stack (GGSGG or GGPPG). The plates were cured for 30 min at room temperature and the obtained composites were used for tensile (ASTM D3039), three-point bending (ASTM D790), short-beam (ASTM D2344) and unnotched Izod impact (ASTM D256) tests.

Table 1 shows the permeability values of all studied reinforcements. It may be readily seen that $K_{\text{SISAL}} > K_{\text{PP CORE}} > K_{\text{GLASS}}$. The PP CORE presented a permeability around 50% higher than that of the GLASS, with a 40% reduction in filling time. For the SISAL mat, the permeability was even higher, three-fold that of the GLASS, with a 70% reduction in filling time, i.e. sisal allows a faster impregnation than the commercial product in the same % V_f.

The previously mentioned hybrid reinforcements were built to mimic commercially available RTM light reinforcements. In these, there are glass fiber mats at the top and the bottom faces, with a highly permeable layer in the mid-plane. The produced hybrid reinforcement called GGPPG, is in fact similar to a reinforcement widely-used by the local composite automotive sector, which has 1200 g/m² glass fiber per 250 g/m² PP core. The permeability of the GGPPG reinforcement (Tab. 1) was $2.03 \times 10^{-9} \text{ m}^2$, whereas for the GGSGG, where a PP layer was replaced by a sisal mat with the same volume fraction, permeability increased, with a 27% decrease in filling time.


 Table 1 - Permeability and filling times (at 0.31 m) for homogeneous and hybrid media - %V_f = 20.2% [14].

Porous media	K (m ²)	K normalized	Filling time (s)	Filling time reduction
GLASS	1.33×10^{-9}	---	350	---
PP CORE	1.94×10^{-9}	1.46 (over K_{GLASS})	211	40% (over GLASS)
SISAL	3.97×10^{-9}	2.98 (over K_{GLASS})	106	70% (over GLASS)
GGPGG	2.03×10^{-9}	---	250	---
GGSGG	2.99×10^{-9}	1.47 (over K_{GGPGG})	182	27% (over GGPGG)

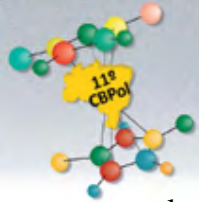
The higher sisal permeability compared with non-woven PP indicates that sisal allows the development of wider channels or pathways for the fluid flow that lead to through-the-thickness flow, speeding up the overall impregnation of the fibrous reinforcement. The lower flow tortuosity of the former may be a consequence of the larger diameter of sisal (average diameter = 195 μ m) in comparison with the PP fiber (average diameter = 56 μ m) and because sisal is highly heterogeneous in diameter [15] which hinders compaction of the layer and ultimately increasing permeability.

The mechanical properties must also be taken into consideration when comparing sisal and non-woven PP. The reinforcement is primarily used to improve mechanical properties, whereas an infiltration medium is employed to promote impregnation of the glass fibers, usually having a detrimental effect on these properties. The mechanical properties of the hybrid composites are shown in Tab. 2. Most values obtained for the GGSGG composite were slightly higher than those for the GGPGG composite, except flexural modulus and short-beam strength. Poor bonding of the untreated sisal to the matrix and a higher void content may be responsible for this decrease.

Table 2 - Mechanical properties of the hybrid composites [14].

		Polyester/GGPGG	Polyester/GGSGG
Tensile	Strength (MPa)	58.9 ± 9.3	62.6 ± 3.6
	Modulus (MPa)	1113 ± 73	1327 ± 199
	Strain at rupture (%)	4.7 ± 0.4	4.2 ± 0.5
Flexural	Strength (MPa)	172.6 ± 17.8	181.1 ± 17.7
	Modulus (MPa)	8746 ± 575	8613 ± 719
	Strain at rupture (%)	2.5 ± 0.3	2.6 ± 0.2
Impact	Strength (kJ/m ²)	59.9 ± 12.6	68.6 ± 10.7
Short-beam	Strength (MPa)	19.2 ± 4.4	14.5 ± 4.7

In all, permeability of the sisal mat was much higher than that of the PP non-woven core, often used as infiltration medium. A hybrid reinforcement with a sisal mid-plane layer also yielded higher permeability than that with a PP layer. In addition, most mechanical properties of the hybrid



glass/sisal were slightly higher or similar to those of the hybrid glass/PP, and the substitution of PP for sisal carries the extra benefit of promoting the use of a vegetable fiber instead of a synthetic polymer. Therefore, the sisal mat proved a viable alternative in engineering applications as a substitute for commercial flow media, leading the group to deposit a patent on it [16].

Conclusions

In this invited paper, whose content was compiled from a recent publication [17], a few applications of different vegetable fibers were presented, namely, oil sorption and infiltration (flow) medium for RTM molded composites. A variety of positive characteristics of vegetable fibers along with stricter demands of legislative authorities are expected to promote their wider use, including more demanding and rewarding applications such as those presented here.

Acknowledgements

The author would like to thank CNPq, CAPES and FAPERGS for the financial support, and the following collaborators: Ademir Zattera, Álvaro Moraes, Clarissa Angrizani, Constantina Lekakou, Felipe Luz, Laís Silva, Maria Rita Sierakowski, Marta Drummond, Paulo Silva, Teoli Annunciado, Thais Sydenstricker, Thiago Bonetti, Thiago Goss, Tiago Schmidt and Valcineide Tanobe.

References

1. D.N. Saheb; J.P. Jog *Adv. Polym. Tech.* 1999, 18, 351.
2. A.K. Mohanty; M. Misra; G. Hinrichsen *Macromol. Mater. Eng.* 2000, 276, 1.
3. A. Bartl; B. Mihalyi; I. Marini *Chem. Biochem. Eng. Q.* 2004, 18, 21.
4. K.G. Satyanarayana; J.L. Guilmaraes; F. Wypych *Compos. Part. A-Appl. S.* 2007, 38, 1694.
5. V.O.A. Tanobe; T.H.D. Sydenstricker; M. Munaro; S.C. Amico *Polym. Test.* 2005, 24, 474.
6. F.F. Luz; S.C. Amico in *Anais do 7º Congresso de Engenharia de Áudio da AES Brasil*, São Paulo, 2009, 102.
7. A.K. Bledzki; J. Gassan *Progr. Polym. Sci.* 1999, 24, 221.
8. A.L. Leao; R.M.F. Teixeira; P.C. Ferrão *Mol. Cryst. Liq. Cryst.* 2008, 484, 523.
9. T.R. Annunciado; T.H.D. Sydenstricker; S. C. Amico *Mar. Pollut. Bull.* 2005, 50, 1340.
10. T.R. Annunciado; T.H.D. Sydenstricker; S. C. Amico; F.W.L. Silva *Petro e Química.* 2005, 278, 71.
11. T.R. Annunciado; T.H.D. Sydenstricker; T. F. Bonetti; S. C. Amico *Ciência Hoje.* 2006, 39, 72.
12. E. Witka-Jezewska; J. Hupka; P. Pieniazek *Spill Science & Technology Bulletin.* 2003, 8, 561.
13. T.R. Annunciado; T.H.D. Sydenstricker; S.C. Amico; n° 015050000567, 2005.
14. T.M. Schmidt; T.M. Goss; S.C. Amico; C. Lekakou *J. Reinf. Plast. Comp.* 2009, 28, 2839.
15. S.C. Amico; T.H.D. Sydenstricker; P.S.C.P. Silva *Metals Materials and Processes.* 2005, 17, 233.
16. S.C. Amico; T.M. Goss; T. M. Schmidt; n° 0000220904125880, 2009.
17. S.C. Amico *Matéria* 2010, 15, 386.