Biodegradable foams made of cassava starch and fibers: Influence in the mechanical properties

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Written for presentation at the
2006 CIGR Section VI International Symposium on
FUTURE OF FOOD ENGINEERING
Warsaw, Poland
26-28 April 2006

Abstract. *The use of cassava or wheat fibers as reinforcing additives in starch cassava foams has showed efficient results at low concentration. Foam made with 1% of cassava fiber shown higher compression strength; increasing the percentual quantity decreases the compression resistance. Foam made with wheat fiber shown the lower result in 2%. The fiber type had no statistical significance in strength, flexibility and density foam, but only the fiber quantity presented significance. At the SEM microscopy analysis, intrinsic adhesion of the fiber-matrix interface was observed in those samples with 1% of fiber. Foams with 1% fiber addition presented more regular structures and it was observed minor internal opened cells in the foam with cassava fiber compared to the wheat fiber foam. Both fibers presented limited dimensions to improve the reinforcement of the open cell structure of the starch foams up to 1%.*

Keywords. Mechanical properties, fibers, biodegradable foams

Introduction

Currently, the most part of raw material used for packaging are from petroleum-based, such as polyethylene and polystyrene. Disposal of used packaging products has been an ecological problem owing to their non-degrability. The utilization of biodegradable packaging materials has the greatest potential in countries where landfill is the main waste management tool (Petersen, Nielsen, Betelsen, Lawter, Olsen, Nilsson, & Mortensen 1999). The use of starch is an alternative, as renewable source, of raw material of biodegradable polymer with low cost (Lörcks, 1998). The starch can be used as packaging due to the formation of a rigid structure of open cell, constituting foam, by a process consisting of swelling, gelatinization and network building by heating thermo pressing (Hofmann, Linke, Tsiapouris, & Ziems, 1998). The foam has a dense outer skin and a less dense interior with large, mostly open cells (Shogren, Lawton, Doanne, & Tiefenbacher, 1998). The foam can be many shapes and used by several application, since food packaging until automotive industry (Mohanty, Misra,& Drzal, 2002).

According to Rosas et al (2004) a natural polymer exposed to thermal process effects can cause generation of fragments and been more easily hydrolyzed in biodegradation.

Although be commercially availed to replace the EPS, the starch foam are brittle and sensitive to water (Fang & Hanna, 2001). To improve the mechanical properties of starch foams, natural fibers can be used. Fibers have many useful purposes but the technological application as reinforcement in polymer matrix took place in recent years. The interest in the use of natural fiber reinforced polymer is growing rapidly due to the high performance in mechanical properties, significant processing advantages, and low cost with low density. Vegetable fiber is a composite consisting mainly of cellulose fibrils embedded in lignin matrix. The fibers characteristics depend on the properties of the individual constituents, the fibril structure and the lamellae matrix, which consists of hemicelluloses, lignin and pectin. Chemically, the vegetables fibers comprise cellulose, hemicelluloses, lignin, pectin and a small amount of waxes and fat. The mechanical properties of a fiber reinforced polymer composite depend on many factors like fiber-matrix adhesion, volume fraction of fiber, fiber aspect ratio (l/d) and orientation of the fiber (Joseph, Mattoso, Toledo, Thomas, Carvalho, Pothen, Kala, & James 2000).

This study consists on the preparation of foams with cassava starch and wheat fiber or cassava fiber as additives. The foams were characterized by physical methods of compression resistance, flexibility, density and SEM in order to compare the effects of fibers addition with different dimension and quantities.

Experimental

Materials and Methods

Cassava starch and cassava fiber (2 mm length) were supplied by Fadel Ind. e Com. Ltda, SP, Brazil. Oxiteno supplied additive polyethylene glycol PEG 300 USP. Wheat fiber Vitacell 200 (250 μm length) was supplied by Clariant. Mixer from Fisatom. Was used a laboratory baking machine from Santos Dumont S.A. (SP-Brazil). The engine consists of a double steel mould, horizontally placed, heated by internal resistances (200ºC) and dimensions were 125 mm long, 250 mm wide, 165 mm wide and 2 mm plate separation. .

Preparation of foams

Firstly is necessary to prepare a gel with part of starch thermally modified in water around 70-80 ^{o}C for 45 min. After cooled, this gel was mixed with solid starch powdered, additive and fiber. All the dough components was vigorously mixed until completely homogenous mixture. The dough was applied on the lower surface of the mold before quickly closing the lid. Baking time was only one minute. The resulting final starch-foam is low moisture content, as typically contained 3-4% moisture. Due to this low moisture content, the rectangular foam has a dry aspect and brittleness. Flexibility was improved after 48 hour, 75% RH and 25 ^{o}C at the ambient of the laboratory.

Physical tests

Foams were equilibrated at 75% relative humidity (R.H.) at 23 ^oC for 48 hour prior to mechanical testing. Foams maintained at constant relative humidity were placed in zip lock polyethylene bags and then removed one by one for testing.

Foam density: was made weighting a measured area of the foam sheet. The ratio weight (g)/ a(mm).area (mm^2), where a is a constant thickness of the molded foam, is considered the density of the sample.

Compression resistance and flexibility: Compression testing was performed using a Texture analyzer TA.XT2i from Stable Micro Systems equipped with a cylindrical probe (36 mm diameter) and a cylindrical base (63 mm). The probe was lowered into a sample of the foam, in constant velocity of 1mm/s, when in contact with the surface, the strength is recorded until the deformation of 15 mm, also if occurs the rupture of the sample. A graph was generated where the maximum force was the compression resistance and the deformation was considered the flexibility of the sample. Three rectangular samples (40x100 mm) were normally tested.

Scanning electron microscopy: scanning electron microscopy (SEM) of starch-based foam was performed with a PHILIPS XL30 electron microscope. The cut samples were glued on aluminium stubs and then gold-coated with a BAL-TEC SCD005 sputter coater. All samples were examined using an accelerating voltage of 20kv.

Results and discussion

Figure 1 and 2 shows the compression resistance and flexibility results for foam prepared with 0, 1, 2 and 3% of cassava and wheat fiber, respectively.

The addition of fiber in the formulation showed that the foam with 1% of cassava fiber has the higher compression resistance of the group. Up to 1% the resistance decrease. Foam made with wheat shown the same compression resistance with 1 and 3%, and lower result was observed with 2%.

Fiber addition improves the flexibility foam until 2%, than the flexibility decreases. It happened with both fiber sources. The results indicated that the limit to improve the flexibility of the cassava starch is 2% of cassava or wheat fiber.

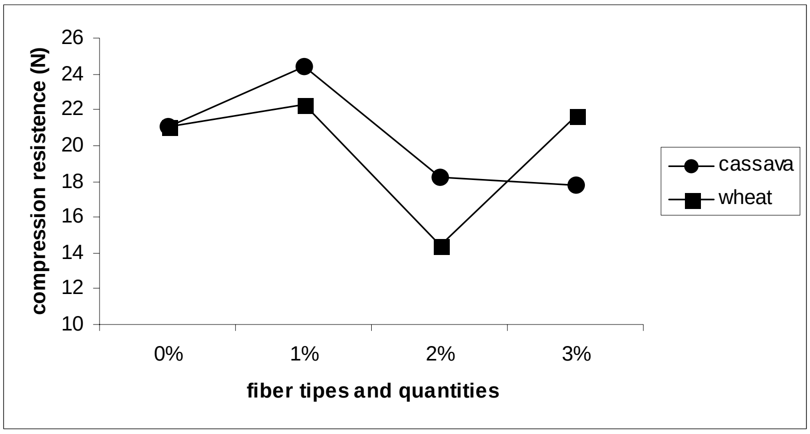


Figure 1. Compression resistance foam with no fiber comparing with foam added 1, 2 and 3% of cassava and wheat fiber.

Lawton, Shogren and Tiefenbacher (2004) added aspen fiber to baked cornstarch foams to improve its mechanical properties. Foam trays were made with fiber content of the batter ranging from 2.5 to 45%. The strength of the foam increased as fiber content of the trays increased, until fiber content reached about 15%. Trays containing between 15 and 30% of fiber had no significant difference in tray strength. Trays containing more than 30% fiber had lower tray strength, probably due to the lack of uniformity of fiber distribution at higher fiber content.

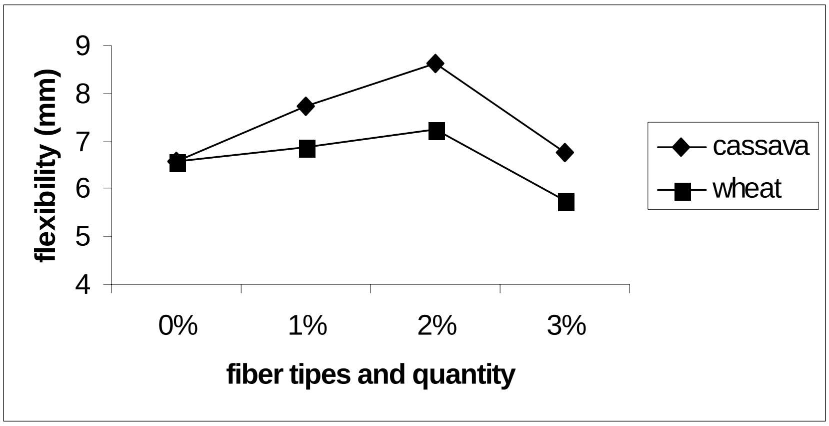


Figure 2. Flexibility foam with no fiber compared with foam added with 1, 2 and 3% of cassava and wheat fiber.

Zaini, Fuad, and Thomas (1996) studied the effect of size and fiber content on the mechanical properties of polypropylene and reported that all size of fiber showed a similar trend of deckling mechanical properties with increasing fiber concentration and composites with larger sized fiber showed higher modulus, tensile and impact strength.

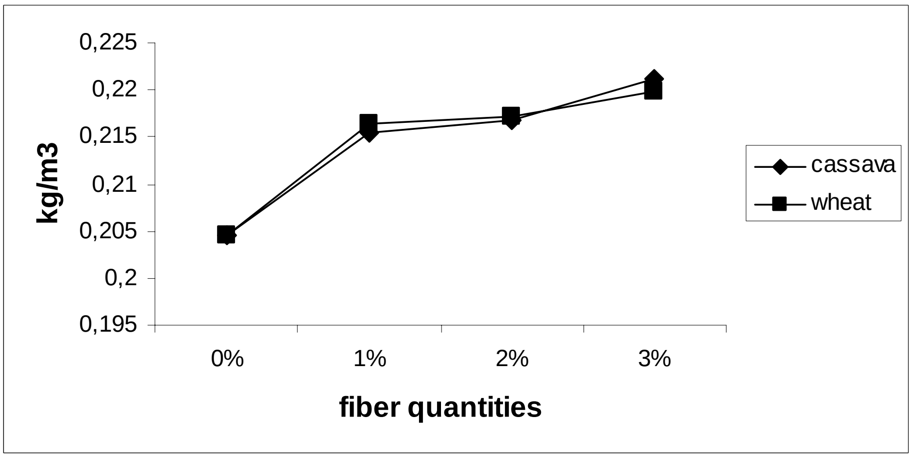
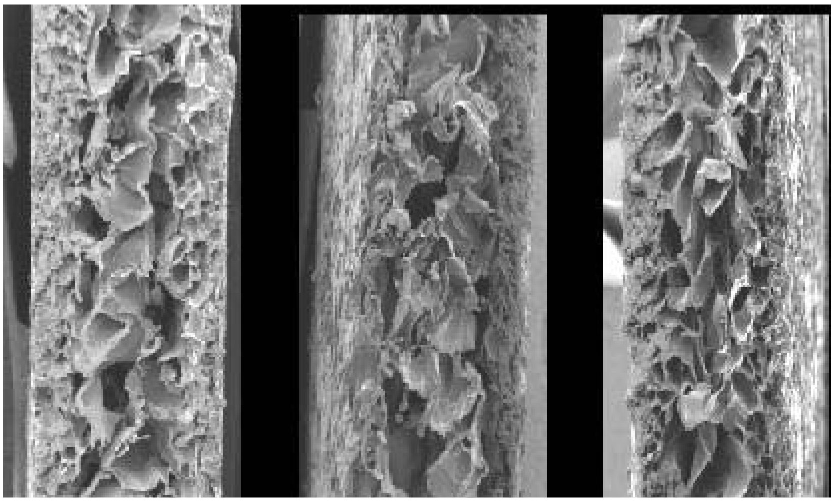


Figure 3. Density foam with no fiber comparing with foam added 1, 2 and 3% of cassava and wheat fiber.

Wollerdorfer and Bader (1998) studied the influence of fibers in mechanical properties of biodegradable polymers. During the extrusion, injection molding shortened the fiber and these short fibers provide a considerable reinforcing effect.

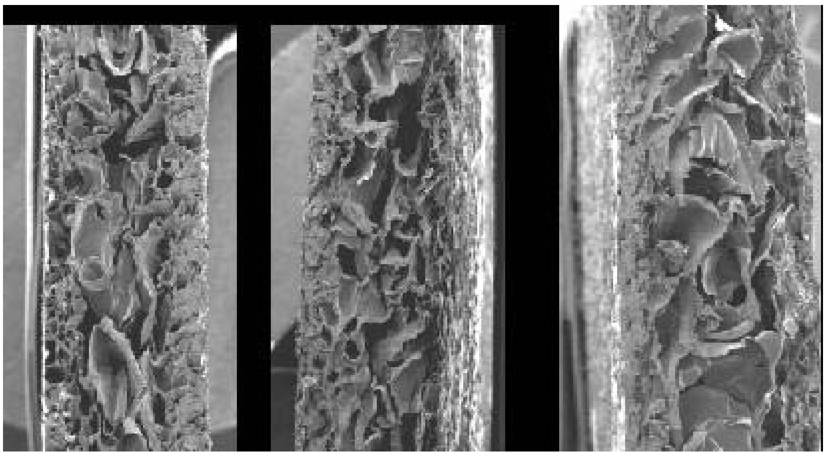
The Figure 3 shows results of the density increasing of foam made with cassava fiber (0, 1, 2 and 3%) and wheat fiber (0, 1, 2 and 3%).

Higher quantity results in foams with higher density but lower flexibility. Glenn, Orts, and Nobes (2004) made starch foam with addition of softwood fiber with 5-7 mm long. The study showed that softwood fiber improved the flexibility and other functional properties of the baked foams, and reduced foam density. Its showed that short fibers as those fibers used in the present study work as reinforcing material only at low concentration.



(A) (B) (C)

Figure 4. Starch foam with different content of wheat fiber: A= 1% , B= 2% and C=3%



(D) (E) (F)

Figure 4. Starch foam with different content of cassava fiber: D= 1% , E= 2% and F=3%

Figure 4 and 5 show the SEM micrographs of foam with wheat fiber and cassava fiber addition respectively. Foam with 2% wheat fiber presented an irregular structure, what decrease the compression resistance. Foams with 1% fiber addition presented more regular structure and foam with cassava fiber presented less internal open cells compared with wheat fiber.

Conclusions

In conclusion, the starch foams with short or powdered fibers (cassava or wheat fibers) as reinforcing additives has efficient results at low concentration. Foam made with lower quantity of cassava fiber shown higher resistance that decrease with the quantity increase. Foam made with wheat shown the same compression resistance with 1 and 3%, and lower result in 2%. At the SEM microscopy's, intrinsic adhesion of the fiber-matrix interface was observed. Foams with 1% fiber addition presented more regular structure and foam with cassava fiber presented less internal open cells compared with wheat fiber. However the mechanical properties changes occur probably because the fibers are not as long as sufficient to reinforce the open cell structure of the starch foam.

Aknowledgment

The authors are grateful to the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for financial support.

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