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ORIGINAL PAPER

Influence of Fibers on the Mechanical Properties of Cassava Starch Foams

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Abstract The utilization of renewable resources in packaging can provide solutions to ecological problems such as waste quantity. Agricultural resources are alternative raw materials, among which there is starch, a natural polysaccharide that can be used to form resistant foam under wet and warm conditions. The starch foam is obtained by thermo pressing process where cassava starch, water and additives are processed to form a rigid structure by swelling, gelatinization and network formation. Natural fibers can be used to improve the mechanical properties of starch foams. In this project was investigated the influence of the addition of fibers in the levels of 1, 2 and 3% of cassava (short fiber) and 1, 2 and 3% of wheat fiber (powered fiber) in the starch dough. The foams were characterized by physical methods of strength, flexibility, density and by Scanning Electron Microscopy (SEM). The increase in fibers quantity has resulted in foams with higher density and less flexibility, whatever the fiber type. Most fibers quantity did not improve the foam strength. Foam made with 1% of cassava fiber showed higher compression strength; by increasing the percentage quantity there was a decrease on the compression resistance. Foam made with wheat fiber presented a lower result in 2%. The fiber type had no statistical significance in strength, flexibility and density foam. Only the fiber quantity was significant. The results showed that both fibers presented limited dimensions to improve the reinforcement of the starch foams up to 1%.

Keywords Starch foam · Natural fiber · Biodegradable packaging · Cassava starch

Introduction

Currently most part of raw material used for packaging is 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 greater potential in countries where landfill is the main waste management tool [1]. The starch is an alternative of raw material to packaging because it is a biodegradable polymer with low cost from a renewable source [2]. According to Rosas et al. [3] a natural polymer exposed to thermal process effects can cause generation of fragments and is more easily hydrolyzed in biodegradation.

The starch is able to form foam by a process consisting of swelling, gelatinization and network building by heating thermo pressing [4]. The patent US 6.146.573 [5] describes the method to produce disposable thin-walled molded articles such as cups, plates, fast-food packages and trays that are produced by applying a starch-based baking composition onto the lower molded part of a multi-part and by baking. The foam has a dense outer skin and a less dense interior with large, mostly open cells [6]. It can be

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molded in many shapes and used for several applications, since food packaging until automotive industry [7].

Starch foam has been prepared to penetrate the market that used to be entirely dominated by expanded polystyrene foam packing [6]. Starch alone, however, is rather brittle and sensitive to water, thus further treatments are necessary to obtain the strength, flexibility and water resistance necessary for commercial applications of foams [8, 9]. Water resistance can be improved by coating with polyester [5, 6] and to improve the mechanical properties of starch foams, natural fibers may be used. Fibers have many useful purposes but the technological application as a way of reinforcing the polymer matrix has taken place in recent years. The interest in the use of natural fiber as a reinforced polymer is growing rapidly due to its high performance in mechanical properties, significant processing advantages, and low cost with low density. The mechanical properties of a fiber as a reinforced polymer composite depend on many factors, like fiber-matrix adhesion, volume fraction of fiber, fiber aspect ratio (l/d) and fiber orientation [10]. Matsui et al. [11] added long fibers in a material that is similar to cardboard made with cassava bagasse and the fibers improved their mechanical properties and the water resistance of material, too. Curvelo et al. [12] used cellulosic fiber from *Eucalyptus urograndis* pulp as reinforcement for thermoplastic starch and the composite shows an increase of 100% in tensile strength and more than 50% in modulus with respect to non-reinforced thermoplastic starch. Lawton et al. [13] made starch foam with 2.5–45% of fiber content and showed that the strength of the foam increased as fiber content of the foam increased, until fiber content reached about 15%.

According to Keller et al. [14], fiber incorporation into natural polymer influences the degradation. The fiber degrades faster than the polymeric matrix due to an effective increase in the surface accessible to microorganisms. Consequently, the fiber content accelerates the material disintegration.

This study consists of the preparation of cassava starch foams with addition of wheat fiber (powered fiber) or cassava fiber (short fiber) as reinforcement. The foams were characterized by physical properties of strength, flexibility, density and scanning electronic microscopy was employed in order to compare the effects of different fibers in dimension and quantity.

Experiment

Materials

Cassava starch and cassava fiber (2 mm length) were supplied by Fadel Ind. e Com. Ltda, SP, Brazil. Wheat fiber Vitacell 200 (250 (μm length) was supplied by Clariant. To mix the dough was used a mixer from Fisatom and to make the foam was used a laboratory baking machine from Santos Dumont S.A. (SP-Brazil). This engine consists of a double steel mould, horizontally placed, heated by internal resistances (200°C), which dimensions were 125 mm long, 250 mm wide, 165 mm wide and 2 mm plate separation.

Methods

Preparation of foams

The dough components were starch, fiber and water at a proportion of about 100% by weight, relative to the solids component. Initially it was necessary to make a gel by heating 1.5% of the total starch in water at 70°C. Then all baking composition (gel, starch and fiber) was vigorously mixed until completely homogenous mixture. A portion of this dough was applied on the lower surface of the hot mold (200°C) before quickly closing the lid. Heating leads to the formation of steam, which has a great effect on the dough flow. Next the steam escapes through steam exhaust vents and the heating promotes the dough solidification and a porous structure [4]. This process scheme is shown in Fig. 1. It took just one minute of baking time. The foam obtained has only 3–4% of moisture content and after 48 h stored at 75% relative humidity (RH) this data was about 11%.

Physical tests

Lawton et al. [13] studied the mechanical properties of foams stored at different relative humidity and concluded that mechanical properties of foams (strength, flexibility) improved between 50% and 80% RH. Foams were equilibrated at an average value of relative humidity of 75% (R.H.) and 23°C for the 48-h period prior to mechanical testing.

Foam density: It was calculated by weight/volume of foam [6].

Strength and flexibility: were performed using a texture analyzer TA.XT2i from Stable Micro Systems equipped with a cylindrical probe (36 mm diameter) and an annular base (D = 63 mm inside diameter). The probe was lowered

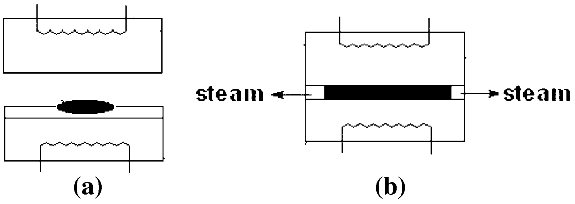


Fig. 1 Model of the thermo pressing process, according to T. Hofmann et al. [4]

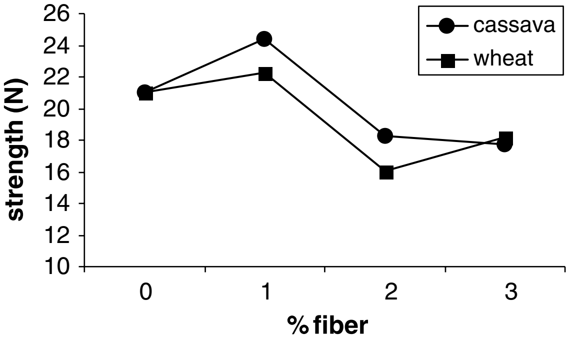


Fig. 2 Strength foam with no fiber comparing with foam added 1, 2 and 3% of cassava and wheat fiber

into the surface of the foam, in constant velocity of 1 mm/s. When in contact with the surface the compression strength is recorded in deformation range of 0–15 mm, or until the point when the sample breaks. A graphic force versus distance was generated when the maximum force (F_m) was the compression strength. The deformation caused until F_m is L_m and one considered the sample flexibility in mm [6].

Scanning electron microscopy (*SEM*) was performed with a PHILIPS XL30 electron microscope. Foam samples were mounted on aluminium stubs and coated with gold (BAL-TEC SCD005 sputter coater). All samples were examined using an accelerating voltage of 20 kv.

All results were analyzed with Analysis Variance Multifactor ANOVA, with the Tukey HDS method and 95% of confidence level.

Results and discussion

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

According to statistical analysis (ANOVA), only fiber quantities have statistical significance ($P < 0.05$) in foam strength. The fiber type did not show statistical significance ($P > 0.05$). Foam with 1% of cassava fiber has the higher strength value. The addition of up to 1% of cassava fiber decreases the compression strength. Foam made with 1 and 3% of wheat fiber showed the same strength values, and the lowest result was observed for 2% content.

Fiber addition improves the flexibility of foam until 2%, then the flexibility decreases. It happened with fiber of both sources. The results indicated that the limit to improve the flexibility of the cassava starch foam was 2% of cassava or wheat fiber. According to ANOVA, only fiber quantities presented statistical significance ($P < 0.05$) in the foam flexibility.

Lawton, Shogren and Tiefenbacher [9] added aspen fiber to baked cornstarch foams to improve their mechanical properties. Foam trays were made with fiber content of the batter ranging from 2.5 to 45%. The foam strength increased with the increase of fiber content on the trays, until fiber content reached around 15%. Trays containing between 15 and 30% of fiber had no significant difference in the foam strength. Trays containing more than 30% of fiber content had the lowest foam strength, probably due to the lack of uniformity in the fiber distribution of higher content.

Zaini et al. [15] have studied the effect of size and fiber content on the mechanical properties of polypropylene and reported that all sizes of fiber showed a similar trend of decking mechanical properties. When increasing fiber concentration and using larger fiber, one observed higher modulus, tensile and impact strength of the composites.

Wollerdorfer and Bader [16] studied the influence of fibers in mechanical properties of biodegradable polymers. During the extrusion, injection molding shortened the fiber and these short fibers provided a considerable reinforcing effect.

Figure 4 shows the foam density increasing with cassava fiber (0, 1, 2 and 3%) or wheat fiber (0, 1, 2 and 3%) content. According to ANOVA, only the fiber quantity presents statistical significance ($P < 0.05$) in foam density. The highest quantity of fiber results in foams with higher density but lower flexibility. Glenn et al. [17] made starch foam with addition of softwood fiber with 5–7 mm long. The study evidenced that softwood fiber improves the flexibility and other functional properties of the baked foams, reducing the foam density. It was demonstrated that short fibers, as the ones used in the present study, acts as reinforcing material only at a low concentration level.

Figures 5 and 6 show the SEM micrographs of foam with wheat and cassava fiber respectively. Foam with 2% or 3% of wheat (5b and c) or cassava fiber (6b and c) presented irregular structures. It was observed that near the surface foam the fiber is accumulated. This non-homogeneity probably causes a decrease of the compression strength. Foams with 1% fiber presented more regular structures associated to higher homogeneity and compression

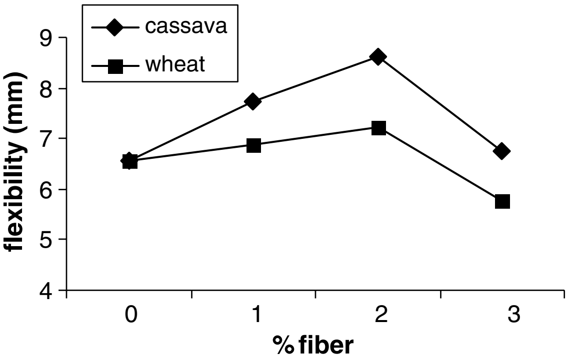


Fig. 3 Flexibility foam with no fiber compared with foam added with 1, 2 and 3% of cassava and wheat fiber

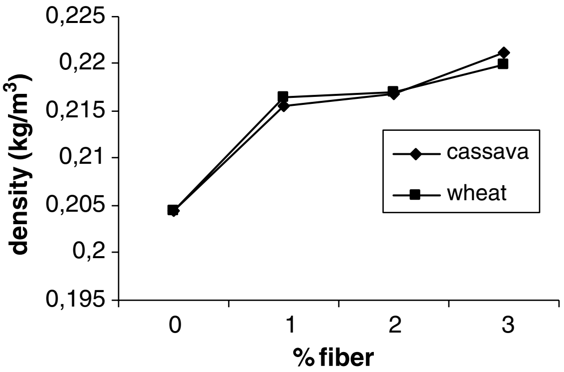


Fig. 4 Density foam with no fiber comparing with foam added 1, 2 and 3% of cassava and wheat fiber

resistance. Foam with cassava fiber 1% (6a) presented minor internal opened cells compared to wheat fiber foam 1% (5a), which contributed to better compression resistance of the foam.

Conclusion

In conclusion, short or powdered fibers (cassava or wheat fibers) as reinforcing additives in starch cassava foams have efficient results at low concentration. Foam made with 1% of cassava fiber presented higher compression strength; by increasing the percentage quantity there was a decrease of the compression resistance. Foam made with wheat fiber showed a lower result in 2%. The fiber type had no statistical significance in strength, flexibility and density foam. 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 wheat fiber foam. Both fibers presented limited dimensions to improve the reinforcement of the open cell structure of the starch foams up to 1%.

Fig. 5 Starch foam with different content of wheat fiber: **a**=1%, **b**=2% and **c**=3%

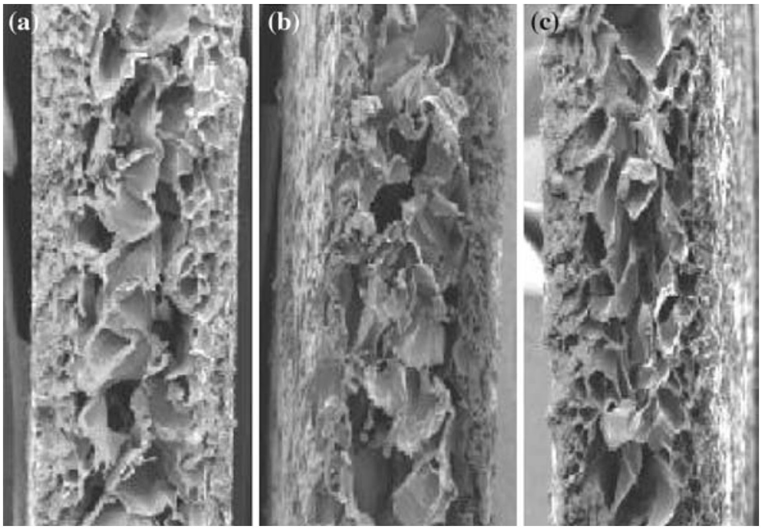
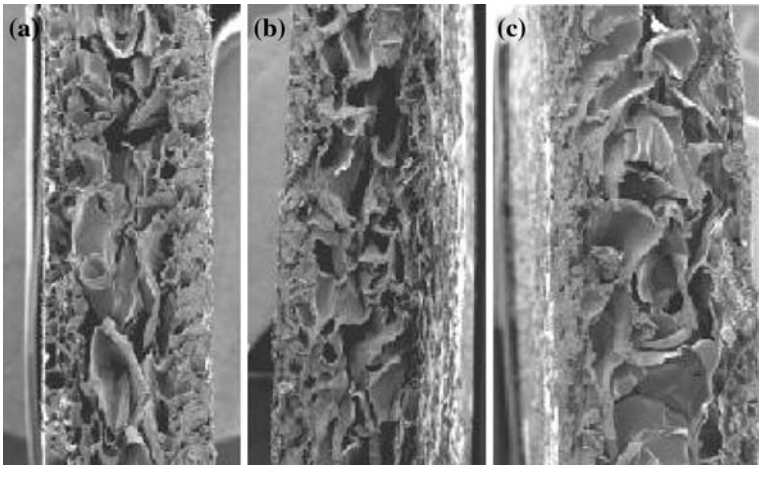


Fig. 6 Starch foam with different content of cassava fiber: **a**=1%, **b**=2% and **c**=3%



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