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Research Article

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Influences of composite adhesive components on the performance of bagasse cushion pads

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ABSTRACT

Today, various packaging materials can convenient our life, but also greatly damage the environment. In order to minimize the harm to the environment, plant fiber cushion materials become a new research focus. In this experiment, different formulations of adhesives were used to prepare the bagasse cushioning pads. And their properties were evaluated by the sensory evaluation, density, compression property and elasticity aspects. Select the most suitable formula of making the cushion material. The results showed that when the formula is bagasse: starch: PVA: glycerol: ammonium bicarbonate: sodium bicarbonate: water = 5:5:3:3:3:2:79, the material can fully foam and the bubble distributed evenly without internal collapse phenomenon. It also has an even structure, good elasticity and good compressive strength. So the formula is suitable for a cushion material.

Keywords: bagasse, adhesive, starch, cushion

INTRODUCTION

Widely used in the packaging system, cushioning packaging can protect the goods from damage caused by shock and vibration during circulation. However, the commonly used cushioning packaging materials are non-degradable plastic products which are harmful to the environment. [1] The development of packaging materials and auxiliary packaging materials which are environmental friendly, healthy, material and energy-saving has become a hot topic of research as environmental pollution and ecological imbalance are increasingly serious nowadays.[2]

Paper cushioning packaging is a type of fully recyclable or degradable cushioning packaging and it is more environmental friendly. The experience of recent years shows that corrugated cardboard as cushioning packaging material is too resilient yet not rigid enough, while the honeycomb cardboard is the other way around— too rigid yet not resilient enough. Besides, the hexagonal honeycomb cardboard currently used is not suitable for high-speed automatic production. The pulp molding product as cushioning packaging is fit for commodities of various shapes, while its pressure-bearing capacity is insufficient. [3]

V In recent years, a new type of packaging material— plant fiber foam product and it's forming technology are being developed. This new foam cushioning product is made from plant fibers (straw and marc, etc) and starch additives. With excellent cushioning performance, this new material is characterized by environmental friendliness, simple production process, low cost and wide sources of raw materials, etc. It can be used to make lined shockproof packaging as well as filler particles replacing EPS and the effect is roughly equal with that of EPS products.[4] Compared with foam plastics, the production of the fiber products is more simple and less resource-consuming. [5]

Properties and features of the plant fiber foam products: 1) Low overall cost. 2) The anti-static and anti-corrosion performance is better than that of EPS foam materials, and the shock-proof performance is superior to that of pulp molding products; 3) as to the force measurement, the shock absorption performance precedes that of EPS foam materials. Multiple auxiliary additives like reinforcing agent, softener, water-proof agent, oil-proof agent and anti-flammability agent can be added in accordance with different package objects to achieve multiple functions. 4) They can be used to fabricate packaging cushion pads and fillers for large household appliances and electronic products, filling the gap that the pulp molding products cannot be used to make such packaging products now.[6]

The technique of the production of plant fiber foam products abroad mainly focus on no chemical foaming agent. At present, the developed countries have made remarkable achievements in this technology: Natural starch and chemical company in the United States has developed the biodegradable cushioning packaging material—ECO-Foam using renewable corn starch as raw material. It is suitable for light goods to replace foam plastics like polystyrene and polyurethane. [7] PSP Company in Bremen, Germany develops a new technique for foam paper production employing waste book, newspapers and flour as raw materials.[8] Industrial Technology Research Institute of Japan develops the technology of dry pulp foaming using waste paper as raw material; The products of Sony corporation TsutomuNog are used as cushioning materials for audio equipment.[9]

Several colleges in China are engaged in the research and development of this technology and have achieved initial results. The technique in China mainly focuses on the use of additive-chemical foaming agent. The new double-foamed plant fiber foam packaging material jointly developed by Wuhan Far-east Green World Group and Tongshan Institute of Science and Industrial Technology uses modified starch and high-fiber fillers as raw material. It used low temperature foaming granulation and high-temperature foaming forming technology. The degradation rate can reach 78.4%.

Bagasse, waste of the processing of sugarcanes, can be decomposed naturally. Its tissue contains vascular bundles of high strength as well as tough, smooth and compactly packed fiber cells.[10] Besides, it has a certain degree of elasticity, resilience and good cushioning function. Therefore, the packaging products made from bagasse have the advantages of environmental friendliness, light weight, good strength, and adhesive-saving, etc.[11] In this work, bagasse is used as raw material in the research and non-toxic and inexpensive corn starch and water-soluble polyvinyl alcohol (PVA) are selected as composite adhesive for the preparation of bagasse plant fiber foam cushioning pad. And the influences of different composite adhesive components on the performance of bagasse cushion pads are studied. Some properties of bagasse cushions in practical application such as the appearance of the product, resilience, compressive strength and density, etc, are tested in order to optimize the formula. It is of practical significance in the development of new plant fiber cushions in the future.

EXPERIMENTAL SECTION

2.1 Materials

Bagasse (commercially available), corn starch (commercially available, Shanghai Heyu Trading Co., Ltd), polyvinyl alcohol (1750), ammonium bicarbonate, sodium bicarbonate, and glycerol purchased from Sinopharm Chemical Reagent Co., Ltd. Purity is analytical reagent.

2.2 Preparation of the cushion

2.2.1 Preprocessing of the bagasse

It includes the pulverization of bagasses and pretreatment of fibers. In order to remove the sugar, the bagasse should be soaked in enough water which must be periodically changed until the sugar is completely removed. Pulverize the bagasse in a pulverizer and spread it on a stray after cleaning. Put it into a drying oven and dry at 80℃ until it reaches constant weight. During the drying process, stir it at the intervals of 1 to 2 hours in case of agglomeration. Take out the bagasse fibers after drying out and bag them for future use.

2.2.2 Preparation of the composite adhesive

Use an electronic balance and weigh precisely 3.0 g of PVA. Pour it into a flask and add 47.0g of pure water. Stir over water bath at 90℃until the PVA is completely dissolved. Disperse the pre-weighed starch (4.0g, 5.0g, 6.0g, 7.0g, 8.0g) into the pure water according to the formula shown in Table 1. Stir over water bath and heat until it is fully gelatinized. Mix the gelatinized starch and PVA solution to obtain the composite adhesive needed.

Table 1 Formula of the composite adhesives

Group	Starch /g	Water /g	PVA /g
1	4.0	43.0	3.0
2	5.0	42.0	3.0
3	6.0	41.0	3.0
4	7.0	40.0	3.0
5	8.0	39.0	3.0

2.2.3 Preparation of the foaming agent
Foaming technology is the key to the preparation of plant fiber foam products. It decides the size and distribution of the diameter of foam holes and their micro structural features, and then affects the mechanical properties of the products. Ammonium bicarbonate and sodium bicarbonate are used as composite foaming agent in this experiment. Weigh precisely 3.0g of ammonium bicarbonate and 2.0g of sodium bicarbonate and then mix them to get the foaming agent needed.[12]

2.2.4 Preparation of the bagasse cushioning material
Weigh precisely 5.0g of bagasse fibers and 37.0g of pure water, and then fully stir them to make cellulose protoplasm. Add 3.0g of glycerol, prepared composite adhesive and foaming agent, and then pour it into a self-made mold after sufficient stirring. Put it into a drying oven heating up for 20 minutes at 80℃. Then raise the temperature to 100℃ and dry for 3 hours to prepare the cushion pad sample needed.

Five different groups of experiments of adhesive components are numbered 1 to 5, each group containing 3 parallel experiments.

2.3 Performance of the bagasse cushion pads
2.3.1 Sensory evaluation of the bagasse cushion pads
The sense is a very important indicator for cushioning materials. It enables people to know whether the cushioning material can be accepted by the senses of men and whether the appearance of the products will be affected. It is a decisive indicator for the marketization of the product. The experiment evaluates its appearance from the three aspects: the collapse of the material, the uniformity of the foaming and uniformity of the structure.

2.3.2 Density of the bagasse cushion pads
Density is one main physical property and the most direct way to evaluate the performance of foam cushioning materials of the same kind. Weighing method is adopted in this experiment to measure the density of the bagasse cushioning pads. Cut the dry bagasse cushion pads in 8 different positons into samples of the size of 2.0cm×2.0cm×1.5cm. Weigh the samples precisely and work out the density, and then take the average value as the density of the formula. 3 parallel experiments are done for each formula.[13] Calculate the data according to equation (1):

$$\rho = m/(l \times b \times h) \quad (1)$$

In the equation: ρ_density of the sample, g/cm^3; m_mass of the sample, g; l_length of the sample, cm; b_width of the sample, cm; h_height of the sample, cm

2.3.3 Compressive strength of the bagasse cushion pads
The compressive strength reflects the performance of the cushioning materials. Cut 5 samples of the size of 2.0cm×2.0cm×1.5cm from the samples of each group. Test the compressive strength with compression apparatus. Use the average value of the 5 experiments as the compressive strength of the formula.

2.3.4 Resilience of the bagasse cushion pads
Resilience of the bagasse cushion pads is described by its rebound rate.[14] Put the sample (2.0cm×2.0cm×1.5cm) on the computer control compression apparatus for 15 minutes, compressing it into the height of 0.5cm. Record the force applied on the equipment and the height of the experiment after 24 hours. In the end, work out the rebound rate of each sample according to formula (2). If the bound rate is k, the thickness of the compressed material is T_0, and the thickness 24 hours later is T_1, then:

$$K = (T_1 - T_0)/T_0 \times 100\% \quad (2)$$

RESULTS AND DISCUSSION

3.1 The influences of adhesive components on the sensory evaluation of the bagasse cushion pads

Table 2 Influence of Adhesive formula on the senses of the bagasse cushion pads

Group	Collapse of the pads	Uniformity of the foaming	Molding effect
1	no	relatively uniform	can be molded; relatively uniform structure
2	no	uniform	good molding effect uniform structure
3	slight collapse	partially non-uniform	can be molded
4	collapse	non-uniform	relatively bad molding effect
5	serious collapse	non-uniform	bad molding effect

Table 2 is a study on the influences of adhesive formula on the senses for the bagasse cushion pads. Samples are analyzed from the collapse of the pads, uniformity of the foaming and molding effect.

As can be seen from Table 2, the collapse of the foam cushion pads, uniformity of the foaming and the molding effect are associated with the starch content in the cushion pads. When the starch content is low, the foaming of the foam cushion pad becomes more uniform with the increase of starch content, so does the cushion pad. However, when the starch content increases to 6%, foam holes in the foam cushion pad starts to become non-uniform. And then partial collapse and loose structure will occur with the increase of the starch content. The foam cushion prepared according to formula 2 is suitable as cushioning material because of its uniform foaming.

The formation and distribution of the holes in the cushion depends on the gas evolution and the speed of the gas dissipation. When the starch content is low, the viscosity of the material system is low as well. It is easy for the gas decomposed by the foaming agent to diffuse in the system and its driving force on the fillers is relatively even, thus the distribution of the components within the cushion pad material system is uniform. The foaming is uniform as well. But as the starch content increases, the system gradually thickens and the mobility gets worse, which will affect the foaming. The driving force on the fillers turns uneven, though the foaming agent content stays the same. It is difficult for the gas to diffuse, thus causing the accumulation of gas and the nonuniformity of foaming. Perforation will then arise and the holes of part of the cushion pad become large, resulting in the overall nonuniform distribution of the cushion pad.

3.2 The influences of adhesive components on the material density

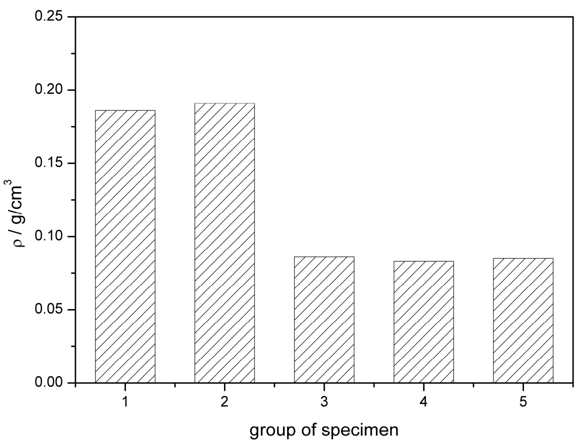

Fig.1 Density of cushioning pads prepared from different formulations

Figure 1 shows the different densities of the cushion pads prepared in accordance with different formulas. As Figure 1 shows, when the content of the starch is low, the density of the cushion increases with the enlargement of the starch content and then decreases. When the starch content is more than 6%, the density does not change with the increase of the starch content. In the material system, when the total mass and the content of other raw materials remain constant, an increase of the starch content means reduction of the amount of water added, leading to the increase of the density. This is mainly due to two reasons: (1) the increases of starch content and the reduction of water leads to the increase of the solid content in the cushion pad. Thus the density of the cushion increases. (2) Water is an effective foaming agent during the preparation. Under high-temperature and high-pressure environment, water vapor within the matrix quickly expands and drives the matrix to form a porous structure and complete the foaming process. The degree of the system foaming and the volume of the cushion decrease with the reduction of water, so does the density of the cushion. With further increase of the starch content, the viscosity of the material will be too high and the mobility of the system gets worse. It is difficult for the gas decomposed by the foaming agent to diffuse, thus causing big holes internally. It can also cause the decrease of the density, which will further result in collapse of the material. The non-uniformity of internal fibers can also cause non-linear change of the density. This inference is also confirmed by sensory evaluation results. This non-uniform foaming material with big holes internally tends to be deformed by external forces. With poor compressive strength and resilience, it is not suitable as cushioning material.

3.3 The influences of adhesive components on the compressive strength

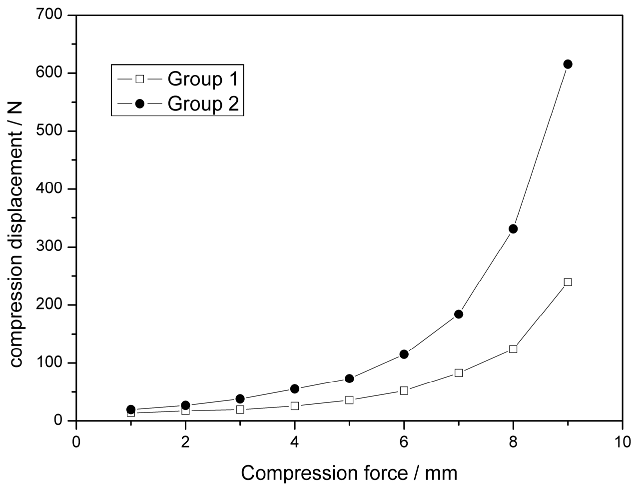

Fig.2 Influence of adhesive components on the compressive property of cushion pads

The sensory and density experiment has confirmed that the bagasse cushion pad is no longer suitable as cushioning material when the starch content is more than 6%. The compressive strength of the samples of two groups with less than 6% of starch content (formula 1 and formula 2) is analyzed. The result is as shown in Figure 2. The required external forces increase with the rise of compressive deformation of the sample. The force on sample No.2 is bigger than that on sample No.1 when the compressive deformation is the same. If the compression displacement is 7mm or less, the required external force is of little difference for the two groups. However, if the compression displacement reaches 9mm, the compressive strength of the 2 groups is distinctive, i.e. the bagasse cushion pad prepared in according to formula 2 is better than that of formula 1, which means that sample No.2 has better compressive strength and is not easy to be deformed.

3.4 Influences of adhesive components on the resilience of bagasse cushion pads

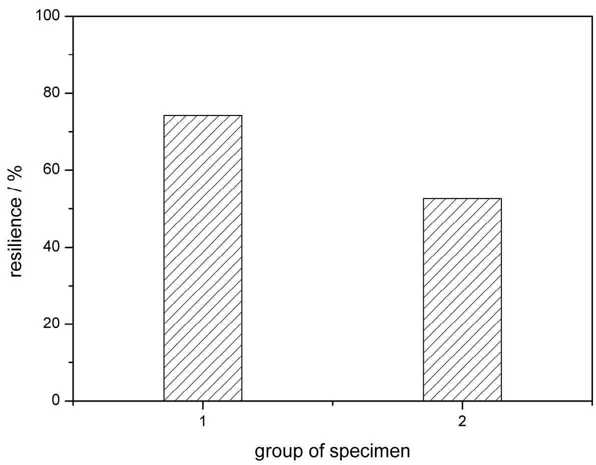

Fig.3 Influences of adhesive components on the resilience of bagasse cushion pads

Figure 3 shows the rebound rate of the bagasse cushion pads prepared in accordance with formula 1 and formula 2.

As can be seen from the figure 3, the force applied on sample No.2 is twice of that on sample No.1 when compressed to the same height. Similarly, the rebound rate of sample No.2 is much smaller than that of sample No.1 24 hours later, showing that the sample of group 2 can bear more external forces without deformation. And it is not easy to rebound after deformation and the material is very compact, thus suitable as cushioning material. The only difference between group No.1 and No.2 is that the corn starch added in group No.2 is more than that in group No.1, which indicates that the rebound rate is concerned with the starch content and that it decreases with the increase of the latter. If the starch content increases, the viscosity of the mixed material rises, making the whole system thickens. The adhesion strength among bagasse fibers becomes stronger, giving the system better strength and lower bound rate.

CONCLUSION

In this experiment, the influences of adhesive components on the appearance, density, compressive strength and resilience of bagasse fiber cushion pads are studied on the condition that the content of bagasse, PVA, foaming agent and plasticizer remains constant. The experimental result shows that the starch content in the adhesive has obvious influences on the properties of the bagasse cushion pads. The structure of the cushion is relatively uniform when the starch content is low. The compressive strength and density increases and the rebound rate decreases with the appropriate increase of the starch content. The sensory evaluation is excellent. If the starch content is increased to 6%, the structure of the cushion pad will get non-uniform and the bagasse cushion pads material system gets too thick with the increase of starch content. And then big holes and collapse will arise, leading to the declining performance of all aspects. The appropriate formula is bagasse: starch: PVA: glycerol: ammonium bicarbonate: sodium bicarbonate: water = 5:5:3:3:3:2:79. Bagasse cushion pad prepared according to this formula has uniform structure with good resilience and compressive strength and no internal collapse. And internally the cushion is fully foamed and the foaming is well distributed, thus suitable as cushion pads.

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