Mechanical Properties of Extruded Wheat Flour Foam

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Abstract: This communication reports a research effort on the density related to mechanical behavior of wheat flour foam to optimization. The different extrusion processing condition can result in different densities of the foams. Mechanical properties measured included static compression and dynamic cushioning curves for the wheat starch foams. The relative compressive strength exhibited a power law dependence on relative density, which is following the equation: $\sigma_c/\sigma_s \approx 0.308(\rho^*/\rho)^{1.5}$. The dynamic cushioning properties of the foam also changed with the density of the foams.

Key words: wheat flour; foam; extrusion; structural packaging; dynamic cushioning curve
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The required structural, cushioning and protection properties of the starch-based expanded cellular systems will depend on properties of the basic materials as well as on the detailed design of their cellular structure. General information on the mechanics of cellular systems[1] and specific studies on the properties of cellular plastics[2−5] and food foams[6−7] are available but, they have not been used for the specific purpose of designing and introducing desirable impact characteristics in starch−based cellular materials.

Recent years a number of technologies have been developed to produce starch— based biodegradable structural packaging foams as alternatives to polymer foams in order to minimize the impact to the environment. The objectives of this study were to investigate the effect of density of the foams on its mechanical properties. Physical characteristics of bulk density and mechanical properties of energy absorbing capacity, rebound resilience energy and dynamic cushioning characteristics were measured on wheat flour foam samples.

1 Experimental

1.1 Materials

Soft wheat flour contained with 9.0% protein and 13.5% moisture was purchased from a superstore. The ratio of amylose to amylopectin in wheat flour is about 25% amylose: 75% amylopectin. Polyvinyl alcohols (PVA) used as additive was Alcotex & Stein 72.5.

1.2 Experiment and testing

An APV MPF 50 twin— screw extruder was used to produce wheat flour foams with different density. The rotation speeds for both screws were set at in the ranges of 250 to 400 r/min. The temperature profile during extrusion was 30, 30, 50, 70, 120, 150 ℃ from the barrel section just after the feed throat to the die. The extrusion condition for the wheat flour foams is shown in Table 1.

The density of wheat flour foams was determined using the glass bead displacement method[8]. An Instron 4203 machine fitted with a compression plate maintained parallel to the base plate was used to obtain the compression characteristics of the foam materials. A modified Rosand Instrumented Impact Tester was used for dynamic cushioning curve measurement testing on the extruded wheat flour foams and EPS.

2 Results & discussion

The foam S1 appears to have no plateau behavior, this is almost certainly due to its high density. The wheat flour foams S2, S3 and S4 under investigation show "plateau" behavior in the stress-strain curves but in the case of S2 the stress increases more steeply in the plateau region than that in the case of S3 and S4, because the former is denser than the latter.

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Tab.1 Extrusion processing conditions for the wheat flour foams S1—S4

Specimen Code	Additive PVA	Feed Rate (g/min)	Moisture content during processing (%)	Screw Speed (r·min^{-1})
S1	3	600	22	250
S2	3	600	18	350
S3	3	800	18	350
S4	3	800	16	450

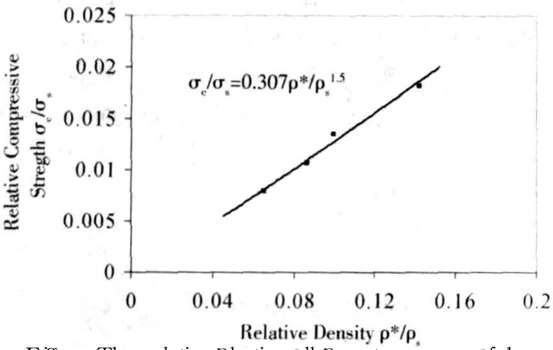

Fig.1 The relative plastic collapse stress σ_c/σ_s of the wheat flour foams as a function of the relative density ρ_c/ρ_s of the wheat flour foams

Compressive strength is a measure of the foam's ability to deform under load. Modified beam theory for cellular foam was applied to find the equations for predicting the relationship of the static compressive strength and the density of the wheat flour foams. For the wheat flour foams S1 – S4 the resulting equation is given by

$$\frac{\sigma_c}{\sigma_s} \approx 0.308\left(\frac{\rho^*}{\rho_s}\right) \qquad (1)$$

Where σ_c and σ_s is compressive strength of the wheat flour foam and the solid wheat flour material, respectively; ρ^* and ρ_s is density of he wheat flour foam and the solid starch material, respectively. Typically, a power—law relationship between compressive strength σ_c and foam density ρ^*, the equation (1), can fit the test data well and is shown in Fig.1. Denser foams tend to have smaller cell size and hence resist deformation better than lower density foams with larger cell size.

Static compression stress—strain hysteresis loops may be used to calculate the energy absorption characteristics of wheat flour foams. If we assume the energy absorbed in the foam during a compression-decompression cycle is called as Ga, and the rebound energy during the decompression part cycle is called as Gr. Then the energy absorbing capacity (Ga/Gr)[1] and rebound resilience, R= (1/(1+Ga/Gr))[1], of the extruded wheat flour foams as well as EPS foam are shown in Fig.3. The energy absorption capacity of the wheat flour foam increases with a decrease in its density and its resilience decrease with an increase in its density (see Fig.2).

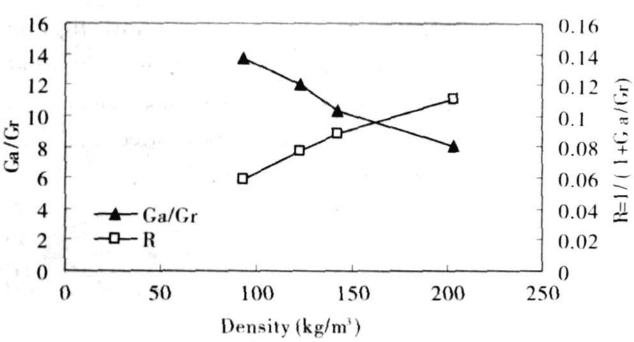

Fig.2 The relationship of energy absorption capacity/resilience of the wheat flour foam and its density

Dynamic cushioning curves of the extruded wheat flour foams, which tested at 50% RH and 23℃, are shown in Fig.3. It can be found that foam S1 appears to possess the greatest value of the minimum acceleration ratio J and the broadest range of the minimum acceleration ratio J; foam S4 appears to have the lowest value of the minimum acceleration ratio J and the narrowest range of the minimum J. Obviously, the lower the density of the wheat flour foam the lower the value of the minimum acceleration ration J and the narrower the range of the minimum acceleration ratio J. For cushioning curves the value of the minimum J means the effective cushioning capabilities of foams, so the lower the better. And the range of minimum J indicates an effective work range for packaging materials, so the broader the better. Compared with EPS foam wheat flour foam S3 has the same value of the minimum J (≈2), but a narrower range of the minimum J. This indicates that there would be optimum combination of density and cellular morphology for the wheat flour foam to possess good dynamic cushioning characteristics as EPS foam.

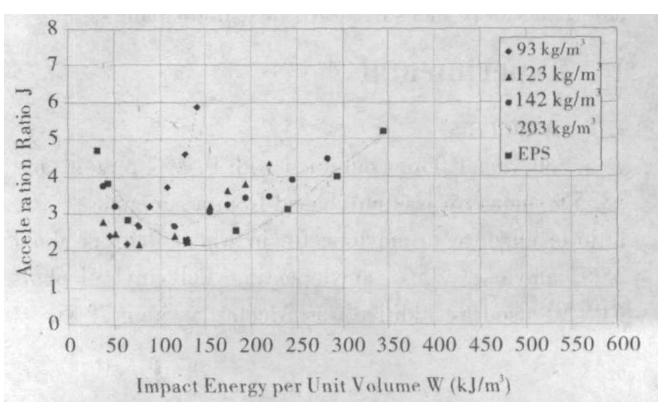

Fig.3 Dynamic cushioning curves of the extruded wheat flour foams S1, S2, S3 and S4, compared with EPS foam

3 Conclusions

The density appears to be an important parameter for mechanical properties of the extruded wheat flour foams and the results demonstrated that the extruded wheat flour foams behave as plastic and brittle cellular materials depending on its density, the compressive strength and the minimum acceleration ratio J of dynamic cushioning curves of the foams increases with its density respectively. Denser foams tend to have small cell size and hence resist deformation better than lower density foams with bigger cell size.

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挤出制备的小麦淀粉泡沫的密度对力学性能的影响

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摘 要：报道了有关结构设计及优化小麦粉泡沫的力学性能与密度的对应关系的研究。揭示了用不同加工条件可以制备不同密度的小麦淀粉泡沫，并对不同密度的泡沫材料进行了静压力学测试和动态缓冲曲线测试。相对压缩强度与相对密度呈幂函数关系，可用式子 $\sigma_c/\sigma_s \approx 0.308(\rho_c/\rho_s)^{1.5}$ 表示。动态缓冲性能也随泡沫密度的变化而变化。

关键词：小麦淀粉；泡沫；挤出；结构包装；动态缓冲曲线

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