

## Bagasse as functional fillers to improve and control biodegradability of soy oil-based rigid polyurethane foams

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**Abstract**—Using agricultural wastes (bagasse) and polyol derived from soy oil as raw materials to develop biodegradable rigid polyurethane foams (RPUFs) is beneficial to reduce the dependence on petroleum resources and promote the sustainable socioeconomic and environmental development. This study focuses on bagasse as a functional filler to improve and control the mechanical properties and biodegradability of the RPUFs. With the increasing levels of bagasse content, the density and mechanical properties of RPUFs increase. The biodegradation of RPUFs has a greater enhancement compared to the foam without bagasse, and all bio-foams have excellent thermal insulation properties. All changes in foam performance are due to the fact that the active hydroxyl groups on bagasse react with excess isocyanate to form urethane, which affects the structure of RPUFs. In this study, scientific design and molecular regulation theory were applied to improve the utilization value of bagasse and develop high-performance biodegradable RPUFs for thermal insulation materials.

Keywords: Polyurethane, Bagasse, Biodegradability, Renewable Resources, Thermal Conductivity

### INTRODUCTION

Rigid polyurethane foams (RPUFs) are used widely, but the existing problem of being difficult to degrade in the natural environment is still extremely serious [1,2]. Now, it is significant to solve this problem by using natural resources, especially agricultural wastes and vegetable oil-based polyols, which are used to prepare biodegradable RPUFs, aiming at reducing the dependence on petroleum resources and obtaining efficient thermal insulation materials due to closed-cell structure and low thermal conductivity of RPUFs [3-5].

Bagasse is an agricultural waste with abundant resources that exists uniquely in the south of China, most of which is directly burned as fuel or to prepare fiber sheets, which has low utilization [6]. Considering economic and environmental objectives, it is great utilization strategy to use bagasse, mainly composed of cellulose, lignin and hemicellulose [7], as bio-mass fillers to adjust and control the degradability of RPUFs depending on its own degradability and its content in RPUFs structure. The large number of hydroxyl groups with active hydrogen in the bagasse molecular chains makes it possible for bagasse to be involved in the synthesis of RPUFs

matrix.

Soy oil has a high yield and low price. According to a survey about the soybean oil market, nearly two-thirds of the world's soybean is utilized for soy oil production, and soybean production will continue to grow in the next five years [8]. The biodegradable RPUFs prepared by modified vegetable oil-based polyols have achieved great results [9-11]. The main component of soy oil is triglyceride, which contains active groups such as double bonds and ester groups in the molecular structure. The soy oil-based polyol with suitable hydroxyl value and functionality is obtained by introducing hydroxyl groups in active groups [12-14]. So, soy oil-based polyol can be substituted for petroleum-based polyol to reduce the dependence of RPUFs on petroleum resources [15,16].

In the field of design and application of vegetable oil-based polyurethane, we have tried our best to make systematic product design and product application research. This paper is a continuation of our previous work [1,2,17,18]. Here, the significant influences of bagasse and soy oil-based polyol on the degradation performance of RPUFs were considered. One type of soy oil-based polyol was used to replace the traditional petroleum-based polyol, and bagasse was used as a functional filler to improve and control the biodegradability of soy oil-based RPUFs as thermal insulation materials. The composite RPUFs retain the high closed-cell structure and excellent thermal insulation properties, which can be used for thermal insulation boards of refrigerators and the like. Moreover, the RPUFs have asy degradability due to the use of bagasse and soy

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oil-based polyol.

## EXPERIMENTAL SECTION

### 1. Materials

Soy oil-based polyol (YS-112) (OH value=112 mg KOH·g<sup>-1</sup>, acid value <0.25 mg KOH·g<sup>-1</sup>) originated from Yuansheng Trading Co., Ltd. (Shandong, China). Petroleum-based polyol (Puranol RF 8238A) (OH value=380 mg KOH·g<sup>-1</sup>) was provided by Jiahua Chemicals Inc. (Shanghai, China). Polymeric methylene diphenyl diisocyanate (pMDI) (Lupranate M20S) (NCO%=31.10, functionality=2.70) was made by BASF, Germany. The chemical structure (Fig. S1) of polyols and pMDI is provided in supplementary materials. Distilled water was used as the sole blowing agent. Bagasse powder (100 mesh size), provided by Guangdong Provincial Bioengineering Institute, was used as filler without further treatment. AK-8805 was purchased from Jiangsu Maysta Chemical Co., Ltd., China, and used as the surfactant. Dabco BL-11 (A-1) was supplied by Air Products and Chemicals Inc., USA, and used as a catalyst.

### 2. Preparation of RPUFs

The RPUFs with different content of bagasse powder were synthesized by a simple “one-shot method” [19,20]. The total polyols were made by mixing petroleum-based polyol and soy oil-based polyol (Puranol RF 8238A and YS-112=50:50 wt%, which is mainly to balance between mechanical properties and cost, and to improve the degradability of RPUFs.). The mass of all other components was based on total polyols mass, as follows: 2.0% (w/w) AK-8805 as a surfactant, 0.7% (w/w) A-1 as a catalyst and 2.0% (w/w) water as a blowing agent; the mass of pMDI was calculated by isocyanate index (R) 1.05.

The RPUFs were prepared according to the following formulation. First, soy oil-based polyol (30.00 g), petroleum-based polyol (30.00 g), distilled water (1.20 g), bagasse, catalyst (0.42 g) and surfactant (1.20 g) were mixed in a plastic cup and the mixture was stirred at 2,000 rpm for 3 min. Secondly, pMDI (56.40 g) was added into the mixture, then the mixture was stirred at a high speed of 2,000 rpm for 8-10 s and immediately poured into a 20×20×4 cm<sup>3</sup> mold, the temperature of the mold was 60 °C. After reacting for 8 min, the foam was removed and left at room temperature (about 25 °C). Then, the RPUFs were cut and tested after being cured for 24 h. The weight of bagasse refers to the total polyol mass, which was 0, 2.5, 5.0, 7.5, 10.0 and 12.5% (w/w), respectively. The corresponding polyurethane composite foams were termed RPUFs 0, RPUFs 2.5, RPUFs 5.0, RPUFs 7.5, RPUFs 10.0 and RPUFs 12.5.

### 3. Characterization

Fourier transform infrared (FTIR) spectra of raw materials and RPUFs composites were obtained by FTIR spectrometer (Model 1600) (PerkinElmer Co., USA) in the range of 4,000-500 cm<sup>-1</sup>. All samples were thoroughly dried in a vacuum oven for 48 h at 60 °C before testing with KBr as the substrate.

JSM-5510LV scanning electron microscope (SEM) (JEOL Ltd., Tokyo, Japan) was used to observe the cell morphology. The RPUFs were cut with a blade into 4×4×2 mm<sup>3</sup> rectangular blocks. The samples were sprayed gold before scanning and examined at 20 kV of accelerating voltage. The observation direction of the foams cell structure was parallel to the free-rising direction. Then the aver-

age cell size was collected from the SEM images ASTM D3576.

After the epidermis was removed from the matured foam composites, the samples were cut into 3×3×3 cm<sup>3</sup> cubes, weighed to calculate density according to ASTM D1622. Three cubes taken from different places of foams were cut and the average density was recorded.

The compressive strength of the RPUFs samples was measured with the dimensions of 3×3×3 cm<sup>3</sup> according to ASTM D1621 by material testing machine (E43.104, MTS Systems (China) Co., Ltd.). The rate of compression was 3 mm·min<sup>-1</sup>, and the value of compressive strength was recorded when the strain was 10% deformation. Three samples pieces were cut from different places of foams and the average compressive strength was reported.

Thermogravimetric analysis (TGA) was carried out by thermogravimetric analyzer (SDT Q600, TA Instruments, US). About 7 mg dry samples powders were measured under nitrogen atmosphere at a heating rate of 10 °C·min<sup>-1</sup> from 20 to 700 °C.

The foam samples of differential scanning calorimetry (DSC) were the same as TGA (about 7 mg dry powder), which were studied by DSC6220 (Seiko Instruments, US) at a heating rate of 10 °C·min<sup>-1</sup> from 30 to 200 °C under a nitrogen atmosphere.

There is a direct relationship between the degradation of foam composites and environmental impacts. The biodegradation of samples was studied by soil burial method according to ASTM D5988. The samples were cut into specimens of 4 cm (width)×4 cm (length)×1 cm (thickness). The specimens were weighed and buried in the soil with the depth about 10-15 cm. Then, they were unearthed every 2 weeks, carefully washed and dried at 50 °C for 48 h. The average weight loss was calculated for the three samples.

In the field of thermal insulation, thermal conductivity ( $\lambda$  value) of RPUFs composites is a very significant data to measure the thermal insulation property. The thermal conductivity of RPUFs is related to the gas in cell, radiation, convection and solid phase of the cell wall. The  $\lambda$  value was studied through the transient plane source method. The samples were made into two small rectangular blocks with a flat surface and the same size of 4×4×1 cm<sup>3</sup>. Then the  $\lambda$  value at 25 °C would be obtained with Hot Disk 2500 (Hot Disk Inc., Sweden) according to ISO 22007-2.

## RESULTS AND DISCUSSION

### 1. FTIR of Raw Materials and RPUFs

FTIR spectra can provide structure and bond information about composites with the characteristic absorption peaks for each specific chemical bond. The chemical structures of raw materials and RPUFs composites were obtained from Fig. 1. FTIR spectra of bagasse shown in Fig. 1(a), stretching vibration absorption peaks appeared at wavenumbers of 1,735 cm<sup>-1</sup> and 1,227 cm<sup>-1</sup>, exhibit the sclerenchyma structure of bagasse, such as cellulose, hemicellulose and lignin [21]. The absorption peaks at 1,735 cm<sup>-1</sup> and 1,227 cm<sup>-1</sup> represent the stretching vibration peaks of the C=O and C-O-C, respectively. The strong absorption peak at 3,442 cm<sup>-1</sup> corresponds to the stretching vibration peak of the hydroxyl group, indicating that the bagasse used in this experiment had a large number of active hydroxyl groups, which provided a favorable condition for the reaction between bagasse and pMDI [22].

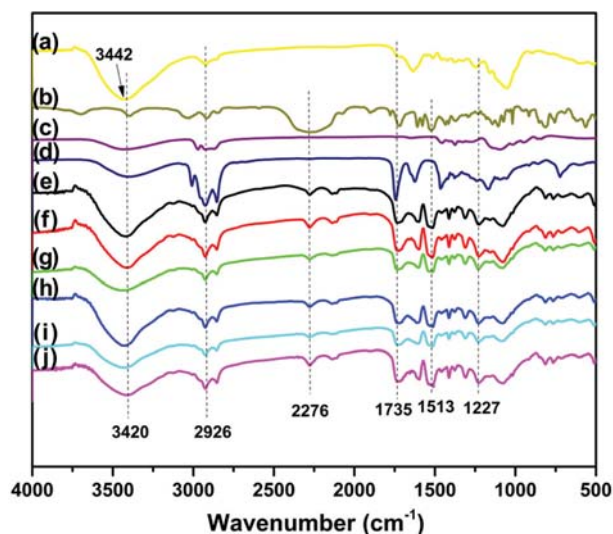


Fig. 1. FTIR spectra of raw materials (a)-(d) and the bio-foams with different bagasse content (e)-(j): (a) Bagasse (b) M20S (c) YS-112 (d) Puranol RF 8238A. Bagasse content: (e) 0% (f) 2.5% (g) 5.0% (h) 7.5% (i) 10.0% (j) 12.5 wt%.

The urethane group ( $-\text{NH}-\text{COO}-$ ), as a characteristic group for RPUFs, has proved to be present due to the three major characteristic absorption peaks:  $3,420\text{ cm}^{-1}$  (N-H),  $1,735\text{ cm}^{-1}$  (C=O ure-

thane), and  $1,513\text{ cm}^{-1}$  (N-H amide II groups). This indicates that RPUFs composites were successfully synthesized. All samples in Fig. 1 have similar spectra; however, the peak value of carbonyl stretching vibration gradually shifts between  $1,735$  and  $1,721\text{ cm}^{-1}$  and the absorption peak of N-H shifts between  $3,443\text{ cm}^{-1}$  and  $3,411\text{ cm}^{-1}$  with the climb of bagasse concentration. This might be attributed to the fact that the active hydroxyl groups on the molecular chain of bagasse affect the hydrogen bonding between N-H and C=O, improving the microphase separation between hard and soft segments due to the strong interaction between bagasse and RPUF molecules [18,23]. In practice, the changes of N-H and C=O absorption peaks suggest that the hydroxyl group on the bagasse is likely to react with isocyanates and form hydrogen bonding between bagasse and polyurethane matrix [24,25]. In summary, the FTIR spectrum indicates that the main chemical compositions of the RPUFs were not changed with the addition of bagasse, but the molecular structure of foams was affected.

## 2. Morphology of the RPUFs

The cell structure and morphology of RPUFs composites with bagasse content from 0% to 12.5 wt% were analyzed by SEM images (Fig. 2). Most of the cells are closed-cell structure, the RPUFs composites consist of mostly closed cells and a few broken cells. With the increase of bagasse content, the number of foam cells in RPUFs gradually increases while the cell size slowly decreases. The cell morphology of foam without bagasse is shown in Fig. 2(a), the average cell size is  $314.84\text{ }\mu\text{m}$ . The average cell sizes of foams with differ-

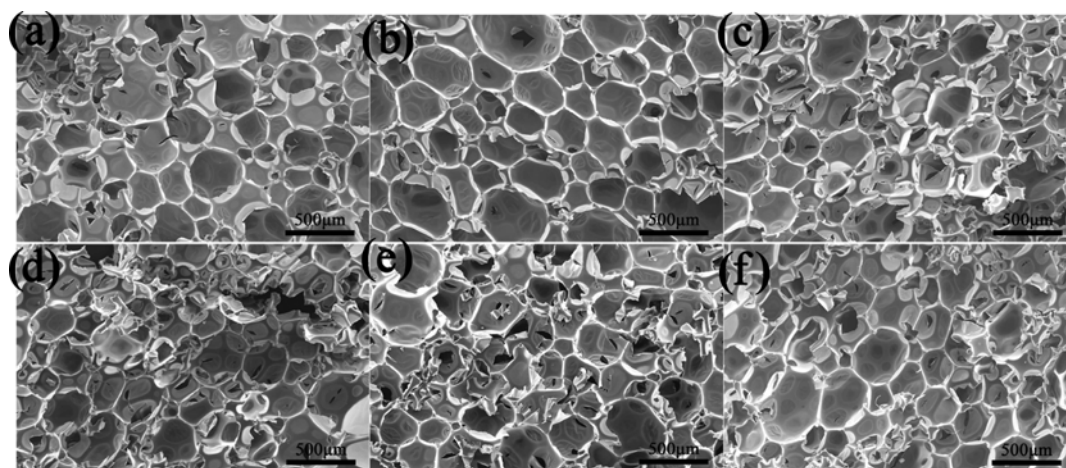


Fig. 2. Surface morphology (parallel to the free-rising direction of RPUFs) of the bio-foams with different bagasse content: (a) 0% (b) 2.5% (c) 5.0% (d) 7.5% (e) 10.0% (f) 12.5 wt%.

Table 1. The cell size, density, compressive strength and thermal conductivity of RPUFs with different bagasse content

Bagasse content (wt%)	Average cell size ( $\mu\text{m}$ )	Density ( $\text{kg}\cdot\text{m}^{-3}$ )	Compressive strength (kPa)	Thermal conductivity $\lambda$ ( $\text{mW}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ )
0	$314.84\pm 62.31$	$56.55\pm 0.68$	$236.4\pm 5.2$	$36.44\pm 0.41$
2.5	$287.06\pm 75.17$	$57.64\pm 1.03$	$237.4\pm 7.9$	$36.46\pm 0.37$
5.0	$268.54\pm 53.42$	$58.30\pm 1.04$	$240.6\pm 10.5$	$36.61\pm 0.33$
7.5	$253.12\pm 59.25$	$59.81\pm 0.78$	$245.6\pm 12.6$	$36.78\pm 0.36$
10.0	$245.39\pm 72.63$	$61.57\pm 0.83$	$246.7\pm 16.2$	$36.94\pm 0.45$
12.5	$234.59\pm 65.92$	$64.15\pm 1.31$	$239.6\pm 15.6$	$37.72\pm 0.52$

ent bagasse concentration (2.5, 5.0, 7.5, 10.0 and 12.5 wt%) are shown in Table 1. With the increase of bagasse concentration from 0% to 12.5 wt%, the cell size of RPUFs reduces by 25%. The reasons are the following: 1) With the addition of bagasse, the gas would produce heterogeneous nucleation on the surface of bagasse particles, the bagasse powder provides more nucleation sites for the formation of bubbles, which increases the number of cells [26]. 2) The viscosity of the reaction system increases with the increasing bagasse content, which hinders the expansion of the bubbles, reducing the cell size [17]. This might mean that bagasse is involved in the reaction with pMDI, and an interpenetrating cross-linked network is formed, which limits the gas spillage and reduces the cell size of RPUFs. So, the bagasse content could control the cell size of the RPUF by affecting RPUFs matrix and network structure.

### 3. Density and Compressive Strength of RPUFs

Density has a great influence on mechanical properties and thermal insulation of the RPUFs. Density and compressive strength of RPUFs are shown in Table 1. The density of RPUFs increases gradually with the increasing bagasse percentage from 0 to 12.5 wt%, which is due to the addition of bagasse powder increasing the number of cells and decreasing the cell size; also, the bagasse powder is uniformly mixed in the cell wall as a filler [27]. This suggests that the change in density is directly due to the effect of bagasse on the cell structure of RPUFs.

With the bagasse content occupying from 0 to 10 wt%, the density and compressive strength increases by about 8.88% and 4.35% respectively (Fig. 3). However, when the bagasse content exceeded 10 wt%, the compression strength decreased by 2.88%. In general, the value of compressive strength has a greater relationship with the crosslinking density for RPUFs [28,29]. The hard segments of the RPUFs network are mainly composed of urethane groups [30]. With the addition of bagasse, the solid content of foam composites increases, which enhances the strength of the cell walls. The hydroxyl groups on the bagasse polymerize with the isocyanate groups to form a more network structure; this increases the urethane groups content of RPUFs composites with bagasse added, providing more physical crosslinking points and improves the concentration of hard segments, thus reinforcing the compressive strength of composites (Fig. 4) [30]. In fact, the RPUFs with bagasse containing 7.5

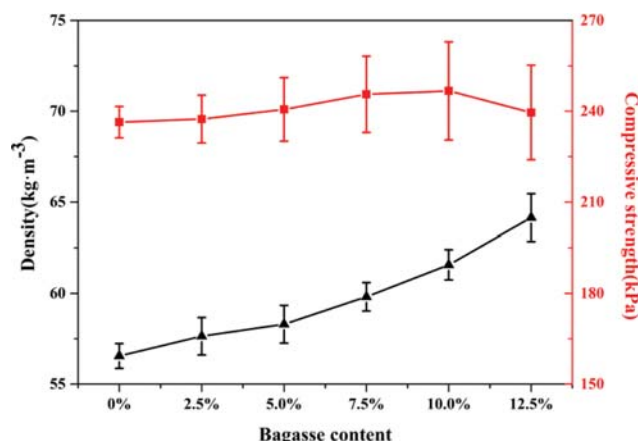


Fig. 3. Density and compressive strength of bio-foams with different bagasse content.

wt% and 10 wt% have similar compressive strength. But when the bagasse concentration exceeds 10 wt%, the compressive strength declines from 246.7 kPa to 239.6 kPa. The higher hard segments content is attributed to the increasing of urethane groups, leading to the foam being harder but more brittle, thus the compressive strength is weakened [31]. The content of bagasse could be used to adjust the density and compressive strength by changing the physical and chemical structure of biodegradable RPUFs.

### 4. Thermal Stability of RPUFs

The TGA and derivative thermogravimetric analysis (DTG) curves (Fig. S2), DSC curves (Fig. S3), main decomposition temperature and glass transition temperature ( $T_g$ ) (Table S1) are provided in supplementary materials. The results show that the addition of bagasse does not change the degradation process and the thermal stability of RPUFs.

### 5. Degradation of RPUFs

Biodegradability is an extremely important factor for environmentally friendly RPUFs. The degradability of bagasse/soy oil-based RPUFs composites was measured by soil burial method [32], and preliminarily evaluated by the weight loss of samples. The weight loss % of RPUFs with different bagasse content is shown in Fig. 5.

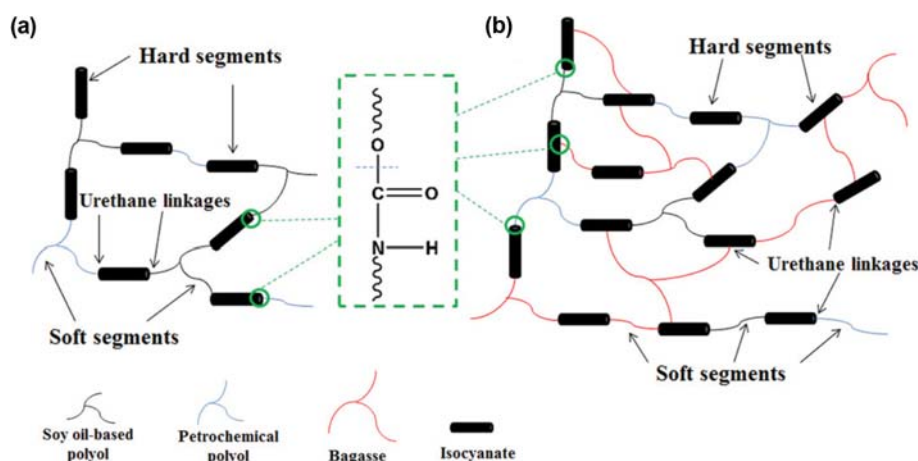


Fig. 4. The effect of bagasse on the structure of RPUFs: without (a) and with (b) the addition of bagasse.



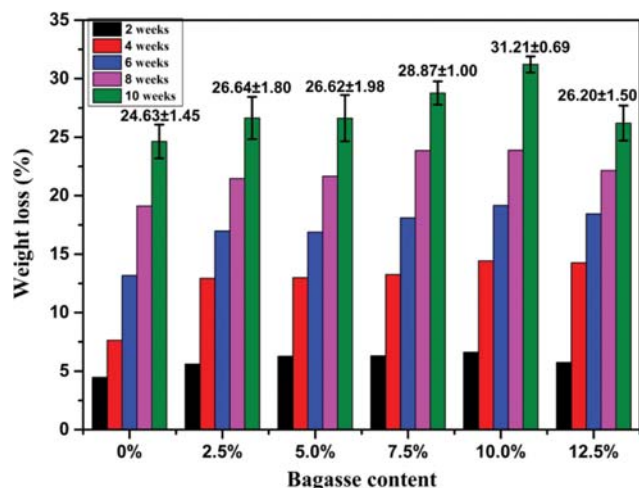


Fig. 5. The weight loss % of bio-foams with different bagasse content.

With the addition of bagasse powder, the biodegradability of RPUFs gradually increases, but when the percentage of bagasse exceeds 10 wt%, the degradability slightly decreases. The main process of RPUFs degradation is the transformation of macromolecules into small molecules by hydrolysis [32]. Bagasse as biomass resources is more susceptible to degrade in the natural environment because the components (cellulose and hemicellulose) could be decomposed into monomers and then decomposed or metabolized into carbon dioxide and water by microorganisms [33]. With the addition of bagasse, the active hydrogen on bagasse is likely to react with pMDI; an easily degradable molecular chain on bagasse is introduced into the polyurethane foam structure, which enhances the degradability of RPUFs [34]. Because the triglyceride chains of soy oil could be broken down into single strands, the biodegradability was enhanced [34]. When the concentration of bagasse increases, most bagasse plays the role of filler and disperses in the solid polymer of RPUFs, which reinforces the degradability of foam samples [35]. When the proportion of bagasse exceeds 10 wt%, the excess bagasse reduces the interfacial area between the hydroxyl groups on the bagasse and the foam matrix, weakens the hydrolysis and microbial decomposition [34]. It could be concluded that bagasse promotes and controls the biodegradability of RPUFs composites due to its easily degradable characteristics and the introduction of easily degradable molecular chains.

## 6. Thermal Conductivity of RPUFs

In the thermal insulation field, thermal conductivity ( $\lambda$ ) of the RPUFs is the most important factor for measuring the thermal insulation property of the foams [36]. The  $\lambda$  value of pure RPUFs without bagasse was  $36.44 \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ , the  $\lambda$  values of PUFs with 2.5, 5.0, 7.5, 10.0 and 12.5 wt% bagasse are shown in Table 1. The  $\lambda$  value of RPUFs is mainly composed of the thermal conductivity of the gas in the cells ( $\lambda_{\text{gas}}$ ), the thermal conductivity of the solid polymer ( $\lambda_{\text{solid}}$ ), the radiation heat transfer between cells ( $\lambda_{\text{radiation}}$ ) and the convection of the gas ( $\lambda_{\text{convection}}$ ) [37].

$$\lambda = \lambda_{\text{gas}} + \lambda_{\text{solid}} + \lambda_{\text{radiation}} + \lambda_{\text{convection}}$$

With the addition of bagasse, the  $\lambda$  value of RPUFs samples gradually increases (Fig. 6). The same conductivity of the  $\lambda_{\text{gas}}$  is due to

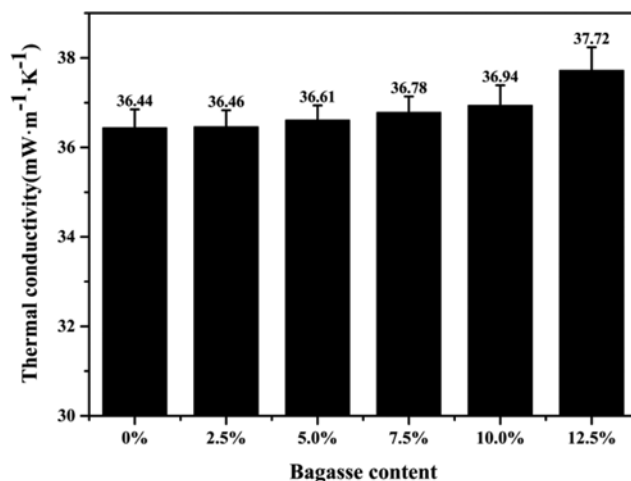


Fig. 6. The thermal conductivity of bio-foams with different bagasse content.

the use of the same blowing agent (distilled water). With the increasing amount of bagasse powder, more and more bagasse is mixed in the solid polymer. However, the  $\lambda$  of bagasse ( $67\text{--}72 \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ ) and RPUFs solid ( $22 \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ ) have a higher value than  $\text{CO}_2$  ( $16 \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ ), hence the  $\lambda_{\text{solid}}$  increases. The cell size of RPUFs has a significant effect on thermal conductivity [38]. The  $\lambda_{\text{radiation}}$  value of foams declines because the increased urethane promotes the micro-phase separation of the soft-hard segments, which increases the crosslinking degree of RPUFs molecular chains and reduces the cell size. At the same time, the density also increases, the influence of the aperture on the  $\lambda_{\text{radiation}}$  would be smaller. In practice, the convection heat transfer of gas between cells is negligible because of the small cell sizes [38,39]. In summary, this indicates that the bagasse has little impact on the thermal insulation properties of RPUFs because of its fine dispersion in RPUFs matrix and its effect on cell structure. The bagasse occupies from 0 to 12.5 wt%, thermal conductivity increases by about 3.51%, it is in line with the conditions of insulation materials [40].

## CONCLUSIONS

Bagasse/soy oil-based degradable RPUFs composites were successfully synthesized by a simple “one-shot method” that enhances the utilization rate of agricultural wastes and alleviates the problem that RPUFs are difficult to degrade naturally. The structure-property relationship of RPUFs based on a 50 : 50 wt% blending of petroleum-based polyol and soy oil-based polyol reinforces with bagasse was thoroughly studied. FTIR and SEM proved that bagasse is involved in the reaction with pMDI, and increases the content of urethane groups and significantly changes the physical structure (cell structure) of RPUFs. The diameter of the cell is reduced from  $314.84 \mu\text{m}$  to  $245.39 \mu\text{m}$ . Density and mechanical properties curves show that the fine dispersion of bagasse in RPUFs matrix and the increase of hard segments improve the density and compressive strength of RPUFs, increasing by 8.88% and 4.36%, respectively. TGA and DSC indicate that bagasse has no effect on the thermal stability of RPUFs within the tolerance. The degradation test reveals

the dispersal of easily degraded bagasse in RPUFs matrix and the introduction of easily degradable bagasse molecular chain in RPUFs structure, which increases the degradation of RPUFs by 26.72% (10 weeks). The thermal conductivity shows that the RPUFs solid content increases with the increase of bagasse, which has a main influence on thermal conductivity, and increases the  $\lambda$  value by 1.37%. RPUFs have better mechanical properties and degradability at 10 wt% bagasse, the  $\lambda$  value is  $37.72 \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ , which meets the definition (below  $50.00 \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ ) of high-efficiency thermal insulation materials. All these results show that the prepared foams could be used as an environmentally-friendly material in thermal insulation fields.

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## SUPPORTING INFORMATION

Additional information as noted in the text. This information is available via the Internet at <http://www.springer.com/chemistry/journal/11814>.

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## Supporting Information

### Bagasse as functional fillers to improve and control biodegradability of soy oil-based rigid polyurethane foams

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#### Materials

Soy oil-based polyol (YS-112) was provided by Yuansheng Trading Co., Ltd. (Shandong, China), Petroleum-based polyol (Puranol RF 8238A) was provided by Jiahua Chemicals Inc. (Shanghai, China), and Polymeric 4,4'-diphenylmethane diisocyanate (Lupranate M20S) was made by BASF, Germany. The -OH on the poly-

ols and the -NCO on the isocyanate indicated that it was reasonable to form polyurethane foams.

#### Thermal Stability of RPUFs

The effect of bagasse loading on the thermal stability of RPUFs composites was studied by TGA and DSC under N<sub>2</sub> atmosphere. The TGA and derivative thermogravimetric analysis (DTG) curves

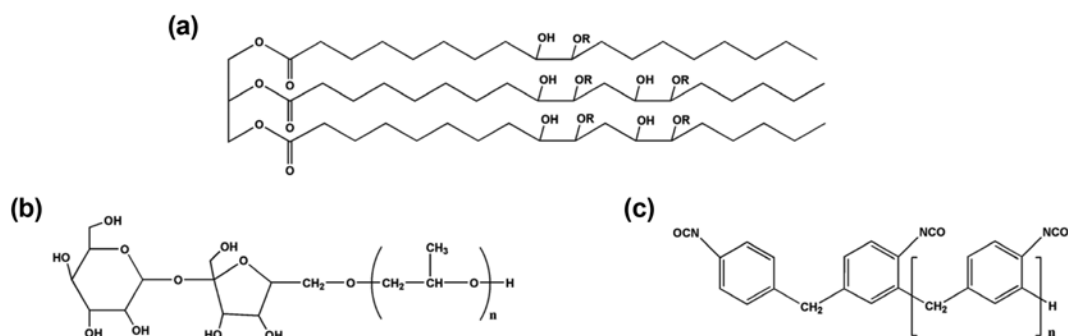


Fig. S1. The chemical structure of polyols and pMDI: (a) Soy oil-based polyol, (b) Petroleum-based polyol [1], (c) pMDI [2].

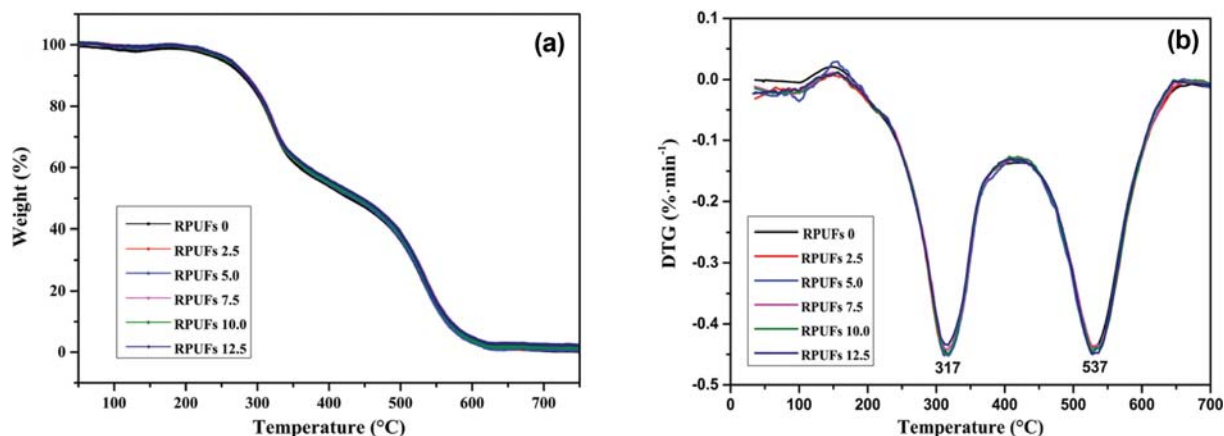
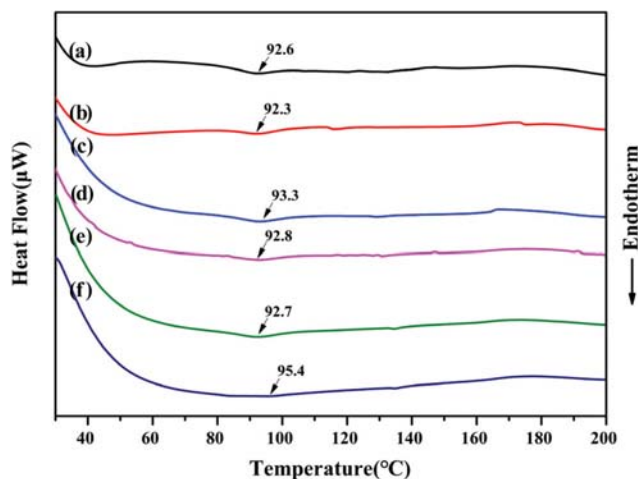


Fig. S2. The TGA (a) and DTG (b) of bio-foams with different bagasse content.

**Table S1. Main decomposition temperature and glass transition temperature ( $T_g$ ) of RPUFs**

	Bagasse content (wt%)					
	0	2.5	5.0	7.5	10.0	12.5
$T_{5\%}$ (°C)	245.95	250.92	252.98	252.24	251.64	252.96
$T_{max1}$ (°C)	317.95	321.92	321.98	322.24	319.64	321.96
$T_{max2}$ (°C)	530.95	530.92	526.99	527.24	527.64	527.96
$T_g$ (°C)	92.6	92.3	93.3	92.8	92.7	95.4



**Fig. S3. The DSC of bio-foams with different bagasse content: (a) 0% (b) 2.5% (c) 5% (d) 7.5% (e) 10% (f) 12.5 wt%.**

of the foams are shown in Fig. S2. The weight loss curve is provided in Fig. S2(a). All the RPUFs curves have almost the same trend. And two maximum peaks were exhibited in the DTG curves of samples (Fig. S2(b)), which meant there were two major thermal decomposition phases, suggesting that the main thermal decomposition process occurred at 250–400 °C and 450–600 °C. The main decomposition temperature and char residues of foams are

listed in Table S1. The initial decomposition temperature  $T_{5\%}$  (the temperature for 5 wt% weight loss) for all samples is about 250 °C [3]. The decomposition temperature of the first stage is around 250–380 °C, which is due to the thermal decomposition of urethane groups (hard segments) [4]. The decomposition temperature of the second stage occurred in about 400–600 °C, which mainly depends on the structure of the soft segments [5,6].

In Fig. S3, the glass transition temperature ( $T_g$ ) of samples was revealed, and the value of  $T_g$  was listed in Table S1. The bagasse has little effect on  $T_g$  value of bio-foams and the reasons are provided as follows: (1) According the study about bagasse by Sutas Janbuala et al., bagasse shows no glass transition [7]. (2) The bagasse might hamper the polymerization due to its complex structure and relatively low hydroxyl reactivity than polyol due to its steric hindrance [8]. In a nutshell, the addition of bagasse did not change the degradation process and the thermal stability of RPUFs.

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