Improvisation in wicking property of flexible polyurethane foams by adding bamboo and gelatin fillers

Improvisação na propriedade de absorção de espumas flexíveis de poliuretano com adição de enchimentos de bambu e gelatina

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Harshi Jaiswal
PhD in Applied Chemistry
Institution: Gautam Buddha University
Address: Greater Noida, 201310, U.P, India
E-mail: harshjswl2104@gmail.com

Mahesh N. Gopalasamudram
PhD in Polymer Chemistry
Current Institution: Jindal Polyfilm
Address: Mumbai Metropolitan Region
E-mail: drgn.mahesh@gmail.com

Jaya Maitra
PhD in Polymer Chemistry
Institution: Gautam Buddha University
Address: Greater Noida, 201310, U.P, India
E-mail: jaya@gbu.ac.in

ABSTRACT

PU foam is one of the softest, most easily accessible, and affordable mattress materials. In PU foam, wider pores and a more open-cell structure have both advantages and drawbacks. Despite having fewer cells PU foam does not control airflow very effectively and commonly faces criticism for causing body heat and for retaining moisture. A warm, humid climate because of stored body moisture and sweat functions as a haven for bacteria and germs and encourages the proliferation of dust mites contributing to excessive odour and allergic reactions. This study aims to investigate the impact of bamboo and gelatin filler dosage or loading on the wicking property of the foam by using a discontinuous foaming process. Foams with gelatin and bamboo fillers were prepared at 2, 4, and 8% by weight concentrations, respectively, along with a standard 32-density foam without filler. A comparative study was conducted on the effect of increasing filler content on the wicking and mechanical properties of the foam. The wicking and porosity levels of bamboo-filled foam were higher than standard foam and gelatin-loaded foam. With increasing concentrations of bamboo filler, a rapid increase in foam wicking by 7–10 mm was noted. However, an increase in gelatin filler concentration resulted in an increase in foam porosity and elongation with a slight improvement in wicking ability. Improvisation in the wicking property of the foam was observed with dosage increment of bamboo filler. According to this research findings, the bamboo powder can be utilized as a filler to enhance wicking properties in flexible polyurethane foam.
Keywords: flexible polyurethane foam, filler, porosity, wicking.

RESUMO
Espuma de PU é um dos materiais de colchão mais macio, mais facilmente acessível e acessível. Na espuma PU, os poros mais largos e uma estrutura de células mais abertas têm vantagens e desvantagens. Apesar de ter menos células de espuma PU não controla o fluxo de ar muito eficazmente e comumente enfrenta críticas por causar calor corporal e para reter a umidade. Um clima quente e úmido por causa da umidade e do suor do corpo armazenado funciona como um refúgio para bactérias e germes e incentiva a proliferação de ácaros do pó, contribuindo para o excesso de odor e reações alérgicas. Este estudo tem como objetivo investigar o impacto da dosagem de bambu e gelatina de enchimento ou carregamento sobre a propriedade wicking da espuma usando um processo de espuma descontínuo. Espumas com gelatina e cargas de bambu foram preparadas em concentrações de 2, 4 e 8% em peso, respectivamente, juntamente com uma espuma padrão de 32 densidades sem preenchimento. Foi realizado um estudo comparativo sobre o efeito do aumento do conteúdo de enchimento sobre as propriedades mecânicas e perniciosas da espuma. Os níveis de perversidade e porosidade da espuma cheia de bambu eram mais altos do que a espuma padrão e a espuma carregada de gelatina. Com o aumento das concentrações de enchimento de bambu, observou-se um rápido aumento na formação de espuma em 7-10 mm. No entanto, um aumento na concentração de preenchimento de gelatina resultou em um aumento na porosidade da espuma e alongamento com uma ligeira melhoria na capacidade de perambulação. Foi observada improvisação na propriedade wicking da espuma com incremento de dosagem de enchimento de bambu. De acordo com os resultados desta pesquisa, o pó de bambu pode ser utilizado como um enchimento para melhorar as propriedades de peruca na espuma de poliuretano flexível.

Palavras-chave: espuma de poliuretano flexível, enchimento, porosidade, wicking.

1 INTRODUCTION
Polyurethane is a polymer formed by a reaction of poly-isocyanate and polyol with the characteristic urethane (–NHCOO–) functional group [1]. Polyurethane is a mixture of many substances like polyurea, biurets, allophanates, etc. that are formed due to the reaction of isocyanates with itself or with other reactive hydrogen-containing reactants like amine and water. Polyurethane (PU) is an ester of unstable carbamic acid and is also known as carbamate. A significant portion of polyurethanes is made up of urethane linkages.

Urethane as well as urea units have a strong tendency to agglomerate and form hard segments. The polyol portion forms the flexible soft segments. This aggregation behavior is of great importance for the mechanical properties. Based on product, the polyurethane (PU) market is divided into flexible foam, rigid foam, adhesives, coatings and sealants, and elastomers. The flexible foam segment dominates the market owing
high use as a cushioning material for furniture, bedding and mattresses, seating, and other soft products [2][3].

PU foam is one of the most economical, readily accessible, and softer mattress materials. It works well as a comfort layer in most mattresses due to its softness [4]. The chemical manufacturing procedure, density, and general structure all affect the quality of PU foam [5]. Fillers are generally inert by nature and are typically added to foam compositions to boost density and any other specific properties like tensile strength, elongation, resilience, flame retardancy, etc., or to lower the total cost of the finished foam [4]. In order to develop a product with a unique heritage and consistent quality, it is vital to identify the fillers according to their nature and proper concentration to improve properties of foam [5]. However, filler could have a negative impact on mechanical characteristics of the foam. Urethane fiber as a filler produces strong abrasion resistance, while calcium carbonate as a filler contributes to the gelling reaction during foaming and load bearing properties [7]. Fillers that act as reinforcing agents include CNFs, or carbon nanofibers, silica, and organoclay. CaCO3 filler can be replaced with waste chicken eggshells, coconut husks, corn cobs, and other fillers that are far less expensive, easily accessible, biodegradable, and environmentally friendly. While corn cob and coconut husk behaved as flame retardants, chicken eggshells as fillers improved Elongation and % Compression set values of the foam [1][2].

PU foam has wider pores and more of an open-cell structure which is both an advantage and a disadvantage [6]. PU foam does not control airflow very effectively despite having open cells which retains moisture and body heat with time. Although cool gel mattresses are already in the market and are effective for keeping the body cool. Foam mattresses commonly face criticism for causing individuals to wake up perspiring in their beds and the combination of the lack of airflow and the body heat generating conditions makes for an uncomfortable sleeping environment. Sweat that a human produces whilst sleeping gets accumulated in the foam mattress since plastics are incapable of absorbing moisture. Usually, people perspire between 250-650 ml overnight. Due to retained body moisture and sweat, PU foam faces criticism on not being the best option for a hygienic sleeping environment. Warm and humid conditions create a haven for bacteria, germs and dust mites to thrive. Person sensitive to the feces and decaying bodies of dust mites or exposure to this debris can encounter allergic reaction such as runny nose, itchy eyes, coughing, and sneezing and in case of Asthmatics severe symptoms like wheezing, tightness in the chest, and shortness of breath can occur.
The body heat retention and general irregular plushness or comfort of a PU foam mattress would cause discomfort such as sleep interruptions or even chronic sleep deprivation, affect the immune system, appetite, mood, focus, and physical performance of an individual. Insufficient sleep has also been related to a wide range of chronic conditions, including type 2 diabetes, cardiovascular disease, and obesity. Humidity can speed up the process of wear and tear in PU foam mattresses causing variety of long-term posture issues. A sagging or uneven mattress is one potential contributor to neck pain. The objective of this research is to study mechanical properties of flexible PU foams with gelatin and bamboo fillers and to develop an environmentally-friendly and cost-effective flexible polyurethane foam with wicking properties.

2 MATERIALS AND METHODS

2.1 PREPARATIONS OF RAW MATERIALS

Gelatin and bamboo fillers from Molychem and BISJ Exporters Pvt. Ltd. were used in the formation of flexible PU foam along with other ingredients including conventional polyether polyol (DOW Chemical International Pvt. Ltd.), toluene diisocyanate(T80), stannous octoate (tin), Bis(2-dimethylaminoethyl)ether (amine), surfactant (Sistersville plant), color and water as a blowing agent.

2.2 FORMULATION OF FLEXIBLE POLYURETHANE FOAM

Foams with organic fillers (2, 4 and 8 parts per hundred weight of polyol) were synthesized, with each chemical component amount chosen to achieve a target density of 32 kg/m3. Tin content was adjusted in order to maintain the desired density range of 32+2 kg/m3. The amount of isocyanate supplied in each formulation was calculated using the combined hydroxyl content of polyether polyol and parts of water. Using an electronic weighing balance, toluene diisocyanate (TDI) and polyether polyol were weighed out in different beakers. To ensure a precise stoichiometric reaction, stannous octate, silicone, amine, and water were measured using syringes. All of these compounds were measured in parts per hundred (pph) parts of polyol. Table:1 shows the various substances and their proportional amounts used for the preparation of the foam samples.
Table 1: Formulations of standard and filler loaded flexible polyurethane foams

<table>
<thead>
<tr>
<th>FOAMS →</th>
<th>STANDARD</th>
<th>B-2</th>
<th>B-4</th>
<th>B-8</th>
<th>G-2</th>
<th>G-4</th>
<th>G-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals ↓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyl</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>TDI</td>
<td>39.44</td>
<td>39.44</td>
<td>39.44</td>
<td>39.44</td>
<td>39.44</td>
<td>39.44</td>
<td>39.44</td>
</tr>
<tr>
<td>Bamboo filler</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gelatin filler</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Colour</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Water</td>
<td>2.81</td>
<td>2.81</td>
<td>2.81</td>
<td>2.81</td>
<td>2.81</td>
<td>2.81</td>
<td>2.81</td>
</tr>
<tr>
<td>Amine</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Silicone</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tin</td>
<td>0.16</td>
<td>0.12</td>
<td>0.14</td>
<td>0.14</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Source: By the Author

The weighed amount of filler was added to the mixing bowl with polyol and was well mixed for 2-3 minutes with the help of a direct drive foaming stirrer. Other reagents were concurrently added to the mixing bowl containing a mixture of polyol and filler and thoroughly stirred for 3–4 minutes until the foam mixture seems glossy and creamy. Finally, the TDI was swiftly poured into the foam mixture while being continuously stirred for 30 to 50 seconds. The rising foam mixture was then poured into the mold and left to cure for 72 hours. Foams were evacuated from the mold and skin was removed after the curing period was complete.

2.3 CHARACTERIZATION OF FOAM SAMPLES

Samples were cut according to each test standards specification to further evaluate the influence of bamboo and gelatin filler on the mechanical attributes of flexible polyurethane foam. Prior to testing, foam test samples were conditioned for 16 hours at (23±2)°C and (50±5) % relative humidity without deviation or distortion.

2.3.1 Density of foam

In accordance with ISO:845, uncored foam density was measured in kilograms per cubic metre by calculation from the mass and volume of the sample. Test specimens were sized using a calibrated measuring tape and weighed on electronic weighing balance to compute the accurate density of foam.

\[
Density = \frac{Mass}{Volume}
\]  
(1)
2.3.2 Resilience of foam

In compliance with ISO 8307:2018(E) standard, resilience test was conducted. A steel ball is dropped in the centre of a test sample with a thickness more than 50mm from a predetermined height on the ball rebound tester, and the height of the ball's rebound is recorded. Resilience is expressed in % of rebound height to the original height from which ball is dropped.

2.3.3 Tensile strength and Elongation of foam

Foam's elasticity is determined by the ISO 1798: 2008(E) standard, which is also used to test foam's strength under stress. After measuring the sample's thickness, sample is fixed into a universal testing machine with a maximum force of + 1% and a speed of (500+50) mm/minute. The sample is pulled by the machine until it breaks at a steady rate. The machine monitors the tensile strength of foam, and the maximum force required to reach at breaking point. The elongation at break is the maximum extension of the foam sample expressed as a percentage of its initial length.

2.3.4 CFD in foam

The compression stress is an assessment of the material's ability to withstand a protracted load. The DIN EN ISO 3386-1: 2015-10 standard is used to perform the test. After measuring the initial sample dimensions, the sample is placed beneath the compression plate of the UTM machine and compressed to (70+5) % of its initial thickness at a speed of (100+20) mm/minute. The test sample is then decompressed at the same rate and the same procedure is applied three times to remove the initial hardness of the foam. In the fourth cycle, 40% of the foam's thickness is compressed, and the machine measures the compression stress value.

2.3.5 Air permeability of foam

The openness or compactness of foam is determined by its airflow. A Cell Flo porosity meter was used to measure the sample's air permeability or porosity. Readings are taken from different points perpendicular to the direction of the rise of foam as porosity is sensitive to sample orientation.
2.3.6 Wicking in foam

Wicking is a typical phenomenon where liquid travels from one surface to another by capillary action. Foam samples measuring 2 cm x 10 cm and with a thickness of 8 and 6 mm were taken. Each sample was marked at its initial height of 10 mm, and then it was submerged vertically in coloured water until that mark. The sample was left undisturbed for two hours. Following two hours, the sample was carefully withdrawn from the solution, and the ultimate height of the coloured water in the foam was measured. The difference between the coloured solution’s final height and its initial height is the wicking height attained by the sample.

\[ \text{Wicking in foam} = \text{Final height of watermark in foam} - \text{Initial height} \]

3 RESULTS AND INTERPRETATION

Table: 2 summarizes the result of various characterizations of the foam samples. The ratio of mass per unit volume in a foam sample is characterized as the density of the foam. In foam technology, density reflects a foam’s total cost, load-bearing capacity, physical characteristics, durability, and support of foam. The improved mechanical qualities displayed by the fillers also hamper the density of the foam. By adjusting the tin concentration in the foam, the density is kept within the range of (32+2) kg/m3. This density range encompasses all developed foams.

<table>
<thead>
<tr>
<th>FOAM →</th>
<th>Standard</th>
<th>B-2</th>
<th>B-4</th>
<th>B-8</th>
<th>G-2</th>
<th>G-4</th>
<th>G-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>TESTS</td>
<td>Density (Kg/m³)</td>
<td>32.7</td>
<td>31.59</td>
<td>31.45</td>
<td>31.00</td>
<td>31.23</td>
<td>31.98</td>
</tr>
<tr>
<td></td>
<td>Resilience (%)</td>
<td>40</td>
<td>50</td>
<td>49</td>
<td>44</td>
<td>41</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Tensile Strength (Kg/sq.cm)</td>
<td>1.281</td>
<td>0.948</td>
<td>0.897</td>
<td>0.815</td>
<td>1.393</td>
<td>1.316</td>
</tr>
<tr>
<td></td>
<td>Elongation (%)</td>
<td>238.05</td>
<td>203.03</td>
<td>219.16</td>
<td>194.36</td>
<td>265.90</td>
<td>285.25</td>
</tr>
<tr>
<td></td>
<td>Porosity (%)</td>
<td>25</td>
<td>62</td>
<td>52</td>
<td>55</td>
<td>31</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>CFD (kPa)</td>
<td>3.02</td>
<td>3.24</td>
<td>2.71</td>
<td>2.41</td>
<td>2.85</td>
<td>2.94</td>
</tr>
<tr>
<td></td>
<td>Wicking sample (8 mm.)</td>
<td>0</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Wicking sample (6 mm.)</td>
<td>1</td>
<td>9</td>
<td>10</td>
<td>8</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Source: By the Author
The resilience of foam is a measurement of its springiness or bounce and is helpful to ascertain the foam's capacity to absorb stress. Lower the ball rebound value, lower is the foam's resilience. Foams loaded with gelatin and bamboo showed higher resilience than standard foam. A progressive decline in the foam's resilience with increase in bamboo filler concentration whereas an increase in resilience with increased gelatin filler loading was noted. The bounce of foam was improved by both additives.
The tensile strength of foam with gelatin filler improved in foams with 2 and 4 parts of gelatin filler, and dropped as filler content in the foam was increased. Improved tensile strength will hold greater weight before breaking. Bamboo filler deteriorated the tensile strength of the foam. Tensile strength increase with chain length of polymer and crosslinking of a polymer chain. As the filler load was raised, a fall in the tensile strength of foam with bamboo filler was seen. The percentage elongation characterises the elastic capabilities of foam and is one of the characteristics that sets good foam apart from bad foam. Figure 4 shows that foam’s elastic characteristics can be enhanced on addition of gelatin fillers. As the filler concentration was raised, the elongation of foams containing gelatin filler increased and foams with bamboo filler showed a noticeable decrease in elastic property.

Figure 3: Effect of increasing dosage of bamboo and gelatin fillers on Tensile strength of Flexible Polyurethane foam

Source: By the Author
The compression force deflection (CFD) is a physical characteristic that is used to assess the firmness and load bearing capabilities of polyurethane foam. As demonstrated in Figure 5, the addition of 2 parts of bamboo filler has a positive impact on the foam's firmness and hardness. It implies that the 2-part bamboo filler foam will have a hard influence on it and prove to be extremely sturdy and durable. The hardness of foam is being degraded by further addition of bamboo filler. When gelatin filler is infused into the foam composition, CFD values are noticeably lower than for normal foam.
A foam with set dimensions can draw a certain amount of air depending on its porosity. A foam's openness or blindness is determined by its porosity value. By altering the tin concentration, porosity of foam can be manipulated. Comparing bamboo-filled foam to gelatin-filled foam and normal foam, bamboo-filled foam had significantly higher porosity levels. Gelatin-filled foam exhibits a continuous rise in porosity with increasing filler concentration as shown in Figure 6. Both fillers improved foam's porosity level.

Figure 6: Effect of increasing dosage of bamboo and gelatin fillers on porosity of Flexible Polyurethane foam

Source: By the Author

Foams have the possibility to be employed as highly wicking materials by enhancing capillarity due to the high porosity. A controlled increase in foam porosity improves the wicking ability. Despite the fact that the gelatin filler increased the foam's porosity, it only exhibited 3 mm of wicking in sample thickness of 6mm. In contrast to no wicking in regular foam, bamboo filled foam was able to attain a wicking height of 10 mm. This highlights the fact that, although wicking depends on the foam's porosity, the type of infused filler has a stronger impact.
Figure 7: Effect of increasing dosage of bamboo and gelatin fillers on 6 mm. thickness wicking sample of Flexible Polyurethane foam

Figure 8: Effect of increasing dosage of bamboo and gelatin fillers on 8 mm. thickness wicking sample of Flexible Polyurethane foam

Figure 9: Visual representation of Wicking samples of standard, gelatin-filled foam, and bamboo-filled foams at different dosages (2, 4 and 8 parts) and at different sample thickness (6mm. and 8 mm).
4 CONCLUSION

It can be concluded therefore, bamboo has the potential to enhance the wicking properties of flexible PU foam, according to physical and mechanical investigations done on samples of the foam filled with the material. In comparison to no wicking recorded in standard foam, bamboo filled foam attained a wicking height of 10 mm. Although the gelatin filler increased the foam's porosity, only 3 mm of wicking was noted in gelatin loaded foams. This emphasizes the notion that, compared to foam's porosity, the size and nature of the infused filler have a greater impact on wicking capability of foam. The results of the porosity and resilience of foam, showed an increasing trend with an increase in filler concentrations. In terms of each mechanical attribute, each filler in flexible PU foam responds differently depending on dosages of filler.

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