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والثلاثون

تحسين خصائص رغوة البولي يوريثان باستخدام مسحوق بيكرونات الصوديوم

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والتدريب والتطوير التربوي

## المستخلص:

يُستخدم البولي يوريثان على نطاق واسع في تطبيقات صناعية متنوعة، إلا أن قابليته العالية للاشتعال تشكل عائقاً رئيسياً. تهدف هذه الدراسة إلى معالجة هذا العيب من خلال تعزيز مقاومة للرغوة البولي يوريثان للحريق. صُنعت عينات الرغوة باستخدام نسب متساوية من بوليولات البوليول والإيزوسيانات، إما في صورتها النقية أو مع كميات متفاوتة من بيكرونات الصوديوم المضافة (١، ١,٥، ٢، ٢,٥، ٣، ٣,٥، ٤ غرام). أدت إضافة بيكرونات الصوديوم إلى زيادة كثافة الرغوة وانخفاض الموصلية الحرارية. كشف تحليل مجهر القوة الذرية (AFM) أن متوسط حجم جسيمات بيكرونات الصوديوم كان حوالي ٤٤,٤٣ نانومتر. تعرضت جميع العينات مباشرةً للهب غاز الطهي. أظهرت النتائج تحسناً في مقاومة الالتهاب في العينات التي تحتوي على بيكرونات الصوديوم، وخاصةً عند تراكيزات تتراوح بين ٢ و ٤ غرامات، حيث أظهرت عينة الـ ٤ غرامات الأداء الأكثر فعالية، وتم حساب تأثير مقاومة انتقال الحرارة من خلال قياسات UL-94 بشكل عمودي للنماذج.



الكلمات المفتاحية: البولي يوريثان ، بيكربونات الصوديوم، التوصيل الحراري ، حجم الجسيمات ، مقاومة الحرارة.

## Improving the properties of polyurethane foam by using sodium bicarbonate powder

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### Abstract:

Polyurethane is widely used in many industrial applications. However, it is highly flammable. This limits its safe use. This study aims to improve the fire resistance of polyurethane foam. Foam samples were prepared using equal amounts of polyol and isocyanate. Some samples were pure. Others contained sodium bicarbonate as an additive. The added amounts were 1, 1.5, 2, 2.5, 3, 3.5, and 4 g. The addition of sodium bicarbonate increased the foam density. It also reduced the thermal conductivity. AFM analysis showed that the average particle size of sodium bicarbonate was about 44.43 nm. All samples were exposed directly to a cooking gas flame. The results showed better flame resistance in the modified samples. The best performance was



observed for concentrations between 2 and 4 g. The 4 g sample showed the highest fire resistance. Heat transfer resistance was evaluated using the UL-94 test.

The samples were tested in the perpendicular position.

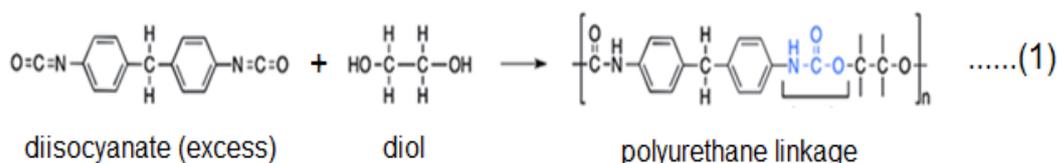
**Keywords:** polyurethanes, sodium bicarbonate, thermal conductivity, particle size, heat resistance.

### 1- Introduction:

Polyurethane foam polymers are highly versatile materials. They are used in many industrial and engineering applications. They have excellent thermal insulation properties. For this reason, they are widely used in the construction industry. They are applied in building structures, automotive materials, roof insulation, and car seats. They are also commonly used in insulating panels.

This is because they show strong long-term resistance to moisture (Bhavik 2024; Langtian 2025; Vipin 2009; Wit et al. 2006).

Polyurethane foam is produced by a chemical reaction between a di-isocyanate and a polyol (Marta et al., 2025). Polyols are organic compounds that contain several hydroxyl groups ( $-OH$ ) (Zhen et al., 2020). They may have two groups (di-hydroxyl), three groups (tri-hydroxyl), or four groups (tetra-hydroxyl). Polyols with higher functionality can also be used. The meaning of the term “polyol” may change depending on the field, such as polymer chemistry or the food industry (Mihail 2005). Isocyanates are represented by the general formula  $R-N=C=O$ . They are organic compounds that contain one or more isocyanate groups. Di-isocyanates contain two isocyanate functional groups. They are essential for the formation of polyurethane polymers. The chemical reaction for producing polyurethane foam is shown in Equation (1) (Zhen et al., 2020).

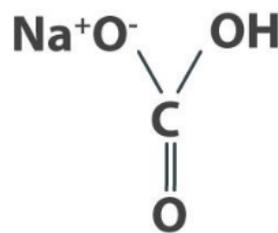


Polyurethane foam has many useful properties. However, it is highly flammable. It can easily ignite when exposed to an open flame. It may also burn due to electrical sparks or lightning. Once ignited, it can cause severe fires. This creates serious risks in storage facilities, public halls, and buildings. Therefore, many researchers have focused on improving its flame resistance. This is done by adding different flame-retardant additives. Several studies have reported successful results (Jing et al. 2014; Marcin et al. 2015; Sabyasachi et al. 2014; Yongjun et al. 2019).

Sodium bicarbonate is a white, odorless, crystalline powder. It is insoluble in alcohol but highly soluble in water. It acts as an alkalizing agent and an antacid. It can be given orally or intravenously. It is sometimes used as a nutritional supplement, especially for elderly patients with heart disease (Noah and Sharon 2019).

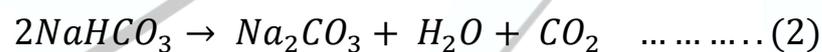
Historically, the ancient Egyptians were among the first to use sodium bicarbonate ( $\text{NaHCO}_3$ ). They used it in mummification. It was also used as an antiseptic, fungicide, and cleaning agent. It was added to bread as a leavening agent. It was used in fire extinguishers (Gabriel et al. 2023). Today, sodium bicarbonate is still widely used. It is used to treat metabolic acidosis. It is also used for hyperkalemia and drug toxicity. It has many applications in the food industry. It is common in daily life.

The chemical formula of sodium bicarbonate is  $\text{NaHCO}_3$ , as shown in Figure 1 (Indunil et al. 2024).



**Figure 1. The chemical bonding nature of sodium bicarbonate (Indunil et al. 2024)**

Sodium bicarbonate decomposes when heated above  $80^\circ\text{C}$ . It breaks down into sodium carbonate, water, and carbon dioxide. This reaction is shown in Equation (2) (Saadia 2025; Timothy et al. 1985).



Sodium bicarbonate is an eco-friendly and low-cost material. Recent studies examined its encapsulation with epoxy resin (EP). They also studied its addition to polypropylene (PP) foam. These methods improved the foam's performance and thermal properties (Dan et al., 2021).

This study investigates making polyurethane foam by reacting polyol with di-isocyanate. It also explores improving the foam's heat and fire resistance by adding sodium bicarbonate. The goal is to reduce fire damage in materials like insulating panels and other industrial applications.



## 2- Experimental Part:

Isocyanate and commercial polyol made in Germany by Bayer were used. Their purities were 98% and 97%, respectively. Polyurethane foam was prepared by reacting the isocyanate with the polyol. Commercial sodium bicarbonate powder with 99% purity was obtained from Bergano Chemicals, China. The powder was sieved to a particle size below 150 microns to remove larger particles.

A cylindrical plastic mold was used to form the samples. It had a diameter of 2.7 cm, a height of 6 cm, and a tight-fitting lid. Before use, the inside of the mold was wiped with light oil. This prevented the foam from sticking.

Polyurethane foam samples were prepared using equal proportions of polyol and isocyanate (50% each). First, 3 ml of polyol was placed in the mold. Then, sodium bicarbonate powder was added. It was mixed manually until uniform. Next, an equal volume of isocyanate was added. Using a small metal spoon, the mixture was stirred quickly by hand for 30 seconds. This gave a homogeneous consistency. For larger amounts, a mechanical mixer can be used. The mixture was left in the mold to complete the chemical reaction. After 15 minutes, the sample was removed by breaking the mold.

Table 1 shows the different amounts of sodium bicarbonate added to the polyurethane foam. The polyol and isocyanate proportions remained fixed.

The following properties of the samples were evaluated:

- **Density:** Calculated from the mass-to-volume ratio ( $\rho = m/V$ ).
- **Thermal conductivity:** Measured using the Lees' Disc method with equipment from Griffin & George (Barragána et al., 2022).
- **Particle size:** Determined using an atomic force microscope (AFM) from TT, Japan.



- **UL-94:** flame resistance tests were also conducted. The time needed to extinguish the samples was recorded following the 1998 Test for Flammability standard.
- Each sample was exposed to a cooking gas flame for five minutes. This tests how the samples burn under the same conditions.

### 3- Results and discussion:

In Table 1, the samples were graded up to 4 grams only. Beyond this amount, it was impossible to mix and obtain a homogeneous polyurethane foam.

Figures 2 and 3 show the prepared samples and those for thermal conductivity testing. The reaction between polyol and isocyanate is highly exothermic. It releases a large amount of heat. When sodium bicarbonate powder is added, it stays dispersed in the foam. It does not dissolve into the polymer matrix. The resulting polyurethane foam samples were cohesive and structurally uniform. No visible defects or cracks were observed. The amount of sodium bicarbonate was gradually increased up to 4 grams. Beyond this, it became difficult to obtain a homogeneous foam mixture. This issue was confirmed in practice.

Figure 4 shows the change in foam density with different amounts of sodium bicarbonate. The density increases as more sodium bicarbonate is added. This is because sodium bicarbonate has a much higher density of  $2.2 \text{ g/cm}^3$  (Wit and Andrzej 2006; Hussein et al. 2018). In comparison, polyurethane foam is much lighter. Its density ranges from  $0.062 \text{ g/cm}^3$  for flexible foam (Ernie and Syazana 2016) to  $0.168 \text{ g/cm}^3$  for rigid foam (Yadolah et al. 2016).

Figure 5 shows the thermal conductivity coefficient with increasing sodium bicarbonate content. The data show a clear decrease in thermal conductivity as the sodium bicarbonate concentration rises. This decrease is due to sodium bicarbonate, which acts as a barrier and reduces heat transfer. These



results agree with Artur 2018), showing improved thermal insulation performance.

Atomic force microscopy (AFM) analysis is presented in Table 2 and Figure 6. It shows the size distribution of sodium bicarbonate particles. The average particle size is about 44.43 nm. The original sodium bicarbonate powder had a particle size of 150  $\mu\text{m}$ . The AFM results show a much smaller size of 44.43 nm. This difference is due to clumping or aggregation of the powder before the assay.

A direct flame test was done using a cooking gas stove. The goal was to check the fire resistance of the samples. When exposed to a continuous flame, the samples behaved differently based on their sodium bicarbonate content Figure 7. Polyurethane samples without sodium bicarbonate burned completely. Samples with 2 to 4 grams of sodium bicarbonate resisted the flame well. The sample with 4 grams showed the highest resistance. When the foam is exposed to high heat, the polymers break down. This forms a black, charred carbon layer. This layer is very heat-resistant and acts as a thermal insulator. It protects the lower polymer layers from fast decomposition. The charcoal layer also blocks flames and slows the release of flammable gases. This reduces the fire intensity. The foam's original closed-cell structure helps limit heat loss during early fire stages. This continues until full combustion occurs. These observations agree with Sean and Terence (2016).

The flame resistance was also tested using UL-94. The time needed to extinguish each sample was measured. The results are shown in Table 3.

When heated, sodium bicarbonate ( $\text{NaHCO}_3$ ) breaks down into carbon dioxide ( $\text{CO}_2$ ), water vapor ( $\text{H}_2\text{O}$ ), and sodium carbonate ( $\text{Na}_2\text{CO}_3$ ). Sodium carbonate can further decompose into sodium oxide ( $\text{Na}_2\text{O}$ ) and carbon dioxide ( $\text{CO}_2$ ), as shown in Equation (2). These decomposition products help in flame retardancy. This agrees with the results reported by



Timothy et al. 1985). The prepared samples show potential for making thermally insulating and flame-retardant polyurethane foams. These foams have promising uses in industrial and construction applications. Fire resistance tests confirmed the quality of the polyurethane foam samples. The last sample, with 4 g of additive, resisted fire for about 30 seconds.

#### 4- Conclusion:

Adding sodium bicarbonate powder to polyurethane foam produced well-bonded samples. These samples were free of cracks and defects, both before and after adding the additive. As the sodium bicarbonate concentration increased, the foam density also increased. At the same time, its thermal conductivity decreased. Most of the prepared samples showed good flame and fire resistance. The optimum sodium bicarbonate content was between 2 and 4 grams. The best overall performance occurred at 4 grams. This formulation is promising for applications that require heat- and fire-resistant polyurethane foams.

**Table 1: the mixing ratios for sample preparation**

Sodium bicarbonate (g)	Poly (ml)	Isocyanate (ml)
0	3	3
1	3	3
1.5	3	3
2	3	3
2.5	3	3
3	3	3
3.5	3	3
4	3	3



**Table 2. Represents the statistical values of the atomic force microscope**

Statistical summary					
Parameters	Unit	Mean	Std dev	Min	Max
Projected area	mm <sup>2</sup>	1661	12097	1.081	106378
Z-maximum	Nm	44.43	7.076	39.76	84.84





Figure 3. The samples preparation for thermal conductivity tests.

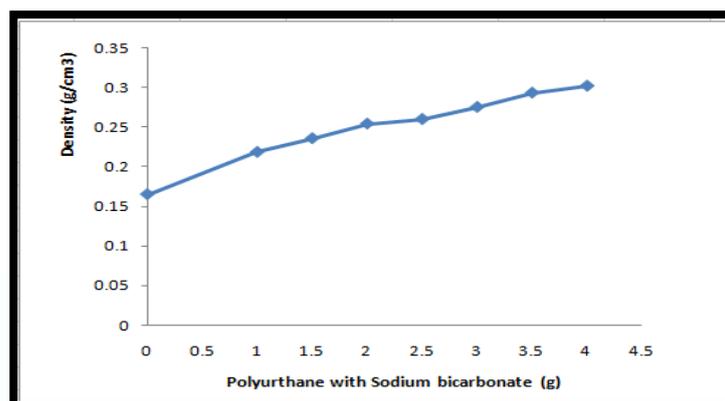


Figure 4. The change of polyurethane density with sodium bicarbonate

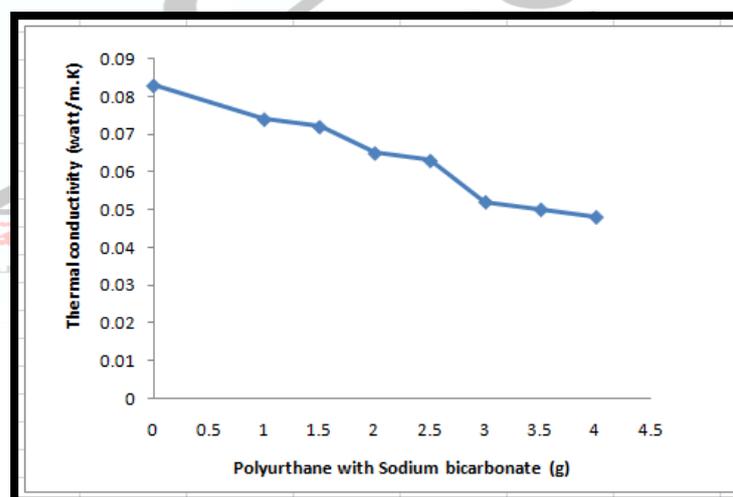


Figure 5. The change in thermal conductivity of polyurethane with sodium bicarbonate

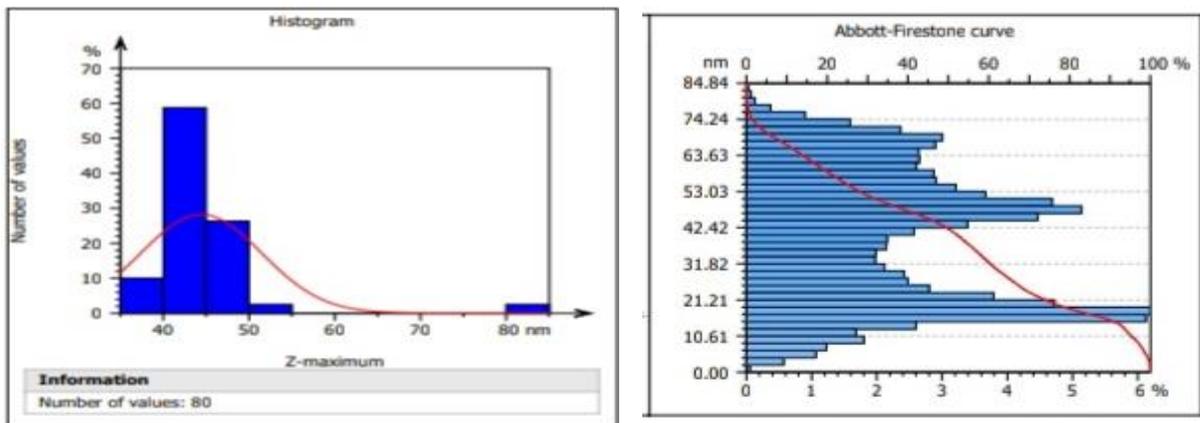


Figure 6. Represents an atomic force microscope image

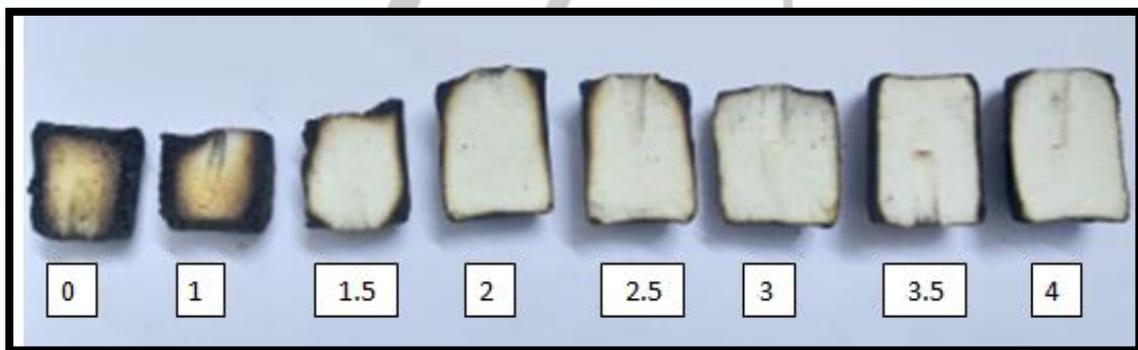


Figure 7. Polyurethane samples after exposure to combustion


**Table 3. The Examination Represents a Type ( UL 94 V-1)**

Sample Number	Sample Orientation	Definition	Burn Time	Particle Drop Allowed		Plaque Holes
				Flaming	Non-Flaming	
0	Vertical	Rapid Burning	120 Second	No	No	No
1	Vertical	Rapid Burning	100 Second	No	No	No
1.5	Vertical	Slow Burning	90 Second	No	No	No
2	Vertical	Burning Stop	60 Second	No	No	No
2.5	Vertical	Burning Stop	44 Second	No	No	No
3	Vertical	Burning Stop	41 Second	No	No	No
3.5	Vertical	Burning Stop	40 Second	No	No	No
4	Vertical	Burning Stop	30 Second	No	No	No

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