

Project title: Chemical Recycling of Polyurethane Foam from Airport Luggage Carriers: A Circular Economy Approach

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Introduction & Background:

This research introduces an innovative chemical recycling technology for waste polyurethane foam from airport luggage carriers. Through an optimized glycolysis process, we successfully converted waste rigid PU foam into high-quality recycled polyol that can replace up to 50% of virgin material in new foam production. Testing of the recycled foam products demonstrated comparable or superior performance across multiple mechanical and physical properties. Our multi-criteria assessment identified that formulations with 30% recycled content offered the best balance of sustainability and performance, with a circularity metric of 0.63. This approach not only diverts waste from landfills but also reduces dependence on petrochemical feedstocks, creating a closed-loop system for PU foam materials that addresses both economic and environmental imperatives.

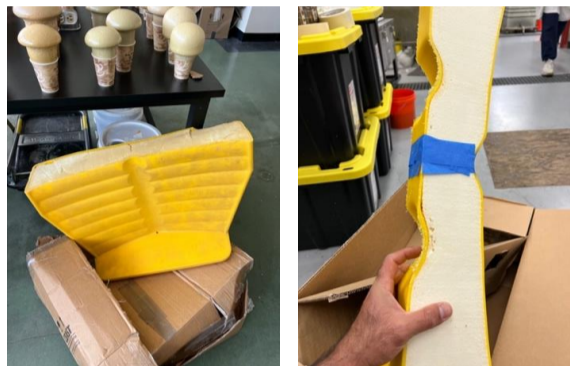


Figure 1 : Polyurethane Foam from Airport Luggage Carrier

Relevance to Circular Economy:

This research directly aligns with circular economy principles by converting waste polyurethane foam, a typically challenging material to recycle due to its chemical structure and high petrochemical content, into reusable and valuable polyol products. Traditional disposal methods often involve landfilling, leading to severe environmental consequences and lost resources.

The circular economy approach advocated here involves chemically recycling rigid PU foam waste into a usable, value-added recycled polyol. This reduces reliance on virgin petrochemical feedstocks, curbs emissions associated with new material production and provides an economically viable alternative to landfill disposal. By demonstrating successful chemical recycling in a semi-scaled laboratory environment, this research significantly contributes to sustainable practices within the circular economy, emphasizing resource recovery and environmental preservation.

Methodology:

The research methodology followed a systematic approach, starting with industrial waste rigid polyurethane (PU) foam from airport luggage carrier totes provided by Vanderlande. The high-density polyethylene (HDPE) cover was manually removed, and the core PU foam was cut into 1-2 cm cubic pieces. Glycolysis, the core recycling process, utilized diethylene glycol (DEG) as the agent in a 5-liter flask reactor under nitrogen to avoid oxidation. Four catalyst mixtures (DEA and NaOH at varying ratios) were tested to optimize reaction conditions.

Post-reaction, the recycled polyol was vacuum-filtered and oven-dried at 105°C. Gel Permeation Chromatography (GPC) measured molecular weight distributions, while hydroxyl number and viscosity were determined via titration (ASTMD-4274-88, ASTMD-4662-93) and rheometric. Recycled polyol's applicability was evaluated by blending it with commercial polyol (Huntsman PIP 250CG) and using methylene diphenyl diisocyanate (MDI) for rigid foam production. Performance characterization included compression testing (ASTM D3574), sun exposure resistance (ASTM D2565), density measurements (ASTM D792), dimensional stability tests at -30°C, 0°C, and 70°C (adapted ASTM D1204), thermal conductivity assessments (ASTM C518-04, ISO8301), and Scanning Electron Microscopy (SEM) analysis using a MIRA3 TESCAN microscope at 15 kV to study foam morphology. The samples range from virgin foam containing 100% commercial polyurethane (PU), to **sample A** with 0% recycled polyol (RP), and samples B to F progressively increasing from **10% RP (sample B)** up to **50% RP (sample F)**, blended with commercial polyol.

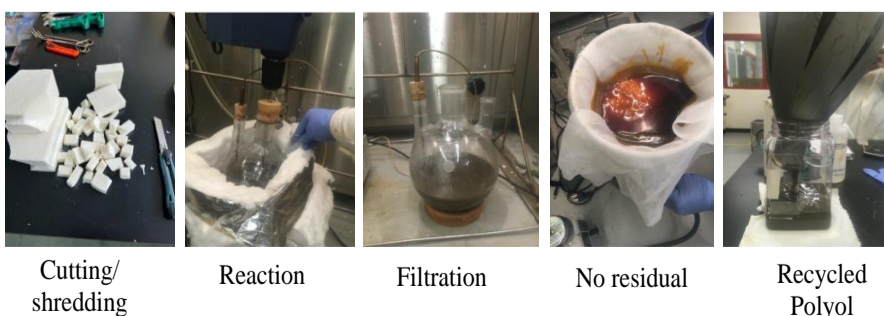


Figure 2: Step by Step Method on Recycling of PU Foam

Results & Discussion:

Glycolysis Reaction Efficiency:

Glycolysis experiments showed that both catalyst choice and concentration significantly affected reaction time and product characteristics. When using a lower percentage of combined diethanolamine (DEA) and sodium hydroxide (NaOH) (1:1, 2.5 wt%), the reaction time exceeded five hours, and the resulting recycled polyol exhibited notably high viscosity (77.5 Pa·s). Increasing the catalyst amount to 5 wt% (reaction 2) shortened the reaction to three hours and yielded a lower-viscosity polyol with reduced molecular weight. When tested individually, DEA alone prolonged the reaction (>5 hours) but produced the lowest molecular weight polyol, whereas NaOH alone accelerated the reaction (<3 hours) but gave higher molecular weight products.

Mechanical Performance:

Compression testing (ASTM D3574) indicated a general increase in maximum compression stress with higher contents of both methylene diphenyl diisocyanate (MDI) and recycled polyol. The maximum stresses spanned from roughly **200 KPa** to as high as **450 KPa**, allowing some formulations to closely match or even approach virgin foam performance (477 KPa).

SEM analysis corroborated these findings. As shown in **Figure 3**, Sample D (30% recycled polyol) exhibited a honeycomb-like pore structure with uniform cell distribution, which aligned with its higher maximum compression stress (450 KPa). In contrast, Sample B (10% recycled polyol) displayed irregular and collapsed pores, resulting in a lower compression stress of 273 KPa.

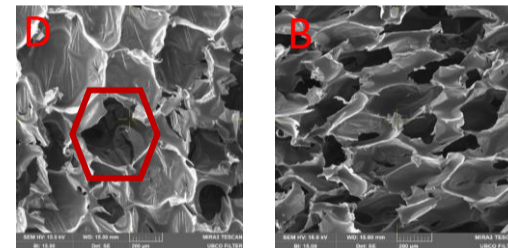


Figure 3: SEM image for the compression of the Form

Circularity Metrics

A multi-criteria decision-making approach (TOPSIS) integrated compression, density, dimensional stability, and thermal conductivity data, assigning weightings of 30%, 20%, 30%, and 20%, respectively. **Table 1** presents the resulting circularity scores, where Samples A (0.66) and D (0.63) emerged as top-performing formulations, surpassing even the virgin foam (0.61) in terms of overall sustainability-performance balance.

| Sample | Circularity Score | Rank |
|--------|-------------------|------|
| A | 0.66 | 1 |
| D | 0.63 | 2 |
| Virgin | 0.61 | 3 |
| E | 0.49 | 4 |
| F | 0.49 | 5 |
| C | 0.44 | 6 |
| B | 0.4 | 7 |

Table 1: Circularity Score

Overall, these findings emphasize that properly optimized recycled polyol formulations can yield foams with near-virgin-like performance in mechanical, thermal, and durability aspects, thereby supporting circular economy objectives.

Conclusion & Next Steps:

This research validates a practical path toward a circular economy in polyurethane foam production by demonstrating the successful chemical recycling of waste foam from airport luggage carriers. The optimized glycolysis process, employing a combined DEA:NaOH (1:1, 5 wt%) catalyst, produced recycled polyols with high functionality (>3) and suitable hydroxyl values (>300 KOH/g). When blended with commercial polyols at up to 50% content, these formulations yielded rigid PU foams whose mechanical, thermal, and UV-resistance properties closely paralleled or even surpassed those of virgin foam. Notably, a 30% recycled polyol formulation (D) offered an ideal balance, as evidenced by multi-criteria decision-making analysis (TOPSIS), which placed it just behind the highest-scoring formulation. These results confirm that repurposed polyols can maintain or exceed the performance of virgin materials while reducing landfill waste and virgin petrochemical consumption. Future work should examine scaled-up production, cycle assessment, and long-term durability to further advance this promising technology.

References:

- Donadini, R.; Boaretti, C.; Lorenzetti, A.; Roso, M.; Penzo, D.; Dal Lago, E.; Modesti, M. *Chemical Recycling of Polyurethane Waste via a Microwave-Assisted Glycolysis Process*. *Polymers* **2022**, *14* (15), 3052. <https://doi.org/10.3390/polym14153052>.
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