Application of Recycled Mattresses for Composite Industries

Final Report

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Introduction

Composites are versatile materials fabricated by combining two or more constituents to enhance physical properties. Their diverse range of applications and tunability makes them core components in a wide variety of industrial sectors such as aerospace, automotive, marine, electronics, and biomedical, among many others. Despite their importance, composites face some challenges such as poor environmental impacts, high feedstock costs, complex manufacturing processes, and low recyclability. To counter that, it is deemed necessary to develop composites that can offer the use of low-cost materials, facile processing techniques, satisfactory properties, and sustainable manufacturing to enable a circular economy. The achievement of these requirements is highly desired in the composites industry. This research describes the fabrication of a polyurethane composite with satisfactory mechanical and flame-retardant properties derived from low-cost and renewable sources including soybean oil and mattress waste.

Polyol, one of the starting materials for polyurethanes was synthesized using soybean oil which is a suitable bio-renewable material that is largely produced worldwide. The presence

of double bonds in the structure of soybean oil allows for a diverse number of chemical modifications to obtain polyols with different structures that can be used to make polyurethanes. TiO_2 was introduced in the polyurethane formulation as a low-cost additive to improve mechanical and thermal properties. The flame-retardant properties were introduced through the addition of melamine, a nitrogen-based compound that can chemically extinguish a fire through the formation of a compact carbonaceous layer along with the evolution of ammonia which can dilute reactive species formed from a combustion process as well as dilute the oxygen present in the neighbor environment. Lastly, non-woven recycled mattress textiles were incorporated in the polyurethane formulation to repurpose materials that would otherwise end up in a landfill. This work presents a sustainable and efficient manufacturing process of a polyurethane composite with versatile and satisfactory properties that may be suitable in construction, automotive and other applications. The details of the procedures used, and the results are summarized in this report.

Experimental Procedure

Additive sample materials (shoddy, coconut fiber (coir), cotton, and TiO_2) were placed in an oven at 60° C for two hours prior to use. Prior to drying in the oven, specifically shoddy and cotton were pulled apart into pieces approximately the size of a quarter and coir was cut with utility scissors into lengths of 16-18 mm. After drying, shoddy, cotton, and coir were subjected to sheering using an in-house blender. Each material was divided in half and sheered twice, with two 15-second time intervals for shoddy and cotton and two 30, 1-second pulses for coir.

The mold was cleaned and prepped using mold cleaner and mold release agent prior to sample curing. TiO_2 powder was added to the soybean polyol under mechanical mixing for a time length proportional to the total preparation/batch size. For a 360-gram preparation, TiO_2 was mixed for 10 minutes, whereas for a 120-gram preparation, TiO_2 was mixed for ~three minutes. For additional melamine composite preparations, melamine was added after the addition of TiO_2 and mixed for ~three minutes as well. Methylene diphenyl diisocyanate (MDI) was then added and mixed for the same time lengths indicated above. Prepared samples of cotton and coir were then placed in a glass dish and the liquid mixture was poured over top of the material in a crisscross pattern, rotating the dish 90° degrees, and repeating the crisscross pattern until the sample volume was diminished. This material/liquid preparation was then mixed by hand for ~ five minutes until the material was thoroughly coated. Any remaining liquid in the mixing cup was removed by scrapping with coated material.

The material was then placed in the mold using a rocking motion with two fingers to fill the space evenly with additional material. For the 360-gram shoddy and cotton batches, all five empty slots were used. For 120-gram cotton-melamine and coir batches, three of five empty mold slots were filled with previously made samples to prevent spillover within the mold

while curing. The two empty cavities were spaced equally apart with previously made samples flanking on both sides. The mold was closed with bolts tightened in a right-to-left fashion with the incorporation of two large c-clamps over the central body of the mold. The mold was placed in a preheated oven with an average temperature of 90°C for two hours, after which the mold was removed and allowed to cool for at least two hours before opening.

After the cured samples were removed from the mold, the dimensions and weight were recorded for density calculations. Using a band saw, the sample block was then cut, into eight pieces for compression studies. For TGA and DSC studies, a thin sheet of a remaining sample was cut in such a way as to preserve an outside edge resulting in a non-cut and cut side samples. Circular samples were then punched out of the thin sheet for analysis. For cotton-melamine burn testing, samples were cut into equally thin sheets such that each thin sheet had two cut sides. They were then placed on a wire frame holder and exposed to an open flame for 10 seconds with total burn time recorded from that point on.

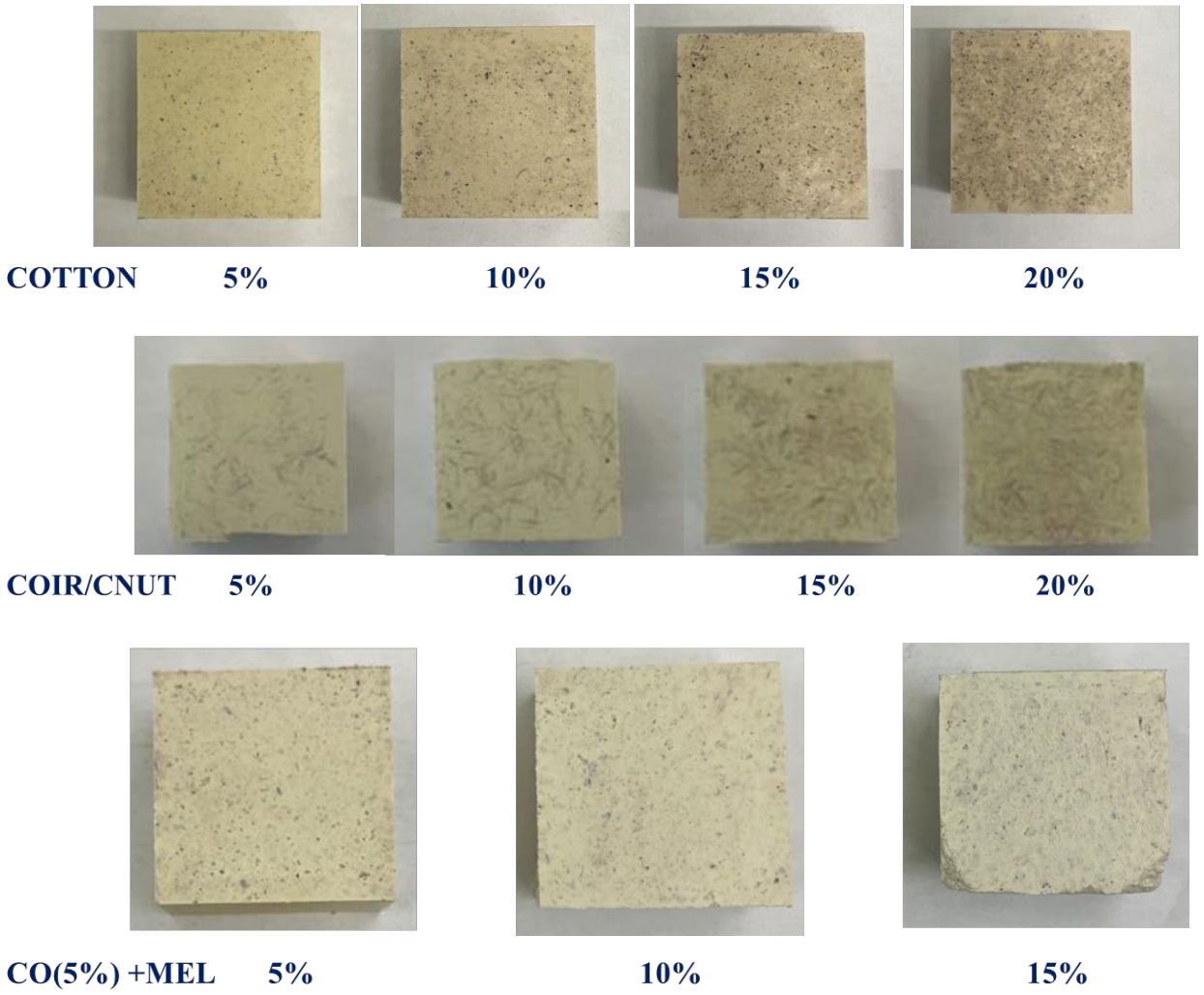
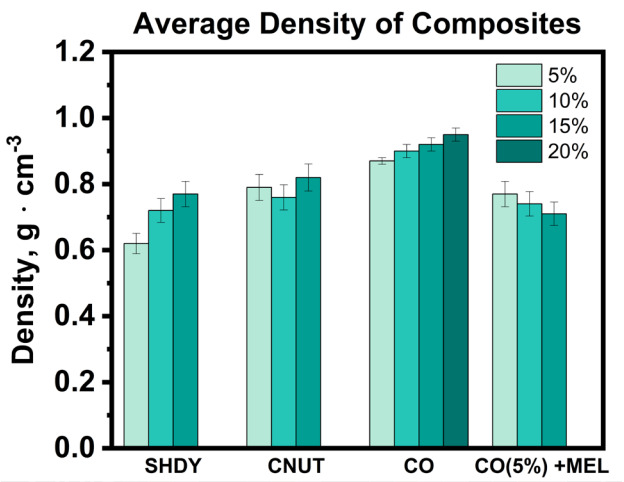
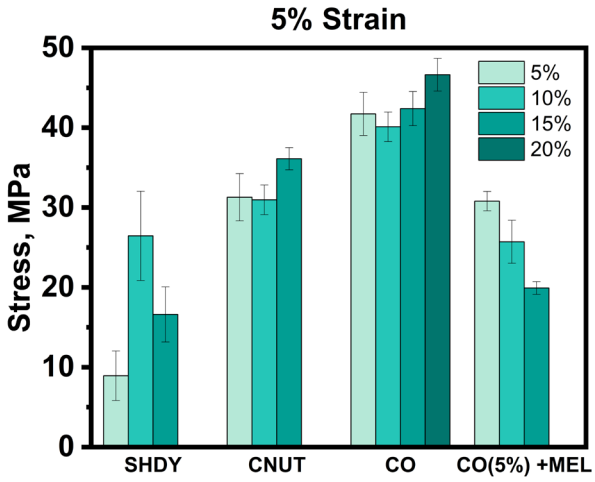


Figure 1: Digital photos of some of the composites.

Density of Materials & Compressive Strength

On average, most composite samples consisting of 3% TiO_2 and fiber (TF), increased in density with increasing fiber. This, however, did not directly correlate with increased stress values at 1%, 3%, and 5% strain. The results indicate a bimodal distribution for increasing stress values for coir and cotton samples with a normal distribution for shoddy centering around the 10% TF sample. Cotton samples exhibited the highest average compression strength overall with an increasing trend of density and fiber percentage. Fiber percentages at or above 20% proved difficult to fabricate with current protocols and may warrant further exploration given the increased stress values shown at 15% and 20% for coir and cotton samples, respectively. Regarding increasing amounts of melamine, there is a direct correlation between increasing amounts of melamine and reduced density and compression strength. This is assumed due to the increasing disruption of the polyurethane crosslinking network by the melamine, resulting in a trade-off between increasing resistance to flammability and overall compressive strength given current formulations.





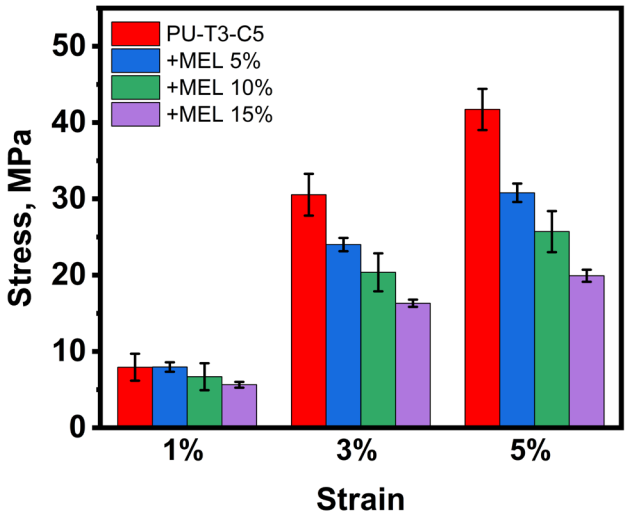
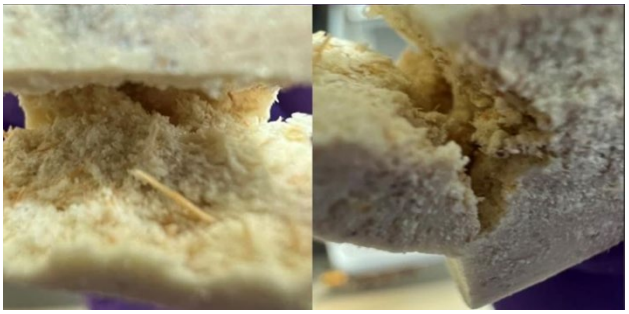


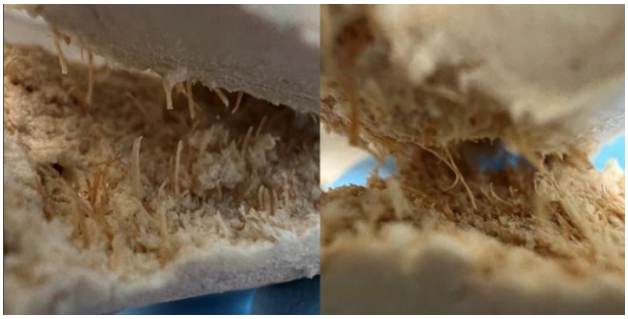
Figure 2: Average density and compressive strength of the composites prepared using shoddy, coir and cotton.

Inspection of the interface in compressed samples showed increasing amounts of fibers as shown below. Differences between the two highest-performing TF samples (coir and cotton) show differences in overall structure with an increasingly flatter surface for cotton samples versus a marked visual increase of a jagged break with smooth coir fibers. This hints at increased interaction between the polyurethane crosslinking and cotton fibers versus that of the coir. This is also evident in the picture below for PU-T3-COTTON20, as such samples exhibited no large-scale breaks during compression.

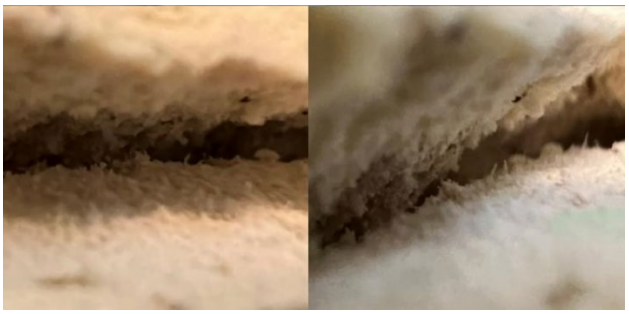


PU-T3-CNUT5

PU-T3-CNUT10



PU-T3-CNUT15



PU-T3-COTTON5

PU-T3-COTTON10

PU-T3-COTTON15

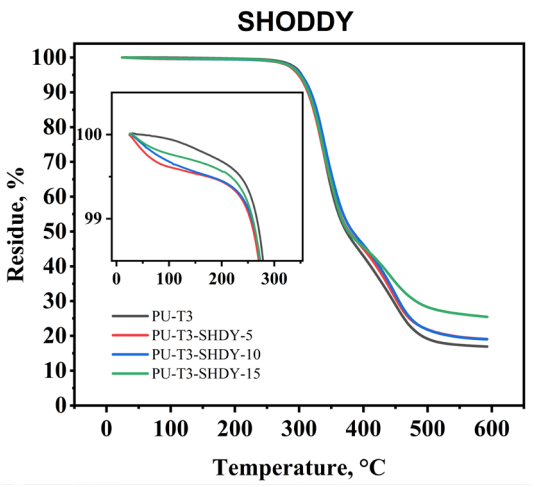
PU-T3-COTTON20

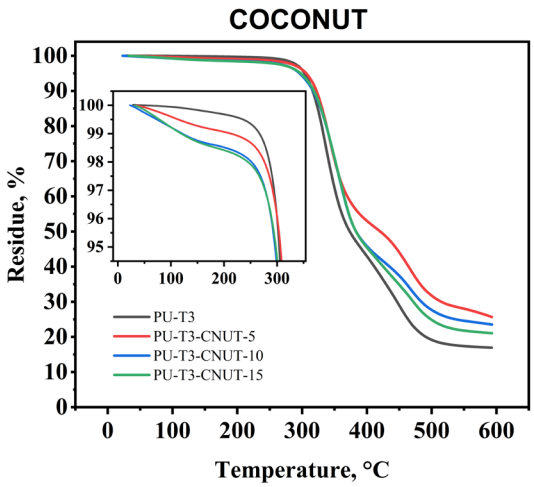
Thermogravimetric Analysis

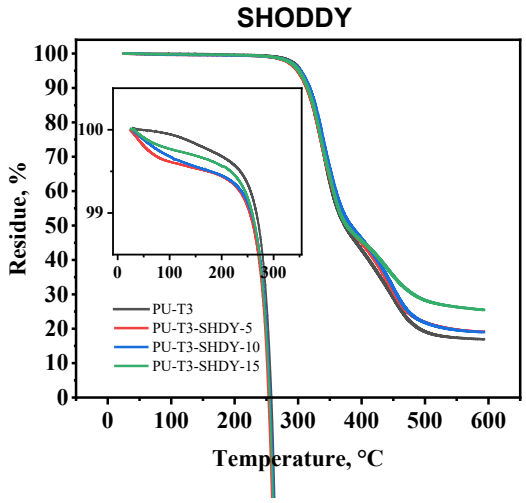
Overall TF samples showed high stability with 2% sample degradation values at or above 245°C for shoddy/coir/cotton samples and 230°C for additional cotton-melamine samples. On average, the change of degradation for TC samples was 6% or 17°C for shoddy/coir/cotton samples. TF Samples with the lowest content of added fiber had values closest to PU-T3 samples. Residue percentages varied among TF samples with the highest value of 27% for 5% cotton while composites of 5% cotton and melamine exhibited residue percentages within 2% of polyurethane-TiO_2.

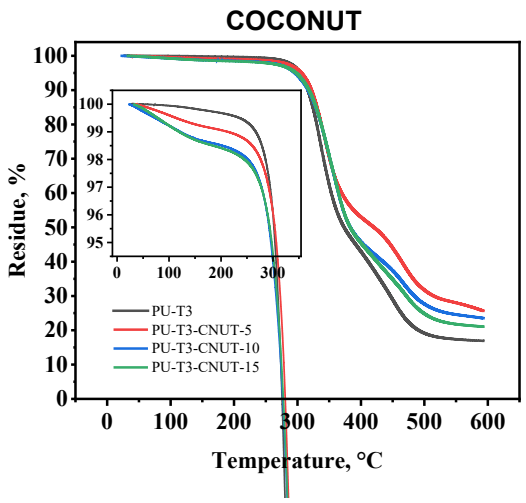
TGA Onset Temperature, PU-TiO_2-Shoddy-Coir-Cotton-Melamine Composites

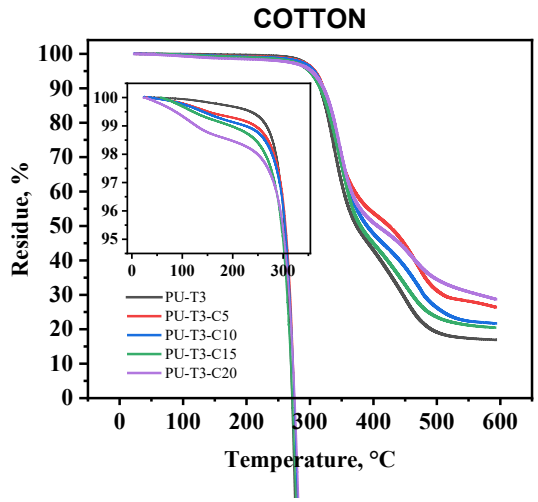
Sample	2%, °C	5%, °C	50%, °C	Residue % @591 °C
PU-T3	286	304	374	17
PU-T3-SHDY5	279	299	378	19
PU-T3-SHDY10	282	303	383	19
PU-T3-SHDY15	281	301	377	26
PU-T3-CNUT5	276	306	421	26
PU-T3-CNUT10	252	296	383	24
PU-T3-CNUT15	245	298	383	21
PU-T3-C5	282	307	425	27
PU-T3-C10	278	306	390	22
PU-T3-C15	265	299	380	20
PU-T3-C20	249	302	407	29
PU-T3-C5 +MEL 5%	257	286	381	19
PU-T3-C5 +MEL 10%	230	269	366	18
PU-T3-C5 +MEL 15%	242	270	359	19

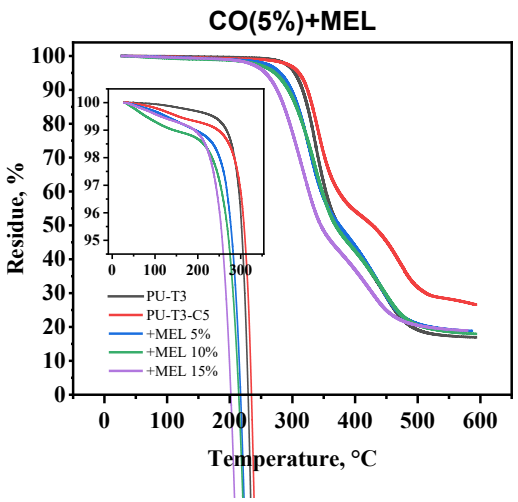

SHODDY
Residue, %
Temperature, °C
PU-T3
PU-T3-SHDY-5
PU-T3-SHDY-10
PU-T3-SHDY-15


COCONUT
Residue, %
Temperature, °C
PU-T3
PU-T3-CNUT-5
PU-T3-CNUT-10
PU-T3-CNUT-15


SHODDY
Residue, %
Temperature, °C
PU-T3
PU-T3-SHDY-5
PU-T3-SHDY-10
PU-T3-SHDY-15


COCONUT
Residue, %
Temperature, °C
PU-T3
PU-T3-CNUT-5
PU-T3-CNUT-10
PU-T3-CNUT-15


COTTON
Residue, %
Temperature, °C
PU-T3
PU-T3-C5
PU-T3-C10
PU-T3-C15
PU-T3-C20


CO(5%)+MEL
Residue, %
Temperature, °C
PU-T3
PU-T3-C5
+MEL 5%
+MEL 10%
+MEL 15%

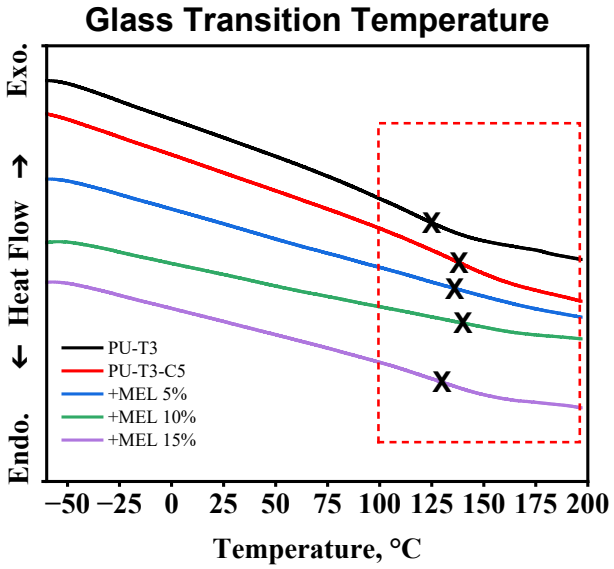
Differential Scanning Calorimetry Analysis

TF samples showed consistent stability across sample composition and heating cycles. Addition of melamine to 5% cotton also showed high stability with an overall change of less than 2 °C for 10% melamine and 4 °C for 15% melamine in *Tg* values.

DSC, *Tg*, PU-TiO2-Shoddy Coir-Cotton-Melamine Composites

Sample	*Tg*† , °C	Sample	*Tg*‡ , °C	Sample	*Tg*‡ , °C	Sample	*Tg*‡ , °C
PU	64	PU-T3	125	PU-T3-C5	138	PU-T3-C5 +MEL 5%	137
PU-T3-SHDY5	64	PU-T3-CNUT5	132	PU-T3-C10	125	PU-T3-C5 +MEL 10%	136
PU-T3-SHDY10	66	PU-T3-CNUT10	127	PU-T3-C15	122	PU-T3-C5 +MEL 15%	140
PU-T3-SHDY15	67	PU-T3-CNUT15	138	PU-T3-C20	126	-	-

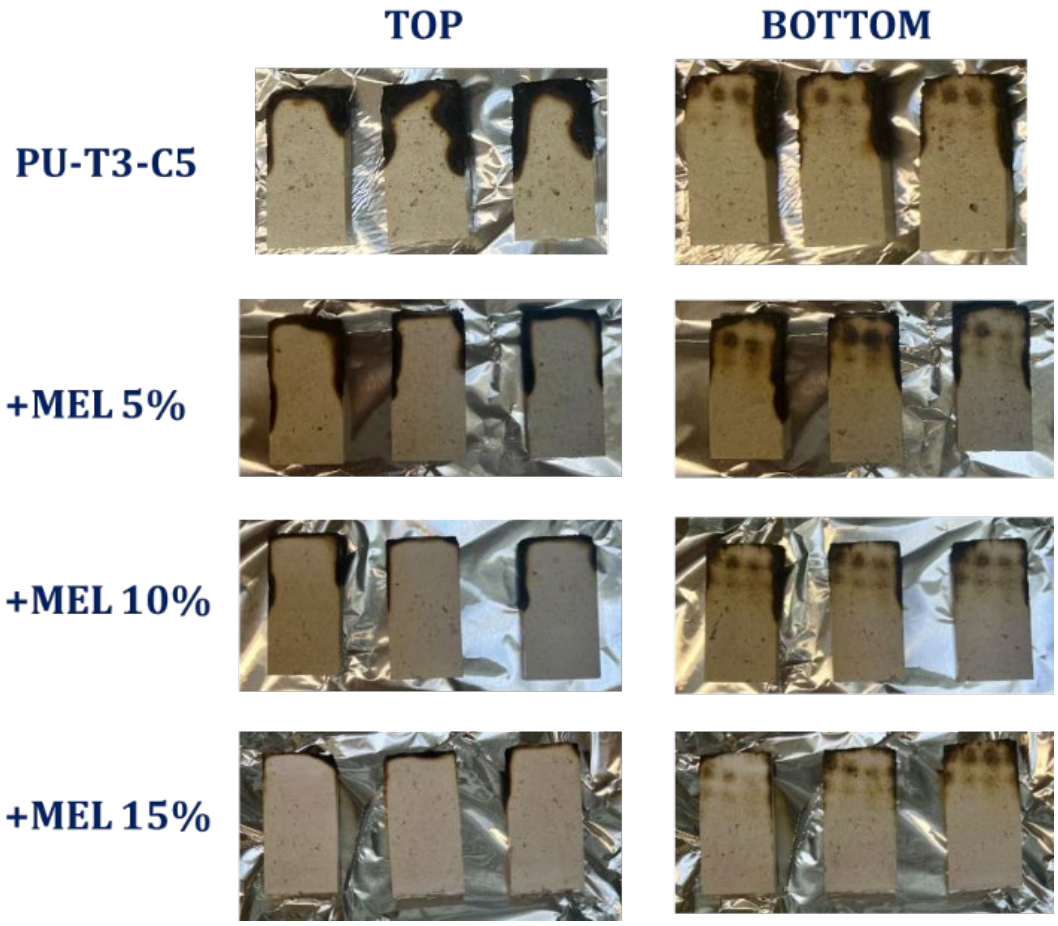
† - 1st Heating Cycle ‡ - 2nd Heating Cycle

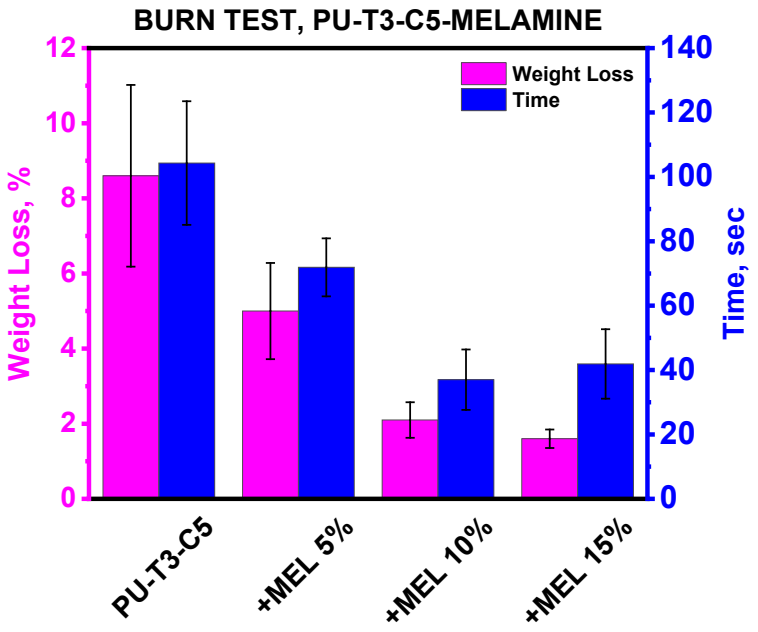


Burn Test Analysis

TF samples consisting of 5% cotton were selected for further study with the addition of melamine as a flame retardant due to high compressive strength and ease of fabrication. Burn test results show a decrease in burn time with the addition of melamine with the lowest amount of weight loss for 15% melamine and the greatest reduction in burn time for 10%

melamine. These results indicate a diminishing rate of return for melamine levels above 10% for 5% cotton TF samples.





Summary

Low carbon footprint, flame resistant composites with excellent physical properties were successfully produced using a mix of bio-based materials and recycled mattress textiles. The broad range of formulations developed demonstrates the ability to tailor performance to specific applications.