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Fire Behavior of 3D Printed Wooden PLA Materials

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Abstract

The reaction of building materials to fire drastically changes the type of response firefighters enact on an emergency scene. The National Fire Protection Association has standards for traditional constructions that dictate the safest methods of attack, extrication, and scene set up; however, with the advent of 3D printed homes made of wood reinforced polylactic acid (PLA), departments are not prepared for the unique challenges it may present. With the binder being a thermoplastic, concerns arise about the material melting when exposed to heat and releasing more toxins than traditional building materials. This paper aims to study the fire behavior of 3D printed wood reinforced PLA coupons and compare it to the reaction of standard PLA and modern construction materials. The two main areas of concern are fire spread and structural integrity, which both play a major part in determining the correct emergency response. These will be evaluated with a fire propagation test and a qualitative observation of the materials' response to heat. Following the ASTM D635 standard, the rate of burning in a horizontal position will be able to be determined with standardized test coupons of plain PLA and wood reinforced PLA. For each material, 10 tests will be conducted. From this, a UL94 rating should be determined. This procedure serves to show how the materials will contribute to the fire load in a structure fire. For this test the behavior of the burned and melted plastics will be observed. This research is currently in progress, but the findings will be used to evaluate the potential hazards of homes using wood reinforced PLA. Understanding the potential differences the material contributes to the ferocity of the fire is vital.

Introduction

In 2022, the University of Maine Advanced Structures and Composites Center unveiled a completely bio-based 3D printed home[1]. It is a fantastic innovation that uses a large-scale 3D printer to print the entire 600 square-foot home using a filament made of wood dust from recycled forest products suspended in resin. The design was created with the hope of providing a sustainable affordable housing option for Maine residents. The home cuts down on manufacturing costs and waste and is protected from supply chain disruptions and labor shortages that drive housing prices up. While there are other 3D printed homes that use concrete, the University of Maine's wooden design is truly the first of its kind. This, however, brings to light the issue of how it will react in a fire.

Firefighters must do pre-incident surveys of housing complexes and buildings in their community, part of which includes building construction type. There are five types of building construction according to NFPA 5000, Building Construction and Safety Code, with manufactured homes like these being most similar to Type 5 construction[2]. However, manufactured homes do not need to comply with these standards and instead follow the HUD's code that promotes more innovations in construction. These types of homes have the least fire resistance and are often in even more danger due to the lightweight building materials and fewer interior compartments, contributing to rapid fire spread. The pre-incident surveys should capture these potential concerns, including if there is any added risk from the thermoplastic based material. Especially if groups of these small homes are set up together in a tight arrangement, the possibility of fire spreading to other nearby homes increases dramatically. Firefighters need to be aware of how these homes may behave differently than typical structure fires and what is required to maintain the safety of the residents and the crew.

In order to observe the fire propagation rate, the procedure will be based on the ASTM D635 standard test method for rate of burning and/or extent and time of burning of plastics in a horizontal position[3]. From this procedure, a UL94 rating can also be gotten, which is a standard that quantifies a plastic's flame spread and dripping behavior[4].

Experimental Setup

The test coupons will be made from standard matte PLA and a wood filled PLA filament from Laywoo-D3. This filament uses a standard PLA base with a 40% wood filling resulting in a density of 1.24 g/cm^3. Ten test coupons will be made from each material. They will be printed with a Bambu Lab A1 printer, as directed by the manufacturers, with 100% infills. The coupons will be 127mm long, 13mm wide, and 13mm thick, as shown in Figure 1. Two reference lines will be marked on the coupons at 25mm and 100mm away from the ignition end. For the active experiment, the entire setup as shown in Figure 2, will be within a fumigation hood. The coupons will be clamped on one end and positioned horizontally, using a level to check for angle. A propane torch with a neck angled at 45° will be used to ignite the other end.

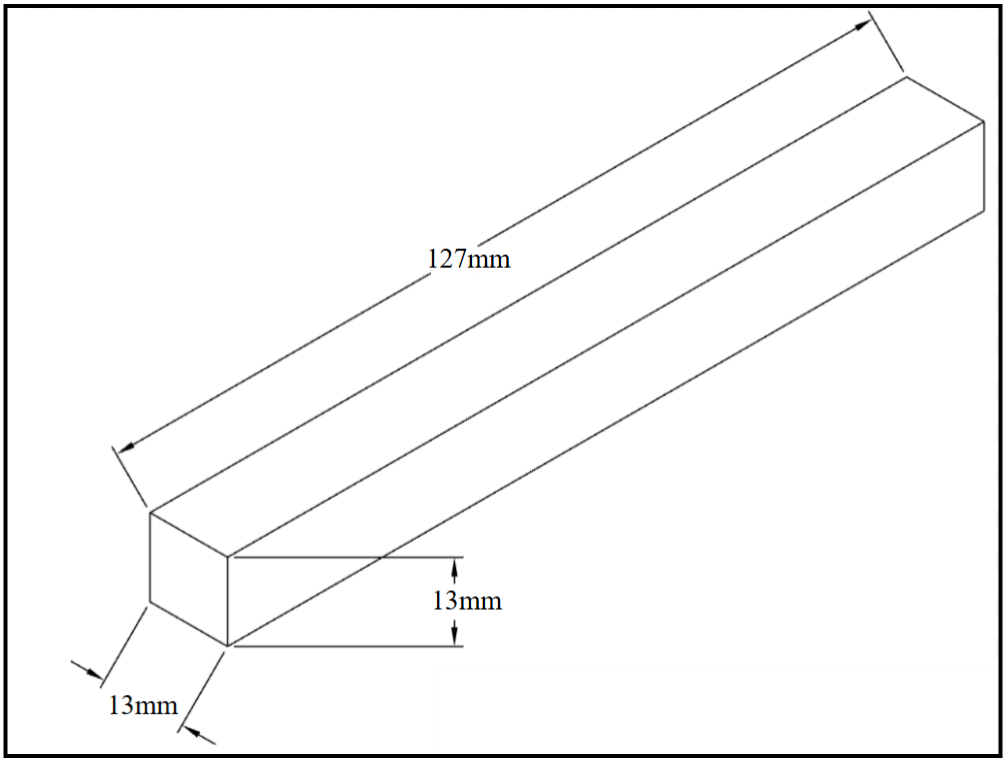

Figure 1. Isometric View of Test Coupon

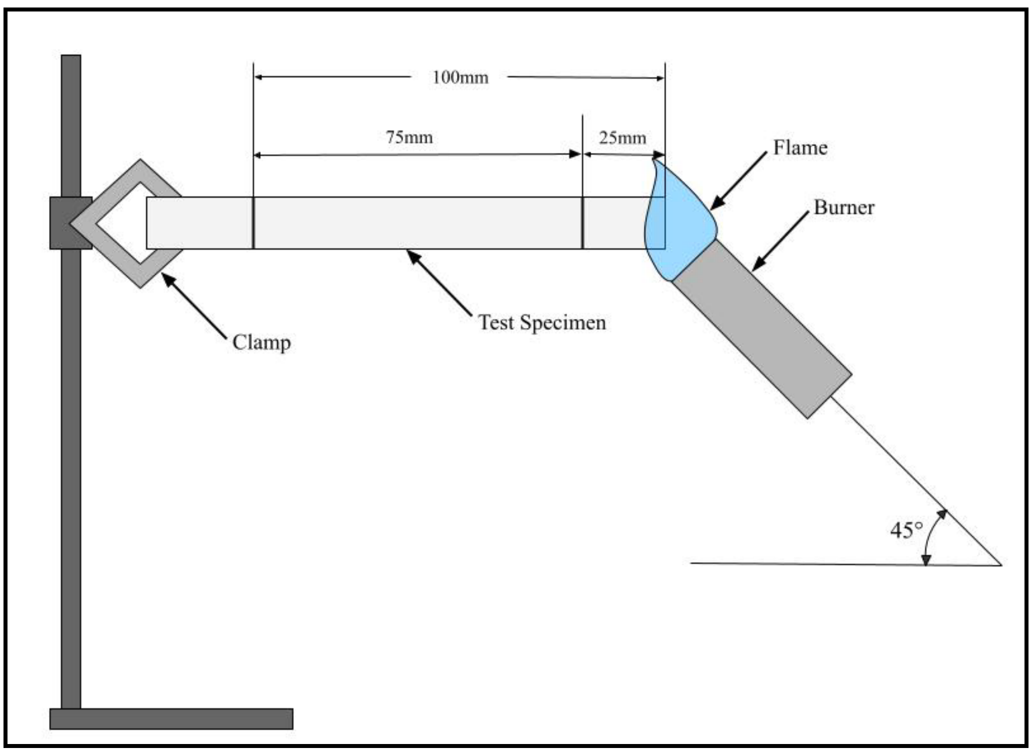

Figure 2. Experimental Setup

Procedure

The test coupon is held in the horizontal position. Ignite the propane torch away from the coupon and adjust the flow until there is a blue flame 20mm in height. Apply the flame to specimen for 30 seconds with at least 6mm of the material in the flame. Remove and turn off the torch. Beginning when the leading edge of the flame crosses the first mark on the test coupon, time how long it takes for the flame to burn 75mm to the second reference line on the coupon. At this time extinguish the flame.

Data

Table 1 - Standard PLA Burn Data

Standard PLA Test	Burn Time for 75mm (min)	Fire Propagation Rate (mm/min)
1	7:53	9.51
2	7:33	9.93
3	7:15	10.34
4	6:53	10.89
5	7:03	10.64

Table 2 - Wood Filled PLA Burn Data

Wooden PLA Test	Burn Time for 75mm (min)	Fire Propagation Rate (mm/min)
1	3:36	20.83
2	3:23	22.17
3	2:53	26.01
4	3:09	23.81
5	4:37	16.25

The current average fire propagation rate for traditional PLA material is 10.26 mm/min and 21.81mm/min for the wood filled PLA material, more than double the rate of standard PLA.

Results and Observations

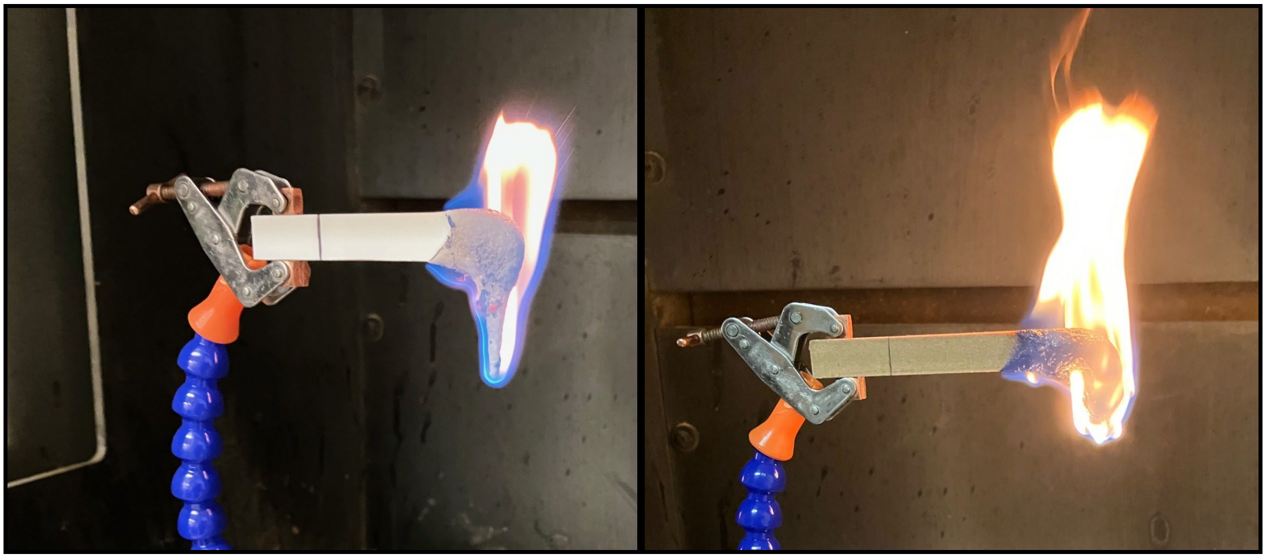

Figure 3. Standard PLA (left) and Wood Filled PLA (right) Coupons During Testing

Figure 3 shows the two specimens as they are actively burning. The standard PLA had a much smaller and hotter blue flame that burned consistently and slowly. Though some bits of plastic char, the majority burns and becomes molten, dripping off. The plastic did not self-extinguish, even after falling, but continued to burn. The wood filled PLA behaved differently. The flame was taller, and the flame front quickly caught and burned up the sides of the coupon. Much less of the material melted off but charred and stayed contributing to the fuel load.

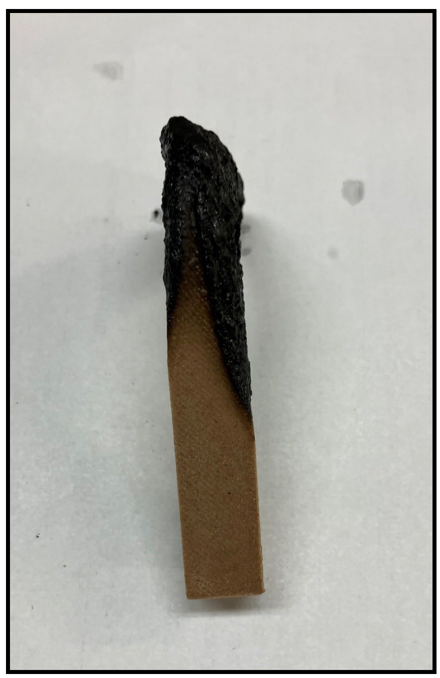

Figure 4 - Extinguished Wood Filled PLA Coupon Top View

As seen in Figure 4, the front flame on the wood filled PLA specimens quickly caught and extended up the sides, forming a V shape on the top. With a flame propagation rate of nearly double the standard PLA, this behavior was not seen in the other group.

Figure 5. Specimens after testing compared to original size of the coupons with Standard PLA (bottom) and Wood Filled (top)

Figure 5 shows the specimens after the flame was extinguished. The materials both retained heat for a while and continued to deform under their weight. The standard PLA dripped and continued to melt more smoothly than the wooden coupon that charred and hardened quickly. As seen above, the burned wood filled PLA coupon is longer than the burned standard PLA, showing how the flame caught and spread on the outside of the test piece before melting and burning the front face consistently.

Conclusion

The wood filled PLA specimens, as expected, burned much faster with a flame propagation rate of more than double the standard PLA tests. This procedure was meant to measure the flame propagation rate horizontally, but in a practical scenario the flame would travel vertically up the walls of a home and add to the fire load. This means it would propagate even faster, serving as a large concern in an emergency. With the rising heat of a component or structure fire, the material could easily begin melting and potentially fail under the load of the house. This testing does not fully encapsulate all the factors that real fire conditions present, so an expansion of this experiment would be very interesting and beneficial. Going forward, a greater array of tests should be done with this procedure, and the experiment should be extended to compare the wood filled PLA material to traditional building materials like oriented strand board.

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