REDEFINING WASTE:
REPURPOSED POST-CONSUMER BAGS AS VAPOR BARRIERS

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ABSTRACT

One of the several facets of building science lies at the interface of chemistry and architecture, where interdisciplinary collaboration draws upon knowledge from each field to develop, assess, and implement novel construction materials. The authors have used principles from these disciplines to explore the feasibility of a vapor impermeable material made from redirected post-consumer waste.

The applicability of thermally fused high-density polyethylene grocery bags as vapor retarders in building envelopes has been studied. Repurposed polyethylene grocery bags were fused using a standard household iron. Sample thickness was varied between 2 and 6 mils. Each sample was subjected to a closed-system water vapor pressure differential for two hours. The amount of water passed through the membrane was measured gravimetrically. The durability was also assessed by measuring the amount of downward force required to create a tear in a sample. Both vapor permeability and durability of the prepared samples were compared against several standard vapor retarders, including both 2- and 6-mil virgin polyethylene. Comparisons of data sets from both experiments demonstrate that the fused repurposed grocery bags are equally vapor impermeable as the standard virgin polyethylene, and the 4- and 6-mil fused samples are equally or more durable than the measured standards. These results indicate that such materials are viable, more sustainable alternatives to currently used materials. Potential mass-fabrication strategies of the material are also explored.

1. INTRODUCTION

The U.S. is addicted to high-density polyethylene (HDPE). In 2007, Americans generated 590,000 tons of HDPE bags and recovered only 11.9% of the virgin material[1]. The remainder of the bags went to landfills, blocked waterways, and endangered wildlife[2], and, because of the material's resistance to degradation, continue to persist in the environment[3]. Unbleached paper bags are thought to be a more environmentally conscious alternative; however, life cycle analysis confirms that HDPE grocery bag production is more resource efficient than that of unbleached paper bags, as it requires 20-40 percent less energy and produces 63-73 percent less atmospheric emissions[4]. Unfortunately, the end-of-life phase of the life cycle renders the material less attractive, as recycled HDPE has limited applicability[5].

Plastic bag recycling efforts are becoming more prevalent[6], but the integrity of the plastics is compromised each time it is recycled[7]. Ideally, a cradle-to-cradle alternative could be implemented in which these polymers are repurposed (Figure 1), thereby maintaining the material's integrity and reducing both economic and the environmental costs associated with virgin plastic production. The collection of these plastic bags for repurposing may signal a shift in infrastructure, as there are currently no curbside recycling collection programs specifically for these HDPE bags. In theory, the collection of these bags could be integrated into existing curbside recycling programs. The only major addition to this system would have to be a sorting method for this material.

HDPE has a relatively high melting point (108-134ºC); therefore, the material can be heated at low temperatures and reformed into a new post-consumer product. The application of gentle, evenly distributed heat can fuse thin films of HDPE, creating large, durable sheets of various thicknesses. This technique was used to fuse layers of HDPE grocery bags. One potential application for such a material is as a vapor retarder in a standard wall assembly, as vapor retarders are typically made from HDPE[8]. A vapor retarder, as differentiated from a moisture barrier, is a layer of material intended to resist the diffusion of water vapor through a wall assembly[9]. Both the durability and vapor impermeability of such a material have been tested and compared to standard HDPE vapor retarder materials.

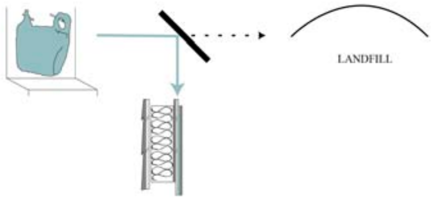

Figure 1. Diversion of HDPE from waste stream to wall assembly

2. HYPOTHESIS

Layers of repurposed HDPE grocery bags can be thermally fused to create materials with comparable durability and vapor impermeability to commercially available HDPE vapor retarders.

3. METHODOLOGY & EQUIPMENT

Glossary

High-density polyethylene (HDPE): Polyethylene thermoplastic made from petroleum. Its chemical structure gives the polymer stronger intermolecular forces and tensile strength and higher melting point than lower-density polyethylene.

Low-density polyethylene (LDPE): A low density polymer with far more chemical branching than HDPE and, consequentially, far weaker intermolecular forces. This results in lower density, decreased tensile strength, increased malleability and faster biodegradation.

Linear low-density polyethylene (LLDPE): A linear polymer with significant numbers of short branches. Physical properties include poor elasticity and low tensile strength

Mil: Unit of length representing 0.001 inch.

Vapor retarder: A layer of material intended to resist the diffusion of water vapor through a wall assembly[9]; also known as vapor barrier.

Vapor Permeance

0.5-mil polyethylene grocery bags were used for all materials. Bag handles were removed and seams were cut so that the bags were laid flat. Layers of bags were placed on top of one another and fused using a standard household iron. The bags were placed between two layers of waxed paper before fusing to prevent melting to the iron. The waxed paper was then peeled off of the polyethylene sample and reused in subsequent material fabrications.

Figures 2 and 3 show the experimental set-up that was used for each trial. A 250-mL Erlenmeyer flask was filled with 50 mL water. This flask was placed in a 100º C mineral oil bath controlled by a Variac temperature controller. The top of the flask was covered with a sample of vapor retardant. A second flask was inverted and placed on top of the sample. A rubber filter adapter placed between the two flasks ensured a tight seal between the flasks and the material. A water vapor pressure differential was established by subjecting the water to heat from the oil bath, whose temperature was monitored by thermometer. The amount of water passing through the membrane was measured using a 4 gram sample of anhydrous sodium sulfate placed on top of the sample. The mass of the sodium sulfate dessicant was obtained before and after the experiment; the difference in mass represents the amount of water passed through the membrane. The type and thickness of material were individually varied.

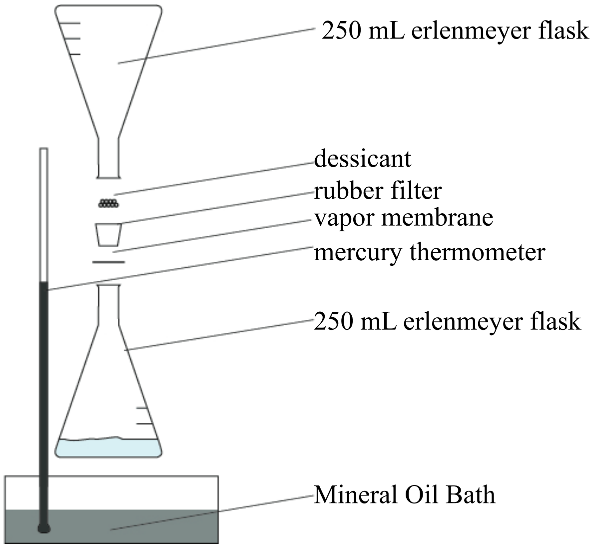

Figure 2. Experimental setup
for vapor permeability measurements.

Figure 3. Water vapor permeability test.

Durability

6-inch by 6-inch samples were stapled three inches from the edge of a piece of plywood. The staple was placed in the middle of the sample. A piece of nylon cord was then duct-taped to the top of the sample. This cord went through a pulley clamped to the edge of the work surface (Figure 4a). Friction in the pulley was assumed to be negligible. Mass at the end of the cord was increased until an 0.125 inch tear was observed in the material, just below the staple. The tearing was measured using digital calipers as shown in figure 4b.

Figure 4a. Tensile strength test

Figure 4b. Tear measurement using electronic calipers

RESULTS

Vapor Permeance

The vapor permeance of both the fused and standard polyethylene materials were tested using the experimental setup described in Figures 2 and 3. A sample of Tyvek moisture barrier was also measured to assess the validity of the experimental design. The results of these experiments are shown in Table 1.

The only material demonstrating appreciable change in mass was the Tyvek moisture barrier, which is engineered to be vapor permeable. Thickness of the material does not appear to influence its vapor impermeability properties, as all samples showed constant mass over the course of the two-hour experiment.

Table I. Vapor permeability results

Material	Initial mass (g)	Final mass (g)	Change (g)
2-mil fused PE	4.2	4.2	0.0
4-mil fused PE	4.0	4.0	0.0
6-mil fused PE	4.2	4.2	0.0
Husky 2-mil PE	4.0	4.0	0.0
TYVEK	4.0	4.5	0.5

Durability

The durabilities of fused samples of varied thickness were also measured against the standard polyethylene materials. Each sample was tested four times. Table II and Figure 5 show the mean forces sustained by each material before a 0.125-inch tearing was observed.

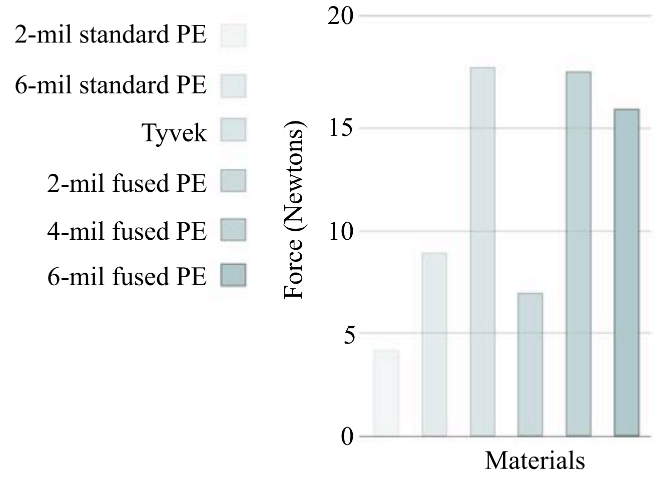

Figure 5. Results of durability test

Table II. Material durability results

Material	Force (N)
2-mil standard PE	4.2 ± 0.9
6-mil standard PE	9 ± 2
TYVEK	18 ± 9
2-mil fused PE	7 ± 3
4-mil fused PE	17.8 ± 0.1
6-mil fused PE	16 ± 5

5. DISCUSSION

As a result of this study, it became apparent that the fusing of HDPE grocery bags worked well if there was an even distribution of heat and pressure from a single side. If the material is thicker than 4 mil, fusing the bags together with a common household iron becomes difficult. If heated too quickly or with excessively high temperatures, the outer layers melt while the inner layers do not properly fuse, resulting in non-uniform, somewhat perforated materials. It is unknown whether this situation will be the same when industrial machinery is used. The fusing technique can be used in connecting multiple fused sheets together, creating a continuous sheet to serve as a vapor barrier in wall systems. Further experimentation is needed to determine the optimum fabrication techniques. The authors would like to explore heating from two sides, which would allow for a lower temperature to be used and for heat to be distributed more evenly. Processes were conducted in a small-scale atmosphere, so it remains unknown whether similar problems will exist when large-scale machinery is used.

Manufacturing

Having tested and proven thermally fused HDPE grocery bags to be a comparable vapor retarder, further investigations were made regarding the plausibility of manufacturing such a product.

In 2008, 832,394,000 pounds of post-consumer film was collected for recycling . This statistic includes HDPE, LDPE, and LLDPE products[10]. The authors found that the amount of plastic film currently collected would supplement the mass production of this fused material in its beginning stages. Therefore, the only immediate change to be taken would be the diversion of these bags from the current recycling stream into one of repurposing. Herein lies one of the main benefits of the proposed manufacturing methods. Instead of used HDPE bags being melted down and reformed into continuous sheets, bags would skip the recycling process and be fused together at low temperatures, saving energy while maintaining a higher quality product. Production of these vapor retarders on a larger scale would signal a more substantial change in infrastructure, and the authors have proposed potential changes in the future work section of this paper.

In order to manufacture such a product on a large scale, a new method would have to be developed, hopefully one which could easily be integrated into factories' existing processes. In order for this transition to be seamless, the fabrication process of the fused grocery bags could stem from the current methods used to produce virgin HDPE film. Existing manufacturing procedures were studied in order to develop a new system that utilizes similar technologies. The following three-step process was conceived as a possible technique for fabricating this new product (Figure 6). Once the HDPE bags arrive at the factory, they can be stamped into approximately 4-mil sheets using a hot press. These rough sheets can then be combined into a single sheet by being lapped over one another and being fused at the edges by a second hot press. After these steps, the material would then pass through the lamination machinery currently being used to join plastic sheeting. This machinery uses a constant temperature from multiple rollers to fuse materials together and would tidy the seams and create a uniformly thick material.

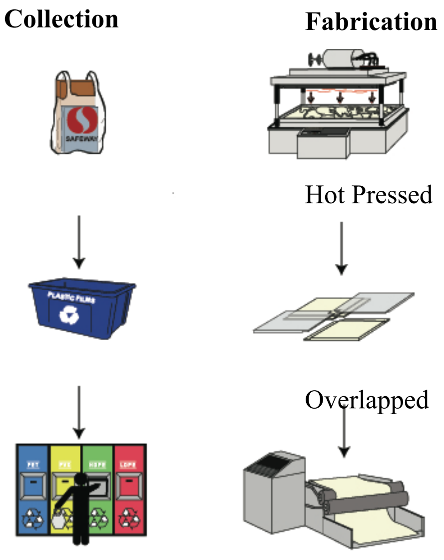

Figure 6. Collection and fabrication proposal

6. FUTURE WORK

The authors suggest that research would need to be done to explore ways of developing the fused HDPE material for large-scale commercial production and implementation. Five aspects regarding this implementation have been considered: scalability, optimization, compliance with American Society for Testing and Materials (ASTM) International standards, integration, and infrastructure.

Scalability

The methods presently described are applicable for small scale production. If this material is to be produced and implemented on a large-scale level, then the necessary industrial machinery must be developed. As mentioned, this machinery would ideally be very similar that which is currently used in the production of PE film.

ASTM Compliance

Standards exist that promote quality control of certain products and materials, and the proposed product would need to meet these requirements. ASTM code E96 addresses vapor transmission through film materials[11]; E154 addresses standards for materials used in slab-on-grade assemblies[12] (Figure 7); D1709 is a durability standard[13]. These are a sampling of codes with which our materials would need to comply.

Integration

Current municipal recycling programs exist, some of which incorporate the collection of more materials than others. However, if the proposed material is to draw from current recycling collection streams, several changes would have to be made. The collection of these bags would have to be made aware to the consumer, as many people do not often realize which materials are able to be recycled. Further, a more developed sorting process would have to be introduced into the process, where HDPE bags would be sorted for reuse, while other materials would be sorted for melting and recycling.

Infrastructure

Such strategies outlined above may require drastic changes to present recycling infrastructure. For example, collection bags may be need required for the separation of HDPE film from other recyclables. Also, collection sites may be needed to supplement the curbside system. These already located at grocery stores across the country; the only significant changes would be to increase their frequency and redirect them to a repurposing center for fusing as opposed to a recycling center for melting.

Optimization

Making so many changes to pre-existing systems requires time and iteration. Small-scale implementation affords the

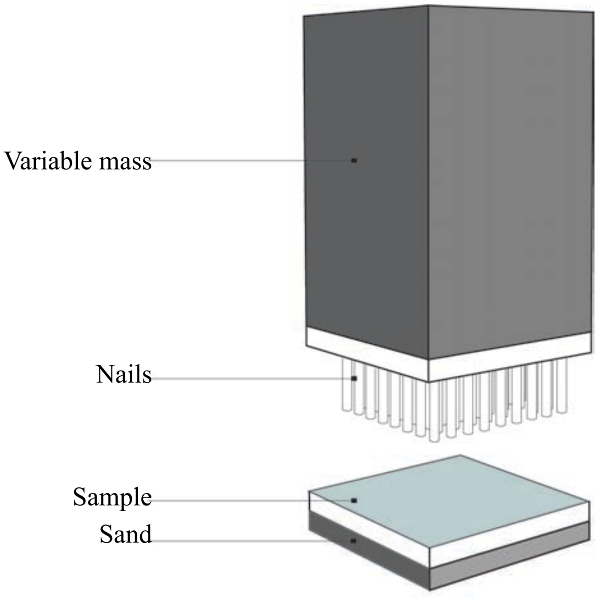

Figure 7. Vapor permeability testing of 2-mil fused polyethylene material.

opportunity to optimize systems to maximize energy and material efficiency prior to large-scale integration.

7. CONCLUSIONS

After implementing the concept and producing a fused material from used grocery bags, the study proved that the repurposed product is a viable and environmentally conscious alternative to conventional vapor retarders made from virgin polyethylene. The 4-mil fabricated sample was found to be the best proposed material because of its durability and adequate water impermiability. The 6-mil material proved to be less viable of an option since its thickness impedes heat diffusion to its central layers. This compromises the fusion of the interior layers, while burning the outside layers and creating small holes. Further, the 6-mil uses more material with no measured benefits, which contradicts the principles of using an environmentally conscious building product at all. Therefore, it was found that the 4-mil material is the preferred option in terms of performance, durability, and material efficiency.

In attempting to fabricate the material on a larger scale, issues of production, transportation, and installation quickly become relevant. If these challenges are resolved, then implementation becomes the only issue. On a small scale, the fused polyethylene could become an accepted building component because of its performance and durability, and the material's appeal only improves as production is scaled up, as this increases reduction to the wastestream. The scope of this project extends much farther than the implementation of a simple building material: It attempts to change the way waste is viewed and to reduce environmental impact through the collaboration of multiple disciplines. This section can and should conjecture (but be sure to note opinions as such). Close the study process, by explicitly noting whether the hypothesis was proven (or the problem answered). Do not introduce new concepts in this section. Remember that "conclusion" means end; "conclusions" means analytically derived results.

8. ACKNOWLEDGMENTS

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