2010

Plastic design and degradation study for developing world applications

ENGR 493

The Pennsylvania State University

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12/6/2010

Plastic design and degradation study for developing world applications

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ENGR 493
The Pennsylvania State University
December 6, 2010
http://personal.psu.edu/mrs5329/ENGR493Project.htm

EXECUTIVE SUMMARY

The focus of this project is to design products from polyethylene bags. These can be implemented in shantytowns outside of Casablanca, Morocco to improve the quality of living of the Berber community. This product development process yields directly from a higher process of: understanding the scale of the global issues of both slum-dwellers and the waste of plastic bags, familiarizing with the specific target community in Morocco, researching previous methods and products produced or manufactured by others, and performing experiments using high-density polyethylene plastic bags.

The product development process stemmed from the group's mission to provide three products that could be introduced to make tangible improvements in the lives of the Berber community. After research to establish specific needs, the team proposed 20 concepts, and filtered these through criterion derived from the project goals and mission statement. Using common engineering concept filtering methods, five products were chosen to investigate further that optimally satisfied the needs of the Berber people. The final concepts for production using high-density polyethylene shopping bags were: (1) a travel-sized pillow, (2) a mattress, (3) a hay-optimized knapsack, (4) a volleyball, (5) and a rug.

Table 1 – Photographic images of five prototypes of concepts.

				
Pillow	*5′ x 2 1/2′ Mattress*	*Volleyball*	*Rug*	*Hay-Optimized Knapsack*

INTRODUCTION

Plastic bag waste has developed into a global issue in recent years, and has alarmed scientists due to the high-level degradation of ecosystems. At a lower level, the pollution caused by plastic bags has produced problems in the clogging of storm drains of developing nations such as Ghana. (Tutton, 2010) There, entrepreneurial efforts have risen to meet the challenge of the increase in plastic waste, both removing the waste from the environment and improving the lives of those who are willing to collect it. This business concept's two-fold methodology held values similar to our design team's vision: to valorize this abundant commodity into useful products. Our team's goal was to give the communities of the bidonvilles the ability to capitalize on their plastic litter and to turn it into a resource that can improve their lives and potentially generate profit.

Issues that arise with the use of high-density polyethylene shopping bags as a raw material for engineering of products are varied. One of the highest priority issues with using this raw material is the photodegradation of polyethylene, as the products used to aid the Berber community in Morocco would most likely be subject to relatively high levels of UV rays. Studies would need to take place in order to understand these effects. Last semester, in collaboration with the Center for Sustainability, a testing rig to analyze the degradation of small squares of 8-ply, fused polyethylene samples exposed to the weathering (both rain and UV rays) of State College, Pennsylvania weather was built. Due to a lapse in communication over the summer, the testing rig was dismantled. A reopening of communication with the Center has been attempted via an email sent to its administration (attached in **Appendix 1**), however no response has been receved as of December 2010.

RESEARCH

In order to develop sustainable products made of polyethylene with any confidence that the material would be appropriate, significant research into the material had to be conducted. Delayed in the testing at the Center for Sustainability, Penn State's online Web of Science journal database became a key source of information. Our materials research was broken into categories of: Environmental degradation, processed material properties, bio-resistance (as defined by Dow Chemical (Corrguard-95: High Performance Amino Alcohol for Metalworking Fluids)), and common/previous product utilization of material for product analysis from groups of prior semesters. Research also investigated the socioeconomic conditions of Moroccan slums and the global and regional environmental issues of plastic bag waste.

Slums

The United Nations defines a slum as "lacking at least one of the following five housing conditions: Access to improved water; Access to improved sanitation facilities; Sufficient-living area, not overcrowded; Structural quality/durability of dwellings; Security of tenure" (The Millennium Development Goals Report 2008, 2008). As the separation of the rich and poor becomes more distinct, the growth of slums becomes a major concern. It is estimated that "924 million people were living in slums in 2001, a number expected to double to two billion people by 2030 'if no firm action is taken,'" according to STWR.org (Parsons, 2010). With the slums of Casablanca, Morocco being some of the largest in the Arab world, this is a major cause for concern. One of the primary issues in the slums, especially in the Bidonvilles of Casablanca is based around disposal of waste. As exhibited by the photos below, plastic bags and other non-biodegradable materials litter the streets and garbage can be found everywhere. This has obvious health implications for the people living in these areas.

Photos illustrating the issue of slums and the presence of plastic bag waste and litter in the streets that presents a health problem.

The UN claims that "simple, low-cost interventions could significantly improve the lives of many slum dwellers" (The Millennium Development Goals Report 2008, 2008). Our goal this semester was to find a way to improve the slum-dwellers' quality of life as well as to create a potential source of income for the people by using their abundant resource of plastic bags. This solution would address two major problems: the non-biodegradable plastic bags that litter the streets and the quality of life of the people residing in these areas.

It is important to note that the fusing of plastic bags, a critical process in the creation of the products which will be discussed later in the report, does require a source of heat, optimally provided by an iron. This in turn requires electricity. While this is not readily available to all slum-dwellers, this group (like previous groups) has assumed that irons and power are provided. In fact, efforts are being made to establish community centers where Moroccans will have access to power and the basic tools needed to construct plastic products.

Previous groups have tested the strength of plastic bag sheets, developed usable plastic yarn (hereafter referred to as plarn) as well as rope, created fused sheets which can be ironed together, and designed products for the communities that can be constructed from these materials.

Material Properties

While research suggests that HDPE can absorb a great deal of radiation without drastic changes in properties (as displayed in Figure 1), there are practical reasons to be concerned for its degradation. Plastic bags in landfills, when not exposed to direct sunlight, are predicted to last hundreds of years. However, those that do absorb UV radiation are known to become brittle and to eventually crack into small particles named "nurdles." These have already caused drastic environmental effects in parts of the world. For instance, millions of tons of nurdles now inhabit the region of the Pacific Ocean between San Francisco and Hawaii, an area at least the size of Texas (Coulter, 1959). This area is known as the Great Pacific Garbage Patch, where the North Pacific Gyre has the tendency to trap debris. Sea and air animals mistake plastic particles and other refuse

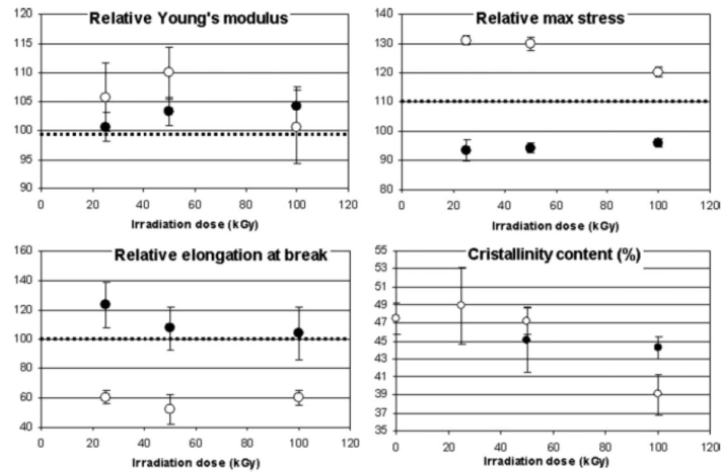

Figure 1 - This figure illustrates the mechanical properties of irradiated samples of HDPE2 plastics compared to a controlled reference as reported in the Journal of Polymer Science. The measurements were recorded in values of kilo-gray for radiation dosage. The black circles reflect molded pieces of HDPE2, whereas the white reflect irradiated pellets.

for food and consume vast quantities of the plastics, leading to drastic health consequences (Moore, 2003). As such, experimentation should be conducted to discover whether the plastic bag products detailed in this report have a reasonable lifespan. More information about these can be found in the "*Recommendations for Future Projects*" section.

The material properties of HDPE immersed for periods of time in rainwater should not exhibit drastic change, according to scientists Callister and Seymour. (Seymour, 1987) (William D. Callister, 2003) Callister and Seymour have experimentally proven that HDPE only becomes structurally questionable in solutions of oxidizing acids such as one of 10% HNO_3 and in non-polar solvents such as C_6H_6. Our team made the assumption that, in a chemical sense, rainwater is not of high enough concentration content in these molecules to cause significant degradation when compared to that caused by other sources such as UV wavelengths.

Radiation caused degradation was quantifiably studied by Rodolphe Sonnier of the Journal of Polymer Science in assessing dosage of irradiation versus structural properties. Figure 1 details the results. (Sonnier, 2009) The study, though focused on gamma radiation, gave insight to the team insofar as testing concerns and length of time that would be needed to achieve optimal results. The study proved that high doses of gamma radiation actually increased structural properties such as Young's Modulus, but increased the "brittle-ness" of the material, which can be a concern as this expedites the creation of the previously mentioned "nurdles." In Table 3 below, HDPE properties provide a clearer understanding of what processed HDPE's strengths and weaknesses are as a material.

Testing from the Fall 2009 semester plastic bag team yielded an understanding of the freshly processed HDPE in Table 2, and the knowledge that repairing the fused sheets actually increased their load capacity. The raw materials of the HDPE, in conjunction with different processing methods such as braiding, fusing, and overlapping these braids into a larger rope, all have a positive effect on the strength of the material and gave the design team an interesting perspective on product development. With such a variable strength across different applications, a better understanding of how the plastic bag material could be manipulated to optimize certain material properties was attained. This allowed for variations in design that incorporated not only fused plastic bags, but also tensile products such as ropes and cables.

Table 2- Table of Learning Factory testing of HDPE2 bags from the ENGR 493 project team in the Fall of 2009.

Day 2- Learning factory (11/12/09)		
Test	Description	Load Capacity (lbs)
2	Repaired sheet- 1 bag on either side of original tear	76.5
4	Repaired sheet- Overlapped with One Back on Either Side	54.5
5	Repaired sheet- Random Bags	121
6	Repaired sheet- 2-ply Overlapped	30
	Rope- 9 strands	12
	Rope- 27 strands	40
	Other information	Maximum Temperature (Degrees F
	$6 iron- Proctor Silex	~120
	$28 iron- Black and Decker	~460

Table 3- Table of Mechanical, Thermal, Electrical, and Processing Properties of the High-Density Homopolymer Polyethylene as derived from eFunda.com's Material Properties website. (Polyethylene and ethylene copolymers: Material Properties of high density homopolymer polyethylene)

Mechanical Properties		**Conditions**		
		State 1	**State 2**	**ASTM**
Elastic Modulus (MPa)	1070 - 1090	tensile		D638
Flexural Modulus (MPa)	1001 - 1553	23 °C		D790
Tensile Strength (MPa)	22 - 31	at break		D638
	26 - 33	at yield		D638
Compressive Strength (MPa) at yield or break	19 - 25			D695
Elongation at break (%)	10 - 1200			D638
Hardness	66 - 73	Shore D		D638
Izod Impact (J/cm of notch) 1/8" thick specimen unless noted	0.2 - 2.1			D256A

Thermal Properties		**Conditions**		
		Pressure	**State**	**ASTM**
Coef of Thermal Expansion (10^{-6}/°C)	59 - 110			D696
Deflection Temperature (°C)	79 - 91	0.46 MPa		D648
Thermal Conductivity (W/m-°C)	0.460 - 0.502			C177

Physical & Electrical Properties		**Conditions**	
		State	**ASTM**
Specific Gravity	0.952 - 0.965		D792
Water Absorption (% weight increase)	0 - 0.01	after 24 hrs	D570
Dielectric Strength (V/mil); 1/8" thick specimen unless noted	450 - 500		D149

Processing Properties		**Conditions**	
		Type	**ASTM**
Melt Flow (gm/10 min)	5 - 18		D1238
Melting Temperature (°C)	130 - 137	T_m, crystalline	
Processing Temperature (°C)	177 - 260	injection molding	
	177 - 274	extrusion	
Molding Pressure (MPa)	83 - 103		
Compression Ratio	2		
Linear Mold Shrinkage (cm/cm)	0.015 - 0.04		D955

Bioresistance

Overall, HDPE has been proven to have a moderately high resistance to bio-degradation. This is exhibited by the ability of these bags to not decompose very quickly in landfills. Research, however, has proven that degradation can be sped up via isolation of certain HDPE decomposing bacteria, specifically arthrobacter sp. and pseudomonas sp. Balasubramanian's study concluded that, "The biodegradation of HDPE by two marine bacteria, namely Arthrobacter sp. and Pseudomonas sp., is reported here under in vitro condition in the synthetic medium. The degradation of HDPE by Pseudomonas sp. was faster than Arthrobacter sp., and the viability of the bacterial biofilm observed under epifluorescent microscope showed that the live bacterial cells were green colour and showed high metabolic activity. Both Arthrobacter sp. and Pseudomonas sp. showed decrease in hydrophobicity of HDPE and crystallinity percentage after 30 days of incubation. Based on the results of biofilm formation, weight loss and FT-ID data, we could able to interpret that Pseudomonas sp. is a better degrader of HDPE. Between the two bacterial strains selected for the study, Pseudomonas sp. efficiently degrades HDPE in 30 days without any prior treatment, yet we have not studied the long-term effect that would be laid as a good rationale for future studies." (Balasubramanian, 2010) This gives credence to the conclusion that bacteria exists that could breakdown HDPE, and testing could be conducted how to prevent such breakdown of the material. However, moving forward on product development without concrete data on the lifetime of this material as a useable product is acceptable, as these bacteria are not present in high enough numbers to cause rapid degradation.

PRELIMINARY MODELLING AND CONSTRUCTION

The preliminary ironing and plarn making allowed the team to get a better hands-on feel for the materials, and to brainstorm internally before the true concept generation period began. For a better understanding of the project timeline, a Gantt Chart has been attached in **Appendix 2**. As evidenced by the Gantt Chart, due to a high amount of intellectual thought regarding the product and less hands-on activities, the physical product development process did not begin for a few weeks. With heightened emphasis on tangible results in the final month of the project, all of the development expectations were met.

CONCEPT GENERATION

The concept generation process was supported by an interview with our TA Lydia Karlheim as to the needs of the target community in Morocco, to derive a sense of what "value" really is in these communities. Lydia informed us of the living situations in the Bidonvilles of Casablanca. There are benches along the walls of the living complexes where people will line up to sleep at night. Using this information as well as implementing an elementary engineering design tool called problem decomposition flow-charts, attached in **Appendix 2**, we began brainstorming solutions. The resulting concept list of twenty concepts is detailed in **Appendix 3**. It should be noted that some of these concepts were developed retroactively as a response to work observed in other groups, which we found could add value to our project and future related projects as well.

CONCEPT SCREENING

The criteria for evaluation were defined as follows:

- *Manufacturability* - The design should be easy to manufacture, and to teach the Berber community how to manufacture
- *Low Maintenance* - The design should not have need to be drastically repaired during the duration of its lifetime
- *Beneficial application* - The product should not be designed for an environment that might pose direct or indirect dangers to the user due to chemical or material properties of the product
- *Extended lifetime* - The product must have a lifetime comparable to that of similar non-HDPE designs

These simple criteria were plugged into a product development tool called a concept screening matrix, and assigned a score. If the product scored below average to the established baseline, it received a score of -1. If it was scored as an average product it received a 0, and if it was above the baseline it received a score of 1. The concept screening matrix is attached in **Appendix 4**. The products were then filtered more finely through a scoring matrix.

CONCEPT SCORING

The concept scoring matrix allowed weighted scoring (Manufacturability 30%, Low Maintenance 10%, Beneficial Application 40%, and Long lifetime 20%) to reflect what the design team felt to be the best allocation of importance among criteria for design concepts. The matrix outputted the top three results to be: a mattress, a pillow, and a backpack. In order to ensure that a minimum of three viable products were created the, group also included the rug and the volleyball designs.

FINAL CONCEPT DESCRIPTIONS AND PROTOTYPES

Comprehensive information about the fusing of plastic bags is available in previous reports, as well as in the YouTube videos and ironing instructions available via the appendix. However, specific information on each product explored in this report will aid future groups in replication of results.

Pillow

Figure 2: Picture of the final product design for a pillow made from HDPE2 shopping bags and irons.

The creation of a pillow can be viewed in one of the YouTube videos previously mentioned. Seaming two rectangular plastic tarps together creates the general form. Wax paper or baking sheets can be placed in the pillow while ironing so that only the edges are fused. The pocket is then stuffed with the unusable parts of the plastic bags (the handles and bottoms which were cut off before fusing) as well as additional bags. The final side can be closed in a number of ways, but the easiest is to allow one edge to be several inches longer so that it can be folded over the other and fused.

Mattress

Figure 3: Picture of Matt Steiner testing the final product design of a mattress and a pillow made from HDPE2 shopping bags and irons.

The mattress is formed in a similar fashion to the pillow, however in addition to being filled with plastic bags, it is filled with plastic bottles to provide rigidity and spring. The bottles were arranged into neat rows and then tied together with strips of plarn (plastic yarn, as detailed in previous reports). Bags were layered between and over the bottles so as to create as even a resting surface as possible.

Rug

Figure 4: Picture of the in-progress product design for a floor rug made from HDPE2 shopping bags only, using plarn.

The rug also featured plarn as a primary construction component. The tying together of horizontal and vertical strips created the framework for the rug. More strips were then weaved in and out of the structure to add material. Despite significant investment of time, the rug never gained the density needed to be practical. Plastic appears to be too light of a construction material for this design. Ultimately, the rug was abandoned as a feasible product and placed into the mattress as extra padding. A combination of weaving and fusing techniques may yield better results, and could be explored by future groups.

Volleyball

The volleyball began as a rectangular tarp of fused plastic bags. This was connected to itself to form a cylinder. Fused squares were ironed across the open ends to close the shape. In order to provide a solid surface on which to iron, a small microwaveable bowl was held inside the ball and ironed against. The ball was stuffed with plastic cuttings and bags, much like the pillow (the bowl was of course removed). In order to be as solid as expected from a volleyball or soccer ball, it was stuffed as densely as possible. The most difficult process was the final step, in which the last opening on the bag was sealed with a small fused square. With careful monitoring of heat and pressure, this was possible to perform quite effectively.

Produce Knapsack

The produce knapsack is designed with Morocco's Berber women in mind. These people traditionally carry tens of pounds of greens and nuts at a time in plastic sheets swung over their back, and consequently suffer chronic back problems. The knapsack was, like the soccer ball, constructed first from a cylinder of plastic tarp. One end was fused closed to a circular panel of plastic tarp to become its base. Arm straps were constructed out of fused strips of about an inch in width and reinforced at their connection to the knapsack with cross bracing strips. Chest and hip braces were attached to the arm straps and to the base of the knapsack, which when tied across the wearer's front act like the braces found on commercial hiking backpacks. The knapsack has not been evaluated for strength. This suggests another task which future groups may which to explore, as discussed in the "Recommendations for Further Projects" section.

EXPERIMENTAL DESIGN FOR DEGRADATION STUDY

Introduction

Thus far readers should be familiar with the process of creating tarps out of plastic grocery bags using heating irons. While this has been explored in great detail, there has been little empirical work done to determine the lifespan of these tarps under the harsh conditions nature provides. This study will track the degradation of small square samples of 8-ply plastic tarp over a 10-week duration. Hopefully the samples will show negligible changes over time, suggesting that the tarps could be implemented for a period of many months without needing to be repaired or replaced. Obviously, the climate observed in State College is much different from that of Morocco and many other areas where impoverished people are abound, but the study should provide its conductors with some qualitative observations on which to base further conclusions. It is recommended that subsequent experiments isolate the effect of long-term UV exposure upon the strength of these tarps over time, as well as the feasibility of implementing them specifically for the purpose of rainwater collection.

Current State of Readiness

A batch of 40 plastic squares has already been prepared for use in the testing. These 8-ply sheets were carefully made so as to have the greatest consistency possible. They are all from unused Wal-Mart plastic bags and have been inspected to insure that no holes were formed in the fusing process due to over-ironing, and that they are the proper size for their mounting frames. These mounting frames and a testing panel on which to mount them have also been prepped for the study.

Remaining Preparation

The provided plastic squares need to be placed in the mounting frames, which must then be screwed into the testing board. These should be numbered and photographed for "before" photos. Select the lighting and background conditions carefully so that any imperfections are visible and so that these conditions can be replicated for the "after" photos. It is important that no screws pass through the surface of a plastic square, as this would create an inconsistent stress state. The testing board must then be secured at an incline and raised several inches off the ground, so any rain or snow that falls during the data collection phase can drain. The addition of drainage channels should also be explored.

The study will be hosted at the Center for Sustainability, with which some communication has already been established. Please see the email sent to the Center attached to the appendix for further information.

Data Collection

For experimentation in the Spring '11 semester, it is recommended that data collection begins on Monday the 31st of January and is concluded on the 11th of April. This ensures that the group will collect five data points (on two week intervals) and will have time to interpret the data before presenting findings. It also places Spring Break (March 7-11) as an "off week," which will be convenient for the group members.

Eight plastic squares should be removed from the testing board for each data collection. The sampling should include squares from several different heights along the test board. These should be photographed and compared to their "before" photos for any signs of degradation. The assignment of some sort of metric, such as a rough estimate of the number or size of any holes that appear, will add quantitative data values to the observations.

In addition, a group member should be responsible for collecting weather data on the area. Average temperature over each two-week period, amount and type of precipitation, and quantity of sunlight should all be considered as possible contributing factors to the degradation.

Making Conclusions

While it may be difficult to attribute any changes in the plastic squares to a particular facet of natural conditions, this experiment should answer the central question of whether a plastic tarp can be expected to last long enough in the elements to be practical if implemented. Focus the majority of analysis around formulating a predictive lifespan of the material.

Further Experimentation

Subsequent studies should explore UV radiation as the primary cause of plastic degradation. More information about this can be found in the "Recommendations for Future Projects" section of the report. Future groups might also seek to determine whether the tarps hold their strength over time. If they remain largely intact but maximum tensile stress decreases with age and weathering, they may not be practical for some uses. A determination of their ability to contain or direct rainwater over time without substantial leaking will also require experimentation.

CONCLUSION

The project achieved many of its initial goals by researching plastic waste issues both globally and locally in bidonvilles of Casablanca, and by using product development to analytically determine a way to turn the litter into a resource for the communities. The products have the ability to be used by those who make the mattresses, pillows, and backpacks, and could be mass-produced easily and efficiently to sell for profit. With a business plan set in place, the bidonvilles could become an ideal location to implement micro-financing solutions establish small companies eliminating waste HDPE2 bags and replacing them with life-quality enhancing products.

The products designed by the team provide a comfortable sleeping arrangement in an area of the world where mattresses might be scarce. Especially in cramped living conditions, mattresses can be constructed to sizes that are appropriate to each specific living quarter in the bidonvilles, and can be constructed with only plastic bags and twenty ounce drinking bottles. The pillow can be manufactured in less than forty minutes with only plastic bags as resources, as well as an iron, and can provide comfort and utility for an extended period of time to those in the community. Lastly, the produce backpack provides a solid proof-of-concept that ironed bags can be manipulated to manufacture an ergonomic solution to the heavy lifting that is embedded in the culture of the Berber people. With collaboration on development of the straps to become sturdier, these bags could replace the tarps used for carrying fifty pounds of hay on their backs.

Our team did not have the opportunity to expand upon the testing at The Center for Sustainability, however augmented this lack of hands-on research with searching the Web of Science database for the material properties of polyethylene as a whole and HDPE2 specifically to allow subsequent groups to use these sources and our data collection to construct an experiment to obtain the results that can drive further product development in this field.

Recommendations for Future Projects

Future projects should be centered about two primary categories. They are: (1) Improvement upon existing and creation of new products, and (2) Experimentation with plastic bag degradation.

Of the products explored in this report, the rug and the produce knapsack could most benefit from further exploration. The former will require a method of adding density before it can become a feasible product, while the latter needs to be tested for strength under loading and for ergonomic benefits over current methods used by Berber women. Groups could also explore ways to quiet the noises made by the pillow and mattress when in use. It is possible that repeated washing would soften the plastic enough to have an effect. Addition of cloth coverings may also reduce the noise. The ergonomic qualities of these products could also be explored and improved upon. Just as this group's innovation produced the mattresses and pillows, future groups will likely be capable of producing new and interesting products. The potential inherent in fused plastic bags and plarn as construction materials is essentially limitless when in the hands of creative students.

The first experimentation to be conducted should be that at the Center for Sustainability, as detailed in the appendix. This will provide its conductors with some qualitative observations on which to base further conclusions about plastic degradation. For further depth, the effect of UV radiation upon plastic sheets could be isolated. Penn State has UV irradiation facilities, primarily used for biological experiments, which are capable of simulating several years of sun exposure during an actual time frame of only a few months. Plastic tarp should be tested not only for observable signs of degradation, such as the formation of holes, but also for changes in material properties, such as tensile strength. Additionally, previous groups' work on plastic tarps' feasibility when implemented in rainwater collection systems needs experimentation to determine whether the tarps are capable of containing and directing water or whether they have a tendency to leak or tear, particularly at fusing sites between squares.

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Appendix 1 – Letter Sent to Center for Sustainability

316 W. Beaver Ave.
Apt. #505
State College, PA
(724) 600-9591
mrs5329@psu.edu

November 8, 2010

Dr. David Riley
Center for Sustainability

104 Engineering Unit A

University Park, PA 16802

Dear Dr. Riley,

I am emailing in regards to a project under the leadership of Dr. Richard Schuhmann for the Engineering Leadership Development program. The specific project requires a small amount of land at the center for sustainability (approximately 5' x 5') for the environmental robustness testing of polyethylene shopping bags to be recycled for use in outdoor products. This space will be needed for one semester, and at most two semesters for continuing research on the weathering effects (i.e. December 2010 – December 2011). This project is aimed at improving the lives of many people living in the slums of Morocco, and allowing these people to valorize "trash" and turn it into a sustainable living environment. Testing these bags is of utmost importance to the continuity of this project, and for this reason we ask for permission to put our testing rig on your property at the center. You may recall a platform had been constructed this summer by Dr. Schuhmann adjacent to the wind turbine at the center; unfortunately this was destroyed before we could begin our testing this semester by unknown parties.

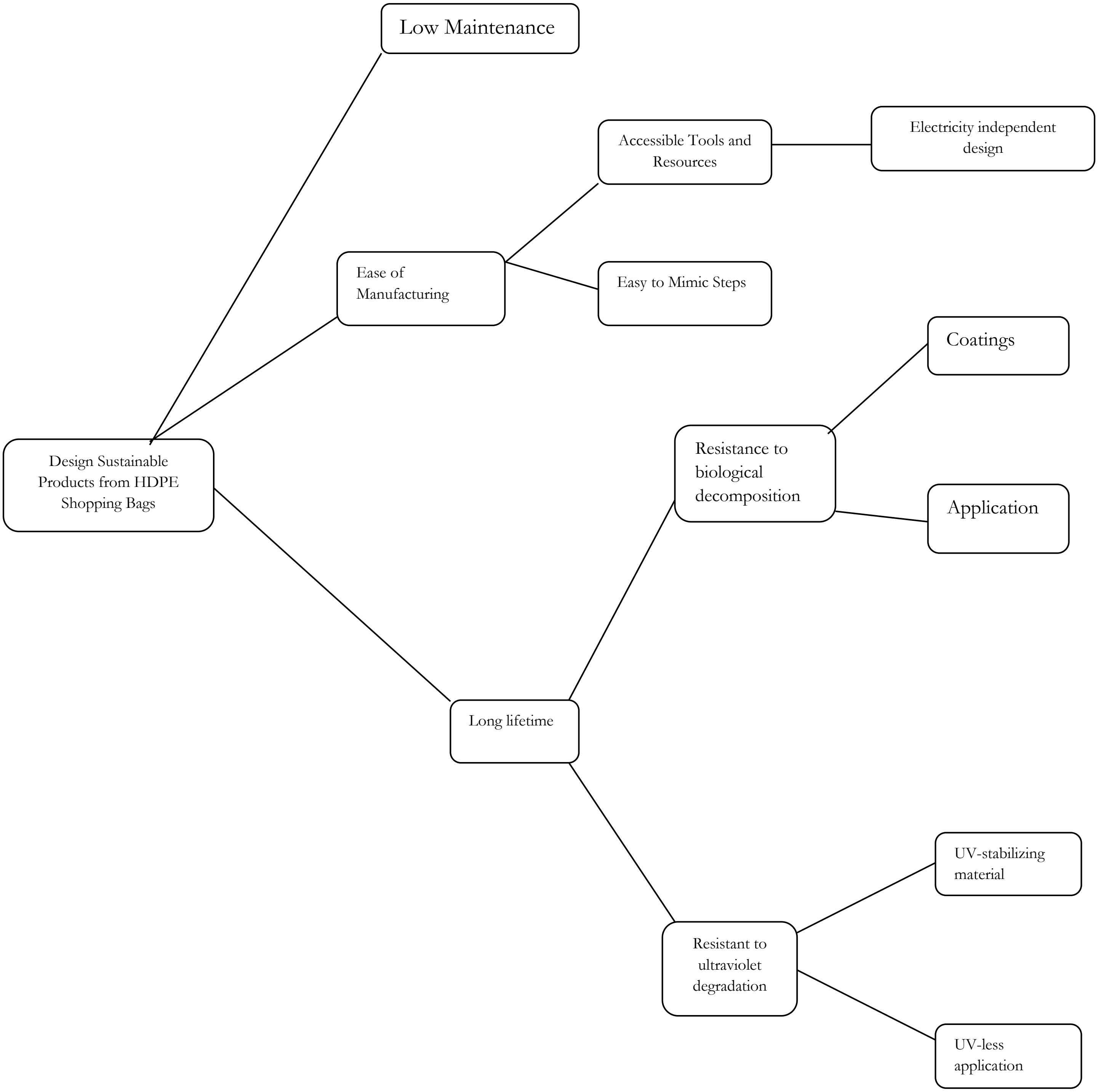
This project not only benefits the underprivileged in Morocco, but could have ever-reaching impacts on many similar villages globally. This project benefits engineering on campus by applying sustainability concepts to real-life scenarios, with real-life benefits to be seen by these engineering students.

If you have any further questions, I can be reached at (724) 600-9591 or mrs5329@psu.edu.

Sincerely,
Matt

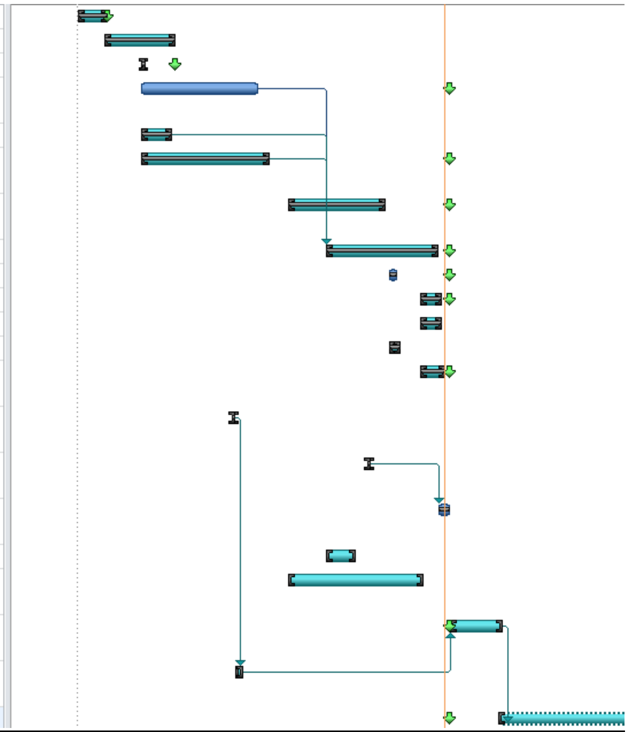
Matthew R. Steiner
The Pennsylvania State University
Schreyer Honors College
B.S. Candidate in Mechanical Engineering
Engineering Leadership and Development Minor

Appendix 2 – Problem Decomposition Flowchart



Appendix 2 – Gantt Chart

Project Introduction	6 days	Mon 8/23/10	Mon 8/30/10
Group Forming	15 days	Mon 8/30/10	Fri 9/17/10
First Meeting - with TA	1 day	Thu 9/9/10	Thu 9/9/10
Research previous methods/products	22 days	Thu 9/9/10	Sat 10/9/10
Bag Ironing Practice	6 days	Thu 9/9/10	Thu 9/16/10
Bidonville - Berber Research	24 days	Thu 9/9/10	Tue 10/12/10
Global Problems with Slums	20 days	Mon 10/18/10	Fri 11/12/10
Product - Pillow	22 days	Thu 10/28/10	Fri 11/26/10
Bag Ironing Practice	1 day	Sun 11/14/10	Mon 11/15/10
Product - Backpack/Hay	6 days	Mon 11/22/10	Sat 11/27/10
Product- Volleyball	6 days	Mon 11/22/10	Sat 11/27/10
Product- Rug	3 days	Sun 11/14/10	Tue 11/16/10
Presentation Powerpoint	6 days	Mon 11/22/10	Sun 11/28/10
Center for Sustainability Visit	1 day	Sun 10/3/10	Sun 10/3/10
First Email to Director of Center for Sustainability	1 day	Mon 11/8/10	Mon 11/8/10
Second Email to Follow with C.f.S.	1 day	Sat 11/27/10	Mon 11/29/10
Mid-Semester Skype	6 days	Thu 10/28/10	Thu 11/4/10
HDPE Materials Research	26 days	Mon 10/18/10	Mon 11/22/10
Testing Instructions - Rig Set Up	10 days	Tue 11/30/10	Mon 12/13/10
Given Permission to Use Center	2 days	Mon 10/4/10	Tue 10/5/10
Testing at Center	45 days	Mon 12/13/10	Fri 2/11/11



Appendix 3 – Concept List

1. **Volleyball**
2. **Jacket**
3. **T-Shirt**
4. **Mosquito repellant recycled plastic sheets**
5. **Roofing Material**
6. **Bean-bag chair**
7. **Rainwater Harvesting Tarp**
8. **Rug**
9. **Drinking Cup**
10. **Mattress**
11. **Blanket**
12. **Pillow**
13. **Backpack**
14. **Hay Carrier/Heavy Load Backpack**
15. **Dinner Plate**
16. **High-Strength Roping (for Pulley Use)**
17. **Tent**
18. **Curtains**
19. **Buckling Restraining Brace for Pillars of Plastic Bottles**
20. **Garbage Can**

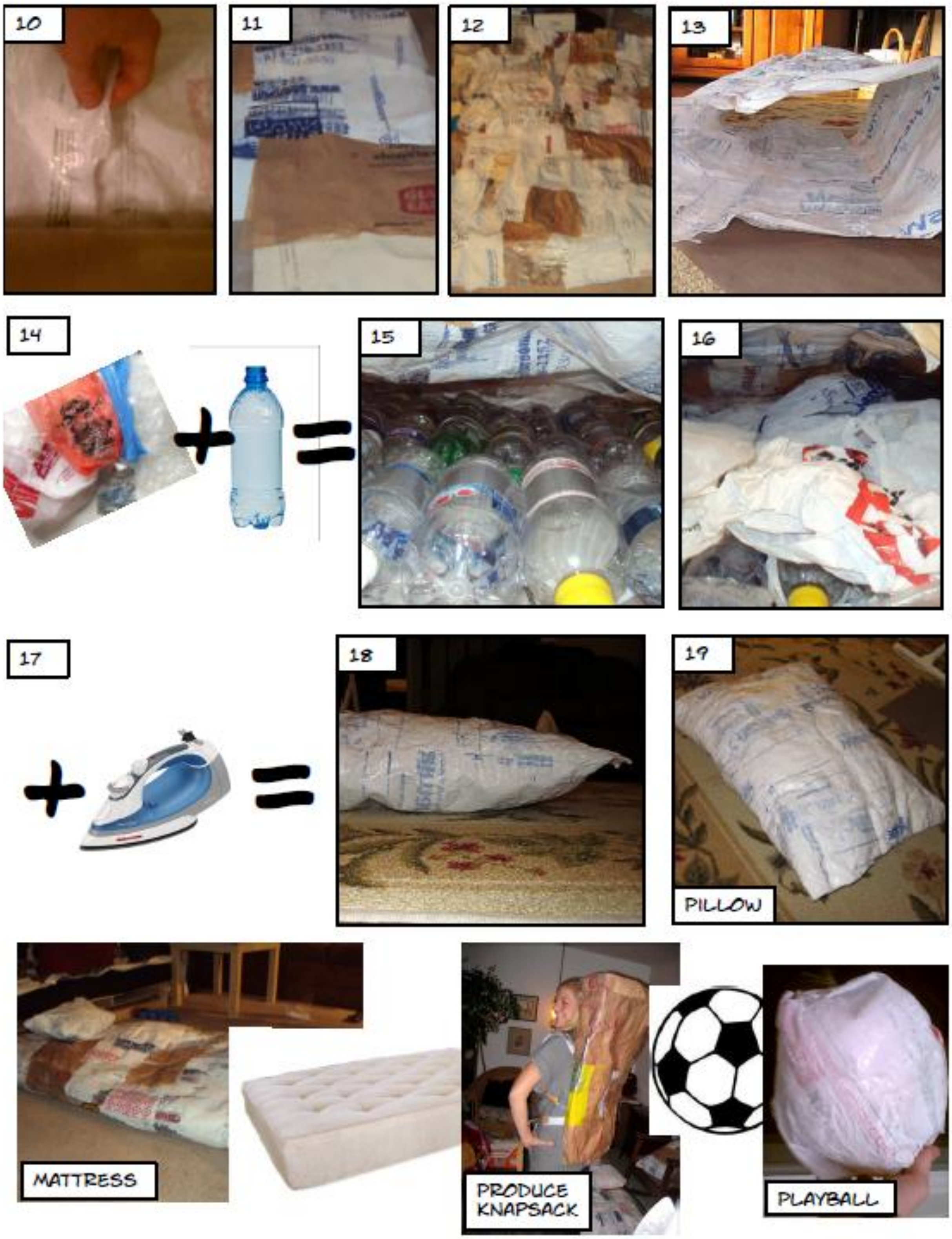
Appendix 4 – Concept Screening Matrix

	Manufacturability	*Low Maintenance*	*Beneficial application*	*Extended lifetime*	**Sum**
Volleyball	1	0	0	1	2
Jacket	-1	0	-1	1	-1
T-Shirt	0	0	1	0	1
Mosquito repellant recycled plastic sheets	1	0	1	-1	1
Roofing Material	1	-1	1	-1	0
Bean-bag chair	1	0	-1	1	1
Rainwater Harvesting Tarp	1	-1	1	-1	0
Rug	-1	-1	0	1	-1
Drinking Cup	0	0	0	-1	-1
Mattress	0	1	1	1	3
Blanket	0	1	1	1	3
Pillow	1	1	1	1	4
Backpack	0	0	1	1	2
Hay Carrier/Heavy Load Backpack	-1	-1	1	1	0
Dinner Plate	0	-1	0	-1	-2
High-Strength Roping (for Pulley Use)	0	1	1	1	3
Tent	0	0	1	1	2
Curtains	1	1	-1	1	2
Buckling Restraining Brace	1	1	-1	1	2
Garbage Can	0	-1	0	1	0

Appendix 5 – Concept Scoring Matrix

	Manufacturability		*Low Maintenance*		*Beneficial application*		*Extended lifetime*		**Sum - Weighted**	**Sum - Unweighted**
	Unweighted	*Weighted*	*Unweighted*	*Weighted*	*Unweighted*	*Weighted*	*Unweighted*	*Weighted*		
Volleyball	4	120	-2	-20	4	160	-3	-60	200	3
Jacket	-4	-120	3	30	-1	-40	4	80	-50	2
T-Shirt	0	0	-3	-30	3	120	-4	-80	10	-4
Mosquito repellant recycled plastic sheets	3	90	-4	-40	5	200	-4	-80	170	0
Roofing Material	2	60	-5	-50	3	120	1	20	150	1
Bean-bag chair	2	60	4	40	0	0	3	60	160	9
Rainwater Harvesting Tarp	2	60	-4	-40	4	160	-1	-20	160	1
Rug	-4	-120	-4	-40	2	80	-4	-80	-160	-10
Drinking Cup	5	150	-2	-20	-3	-120	-4	-80	-70	-4
Mattress	1	30	4	40	5	200	4	80	350	14
Blanket	2	60	2	20	1	40	4	80	200	9
Pillow	5	150	5	50	4	160	5	100	460	19
Backpack	3	90	3	30	3	120	2	40	280	11
Hay Carrier/Heavy Load Backpack	-1	-30	-2	-20	4	160	-1	-20	90	0
Dinner Plate	4	120	-4	-40	0	0	-3	-60	20	-3
High-Strength Roping (for Pulley Use)	-1	-30	4	40	2	80	1	20	110	6
Tent	-4	-120	-3	-30	4	160	-2	-40	-30	-5
Curtains	4	120	4	40	-3	-120	5	100	140	10
Buckling Restraining Brace	3	90	4	40	-4	-160	5	100	70	8
Garbage Can	0	0	-4	-40	-4	-160	-2	-40	-240	-10

Appendix 6 – Comic to Describe Manufacturing Process


10
11
12
13
14
15
16
17
18
19
PILLOW
MATTRESS
PRODUCE KNAPSACK
PLAYBALL

Appendix 7: YouTube URLs

http://www.youtube.com/watch?v=GyL0u91cBQU

http://www.youtube.com/watch?v=95fYJ5a6O9U