Agenda

1. Purpose and Goal
2. Prototype Design
3. Sample Production
4. Issues and Future Improvements
5. Sample Testing
6. Cost analysis
   - Cost of device manufacturing
   - Cost of operation
7. Gantt Chart
Purpose and Goals

• Develop a **low-cost** and **low-tech** method to produce drip irrigation pipes by recycling High Density Polyethylene (HDPE) shopping bags

• Maximize pipe-strength to cost ratio

Criteria of Success:

• A functional and scalable process and prototype of irrigation tubes
  • Tube diameter = 0.75”
  • Water pressure = 0.15 atm

\(^1\) Krishak Bandhu Family Nutrition Kit
Initial Prototype Design
Heat Transfer

\[ q_{\text{rad}} = \varepsilon \sigma (T_h^4 - T_{\text{surf}}^4) \times A_r \]

\[ r \sim 2\,\text{cm} \]

\[ q_{\text{conv}} = h (T_{\text{surf}} - T_0) \times A_s \]

\[ T_{\text{surf}} = 125 \, ^\circ\text{C} \text{ when } T_h = 300 \, ^\circ\text{C} \]
Prototype Number 1

Insulated heating element
Heated Roller
Free Roller
Adjustable collars allow for roller alignment
Allow for lateral adjustments
Sample Production

- Temperature varies based on voltage input
- Pressure is unquantified/unknown at the moment

Voltage: 40V
Temp Range: 118+
Issues and Improvements

- Poor temperature control: Add temperature control
- Unknown pressure: Attach pressure gauge or eliminate pressure variable
- Free roller doesn’t always spin: Add gears
- Welding up to 6 layers of bags only: Heat the second roller
Strength Model: Non-Fickean Diffusion

What we expected in theory:

\[
\frac{\sigma_w}{\sigma_m} \propto \left[ \frac{t_m}{t_{rep}} \right]^{1/4}
\]

\[
t_{rep} \propto \frac{1}{D_g}
\]

\[
\frac{\sigma_w}{\sigma_m} \propto [v \cdot T]^{1/4}
\]

\(\sigma_w\) = strength of weld
\(\sigma_m\) = strength of raw material
\(t_m\) = time spent above melting \(T\)
\(t_{rep}\) = reptation time
\(v\) = velocity
\(T\) = processing temperature
\(D\) = diffusion


Image Source: http://nobelprize.org
Peel Test


*with some modifications (sample length, and extension rate)
Peel Test Results

Maximum Load vs. Relative Temperature

\[ P_{max} = 0.78 \text{ atm} \]
Next Steps in Sample Testing

• Strength shows some dependence on temperature

• Crystallinity doesn’t show any dependence on temperature

• Imaging
  o Weld surface (SEM, Light Transmission Microscope)
  o Weld cross-section (Stereomicroscopy)
Cost of Device Production

- Aluminum rollers
- Heating element
- Insulation
- Machining
- 8020 Aluminum Extrusion
- Steel rods
- Overhead Cost (nuts/bolts, shipping, etc)

Total Cost of Device* ~ $290-$300

*Final prototype may cost more/less depending on improvements and replacement of parts
Cost of Production

Considering:
Annual Labour Cost (based on minimum wage)
Annual Energy Cost (based on price/kWh)

Total Cost Per Kit* ~ $1.60

*Each kit includes 20 meters of tubing based on the Krishak Bandhu Family Nutrition Kit ($6.00)
Gantt Chart

1. Decisions/Designs:
   1.1 Choose Project  100% complete
   1.2 Initial Conceptualization of problem  100% complete
   1.3 Brainstorming of possible solutions  100% complete
   1.4 Picking a heat source  100% complete
   1.5 Creation of Final Design  100% complete

2. Testing
   2.1 Early "proof-of-concept" testing  75% complete
   2.2 Prototype Testing  5% complete

3. Design Construction
   3.1 Idea Mock-Ups  75% complete
   3.2 Creation of components  25% complete
   3.3 Initial Prototype  50% complete
   3.4 Final Prototype  0% complete

4. Documentation
   4.1 Create Website  100% complete
   4.2 Update Website with Progress  60% complete
   4.3 Maintain Lab Notebook  40% complete
   4.4 Final Presentation  0% complete

Last Time
Gantt Chart

1. Decisions/Designs:
   1.1 Choose Project 100% complete
   1.2 Initial Conceptualization of problem 100% complete
   1.3 Brainstorming of possible solutions 100% complete
   1.4 Picking a heat source 100% complete
   1.5 Creation of Final Design 100% complete

2. Testing
   2.1 Early "proof-of-concept" testing 100% complete
   2.2 Prototype Testing 50% complete

3. Design Construction
   3.1 Idea Mock-Ups 100% complete
   3.2 Creation of components 60% complete
   3.3 Initial Prototype 75% complete
   3.4 Final Prototype 0% complete

4. Documentation
   4.1 Create Website 100% complete
   4.2 Update Website with Progress 60% complete
   4.3 Maintain Lab Notebook 66% complete
   4.4 Final Presentation 0% complete

TODAY
Peel Test

ASTM D6392-08: "Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods"

Geomembranes are composed of Polyethylene of various densities, Polyvinyl Chloride, or Polypropylene.

<table>
<thead>
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<th>Variable</th>
<th>ASTM</th>
<th>Actual</th>
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<tbody>
<tr>
<td>Sample Width</td>
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<tr>
<td>Sample Height</td>
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<tr>
<td>Extension Rate</td>
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<tr>
<td>Grip</td>
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<td>20 mm x 25 mm</td>
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Sample Peel Test Results

![Graph showing load (N) vs. extension (mm)]
Tube Strength

- Maximum Weld Strength:
  \[ \sigma = \frac{18.5 N}{2.5 cm} \]

- Maximum Pressure:
  \[ P_{max} = 0.78 \text{ atm} \]
X-Ray Diffraction Test Parameters

No ASTM Standards found for measuring polymer crystallinity using XRD

Equipment:
PANalytical Multipurpose Diffractometer in 13-4027

Parameters:
• 5° to 70°
• 90 min/sample
• At 40mA
• Max penetration depth exceeded thickness of entire sample
X-Ray Diffraction Data

% Crystallinity vs. Relative Temperature

- Raw Bags
- High Pressure
- Low Pressure

% Crystallinity vs. Relative Temperature graph showing data points for different pressure conditions.
# Strength and Crystallinity Results

<table>
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<tr>
<th>Sample</th>
<th>Side Pressure</th>
<th>Maximum Load N</th>
<th>Crystallinity %</th>
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<tr>
<td>9</td>
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<td>15.25</td>
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</table>
Cost of Device Production

- Aluminum rollers: $80
- Heating element: $70
- Insulation: $10
- Machining: 5 hours x $10/hour = $50
- 8020 Aluminum Extrusion: $20
- Steel rods: $40
- Overhead Cost: $20

Total Cost of Device: $290
Cost of Operation and Production

Annual Labour Cost:
($2/hour \times 8 \text{ hrs/day} \times 250 \text{ days}) \approx $4000

Annual Energy Cost:
($0.20 \text{ kWh} \times 480 \text{ kWh}) \approx $120

Total Annual Cost of Production \approx $4420

Length of Pipe produced per day \approx 220 \text{ m}
Length of Pipe produced per year (250 days) \approx 55000\text{m}
Number of kits produced per year (kit \approx 20\text{m}) \approx 2750

Total Cost Per Kit \approx $1.60
Heat Transfer Model

Will temperature at contact point be high enough?

\[ Bi = \frac{hL}{k} \]
\[ h = \frac{50 \text{W}}{m^2 \text{K}} \quad L = 2 \text{cm} \quad k = \frac{235 \text{W}}{m \text{K}} \]
\[ Bi = 0.004 << 1 \]

Yes!

Will the heating requirement be reasonable when considering losses?

Heat in

\[ q_{\text{rad}} = \varepsilon\sigma(T_{\text{heater}}^4 - T_{\text{surf}}^4) \]
\[ q_{\text{abs}} \cdot Area_2 = \alpha q_{\text{rad}} \cdot Area_2 \]
\[ \alpha = 0.5 \quad \varepsilon = 0.7 \]

Heat out

\[ q_{\text{conv}} = h(T_{\text{surf}} - T_f) \cdot Area_3 \]
\[ 2Area_1 = Area_2 \]

\[ q_{\text{abs}} \cdot Area_2 = q_{\text{conv}} \cdot Area_1 \]
\[ \alpha \varepsilon \sigma(T_{\text{heater}}^4 - T_{\text{surf}}^4)Area_2 = h(T_{\text{surf}} - T_f) \cdot Area_1 \]
\[ 5 \cdot 7 \cdot 5.67 \cdot 10^{-8} \cdot (T_{\text{heater}}^4 - 398K^4) \cdot 2 = 50 \cdot (100K) \]

\[ T_{\text{heater}} = 350^\circ \text{C} \]

Yes!