INTRODUCTION

As product designers and consumers become savvier in green product awareness, additional tools need to be developed to guide design development and to clarify the ingredients that go into a product. The quantitative and qualitative requirements for eco-labels (Lavallée, S., Plouffe S., 2004) – labels similar to the nutrition labels on processed foods – are proposed as quick information-providers that would help people understand the complex ecosystem of materials, production, transportation, water eutrophication, energy consumption and end-of-life that should be valued in any sustainable product. Single-figure Life Cycle Assessment tools, including Okala, Sustainable Minds, and Eco-Indicator 99, provide numeric data that could be included on such a label. One of the measurements included in these tools denotes the impact that a given material has. The material impact is used as a multiplier for the mass of material existing in the assessed product, and the resultant is the ecological impact of that material in the product. The material impacts taken on their own do not tend to show polymers as being environmentally horrible materials compared to metals, glasses and even woods.

While LCA’s have become highly useful tools for designers to analyze products during design (Lewis, H., Gertsakis, J., 2001), if these figures were provided to consumers, would they believe that plastic products have lower impacts than metal, glass and wood products? Probably not. Polymers have a poor reputation for sustainability, and are frequently understood to be toxic to human health.

To examine how polymers are understood, and which could be accepted as sustainable, Kansei Engineering studies have been conducted with a variety of materials. Kansei studies are designed to codify the feelings that consumers have about satisfying product features (Nagamachi, 1995). In the Kansei material studies, human test subjects are presented with physical samples of similar size and shape in a variety of un-identified materials. The subjects are asked to rank the samples on numeric scales that address emotionally-based considerations in sustainable product development, such as where a material lies on a scale from Delicate to Durable. The results of the rankings are averaged to give a quantitative indicator of each material for each issue. The Kansei studies quantify consumers’ innate feelings about what makes the materials attractive in sustainability issues, based on tacit knowledge and life experiences (Nagamachi, 2002) rather than based on the material’s name, reputation or use in a given product.

This paper highlights the results of two Kansei studies of materials, and compares the results to the single-figure impacts given in the Okala LCA tool. The goal of this work is to find where peoples’ perceptions of materials are in accordance with the scientifically-based LCA figures, and where they diverge. The junctures may show the greatest promise for polymer materials to be accepted by consumers today. The combined studies also provides insight into how people will perceive materials information provided on an eco-label for a product. Designing with this information in mind may aid our development of more sustainable products that are accepted in today’s market of interested, somewhat educated, sustainable product consumers.
METHODS AND MATERIALS

In the first study (Muenchinger, 2012), fifty-five people participated in ranking ten materials samples on sustainability issues. All of the participants were students in an introductory product design course. The material samples used for this analysis were spheres of 12.7mm (0.5 in) in diameter, and included: aluminum 3003 (Al), low carbon 1000 steel, stainless steel 302 (SS), hard wood, high density polyethylene (HDPE), polypropylene (PP), high impact polystyrene (HIPS), and polytetrafluoroethylene (PTFE), silicone and natural rubber. These materials were chosen for their ubiquity, and because most have specific impact factors in the Okala Impact Factor 2007 guide (White, et. al, 2007). These spherical samples were provided in a compartmentalized box (see Figure 1).

The analysis from this study is solely of the polymeric materials. Future analysis will be conducted of the polymers, metals and wood.

Figure 1 & Figure 2: Sample kit of spherical materials for study #1 & sample set of flat polymers for study #2.

In the second study, forty-one people participated in ranking eight materials on sustainability issues. All of the participants were students in a manufacturing and materials product design course. The material samples used for this analysis were sheet stock samples 76.2 mm (3 in) x 76.2 mm (3 in) x 3.175 mm (0.125 in) thick (see Figure 2), and included: polyamide 6/6 (PA), high-density polyethylene (HDPE), polymethylmethacrylate (PMMA), polypropylene (PP), polyoxymethylene (POM), polytetrafluoroethylene (PTFE), silicone, and styrene acrylonitrile thermoplastic elastomer (SAN TPE). These materials were chosen for some overlap with the first study, and to provide a larger set of polymers to assess.

In both of these studies, subjects provided rankings for each material on 10 scales, each designed to address an issue of sustainability. The scales span the numbers 1-7, a typical span used in Kansei studies, and are anchored on each end by contrary words that box an issue. The 10 word pairs used were: Rare – Common; Delicate – Durable; Lasting – Degradable; Raw – Sophisticated; Harmless – Toxic; Inexpensive – Costly; Luxurious – Meager; Natural – Artificial; Precious – Valueless; Recyclable – Waste. The word pairs were created to be familiar words, understandable in the context of personal experience with materials, and not requiring prior scientific or engineering expertise with materials. The word pairs were the same for each of the two studies to keep a consistent base for comparison between them.
RESULTS

Average rankings of the polymers for each of the 10 word-pairs are shown in Figures 3 and 4 below. Figure 3 shows the results of the first study performed with the spherical samples, and Figure 4 shows the results of the second study with the sheet samples.

Figure 3. Sustainability rankings of six polymers on scales of 1-7. Rankings maintain 1 as the more sustainable choice of the word-pair and 7 as the least sustainable. Right vertical axis shows logarithmic scale for Okala Impact Factors of the polymer (if provided) in Okala millipoints (mpts).
Figure 4. Sustainability rankings of eight polymers on scales of 1-7. Rankings maintain 1 as the more sustainable choice of the word-pair and 7 as the least sustainable. Right vertical axis shows logarithmic scale for Okala Impact Factors of the polymer (if provided) in Okala millipoints (mpts).

**INDIVIDUAL WORD-PAIRS**

Several trends are apparent in the raw data. These trends may be referenced in Figures 3 and 4. Trends consistent throughout all of the polymer samples include:

- Polymers tend to perceptions ranked towards *Artificial* rather than *Natural*, with the notable exception of SAN TPE in the second study.
- Polymers tend to perceptions ranked towards *Inexpensive* rather than *Costly*, with PMMA and POM ranking at midline in the second study.
- Polymers tend to perceptions ranked towards *Meager* rather than *Luxurious*.
- Polymers tend to perceptions ranked towards *Valueless* rather than *Precious*.
- There is a slight trend of perceiving polymers as more *Lasting* than *Degradable*, with SAN TPE ranking at midline in the second study.
- In the second study, which consisted entirely of polymeric materials, there is a slight trend of perceiving polymers as *Sophisticated* rather than *Raw*, with PTFE and silicone at midline, and SAN TPE towards *Raw*.
- In the second study, all polymers tend towards *Common* rather than *Rare*. The results are similar in the first study, but not as strong.

Trends are also apparent for individual polymers in the raw data, including:

- PTFE is perceived around midline in the majority of the rankings in both studies.
- SAN TPE has the overall lowest grouping, or most sustainable, set of perceptions of all of the polymers.

**DISCUSSION AND CONCLUSION**

Any single issue of sustainability can be observed in the results from the Kansei studies to help make a decision regarding materials selection. For example, a product designed for easy municipal recycling systems may be assured by the results for HDPE showing suitable perceptions of recyclability. The choice between HDPE and PTFE, the 2 low-ranking polymers in perceptions of recyclability, can be made easily for HDPE when combined with the Okala figure factor or HDPE approximately 200 times lower in impact. Designers may also find, however, that the properties of PTFE could be examined and engineered into HDPE to aid the perception of recyclability of HDPE polymers. Conclusions may be drawn about each of the polymers and their appropriateness for use in products being designed to address different issues of sustainability. The polymers are discussed in the order of their impact factors (see Figure 5).

<table>
<thead>
<tr>
<th>Material</th>
<th>Natural Rubber</th>
<th>HDPE</th>
<th>PP</th>
<th>SAN TPE</th>
<th>HIPS</th>
<th>PMMA</th>
<th>PA 6/6</th>
<th>PTFE</th>
<th>POM</th>
<th>Silicone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Factor</td>
<td>4.1</td>
<td>12</td>
<td>13</td>
<td>19</td>
<td>19</td>
<td>38</td>
<td>49</td>
<td>2100</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Figure 5. Okala Impact Factors (in milipoints). All factors used are for primary materials with no recycled content. The impact factor for natural rubber is for certified sustainable natural rubber.

**NATURAL RUBBER**
The elastomeric polymer natural rubber was tested in the first Kansei study. Natural rubber was not perceived as significantly more “natural” than silicone in that study. Silicone even performed slightly better in sustainability perceptions. The natural rubber sample was opaque beige, and the silicone sphere was translucent white. As the durometer of the samples was the same, perhaps the translucency of the silicone was responsible for shifting the perception of this material to a more sustainable trend. A Kansei study of materials with various transparencies and/or translucencies would be an appropriate follow-up to investigate the importance of this feature in perceptions of sustainability.

**HIGH-DENSITY POLYETHYLENE (HDPE)**
HDPE was tested in both Kansei studies. HDPE is perceived to be one of the more common and more artificial polymers. It is also perceived to be more recyclable than most other polymers. These studies support the use of HDPE in products designed for recycling in developed municipal recycling systems, such as food product packaging. People have considerable contact with HDPE in single-use packaging, and yet it is considered a durable material. HDPE may be considered durable, lasting and sophisticated, however the coupling of those perceptions with its perceived valueless-ness suggests that HDPE’s use in products designed for long-term use, such as heirloom products, would not be an appropriate sustainability tactic.

**POLYPROPYLENE (PP)**
PP was tested in both Kansei studies. Polypropylene received similar marks to HDPE, and has a similar impact factor. It is seen as slightly more durable than HDPE. Because PP and HDPE rank so similarly, HDPE is a better sustainable choice when deciding between the two materials because it has a slightly lower impact factor, and because it is more pervasive in municipal recycling systems.

**HIGH-IMPACT POLYSTYRENE (HIPS)**
HIPS was tested in the first study. HIPS had a remarkable mix of being perceived as both durable and recyclable. It is perceived as having somewhat higher worth than the other materials. It is not perceived as a strongly toxic. As it has a low impact factor, HIPS may be a very good choice for more durable product, replacing materials with higher impact factors, such as PA and acrylonitrile-butadiene-styrene (ABS), in structural applications. To support these findings, a secondary test with HIPS material in another form-factor or in a product would be appropriate.

**STYRENE ACRYLONITRILE (SAN TPE)**
The elastomeric SAN TPE was tested in the second study. SAN TPE is perceived as more natural than other polymers. What causes this perception? It’s elastomeric partner, silicone, was not considered as natural, even though it was the same size, color and durometer. In the first study, neither the natural rubber sample nor the silicone sample was perceived as a natural material. SAN TPE does have a low impact factor, and was perceived to have somewhat overall better sustainability characteristics than it’s elastomeric partner, silicone. While no impact factor for silicone is provided, consideration of the expense and processing energy requirements associated with silicone may indicate that SAN TPE is a preferred environmental alternative to silicone.

**POLYMETHYL METHACRYLATE (PMMA)**
Acrylic, or PMMA, was tested in the second study. PMMA has a very slight indication that it is not considered as artificial as other polymers. Perhaps the transparency of the material sample caused this perception. Testing PMMA in various colors and transparencies for their perceived impacts would be an appropriate follow-up to this study. As its impact is higher than HDPE, PP and HIPS, these other materials should be used when possible due to their lower impacts. Transparency or translucency may be a feature to strive for in sustainable products as well.

**POLYAMIDE (PA)**
Nylon 6-6, or polyamide, was tested in the second study. PA has an impact factor more than double that of HDPE, PP and HIPS. It does not show to produce perceptions of durability, lasting-ness, luxury or preciousness that would indicate it could be a good choice in products designed for these sustainability strategies. Rather, if HDPE, PP, or HIPS can perform the functional job, PA would not be missed by sustainability-focused consumers.

**POLYTETRAFLUOROETHYLENE (PTFE)**
In both studies, PTFE is perceived as substantially less environmentally damaging than the impact factor indicates. For example, it is perceived as one of the lesser artificial, and more recyclable polymers. While the use of PTFE should be avoided, this material should be examined for the properties that lead it to be seen in this way. If these properties could be engineered into polymers with lower impacts, such as HDPE, people may be more satisfied overall with their experience with objects designed using polymers. The smoothness, or lubricity of the material may imply to people a low environmental impact.

**POLYOXYMETHYLENE (POM)**
Polyoxymethylene was tested in the second study. POM is seen as one of the most durable, lasting and sophisticated polymers. While its impact factor is not provided, this could be a good choice for products developed for longevity in the consumer’s life. Analysis of this material for the impact would be helpful.

**SILICONE**
Silicone shows very differently in the two studies conducted. In the second study it appears to be considered less sustainable through the word-pairs than SAN TPE, indicating that the latter should be specified when possible. As silicone is typically more durable than natural rubber and thermoplastic elastomers, consideration into highlighting the durability of this material should be made in product features or marketing. The inert nature of this material to humans may also be a good feature to showcase when using this material for sustainability-oriented products.

For all of these polymeric materials, natural and synthetic, the most obvious outlier issue in peoples’ associations of polymers with sustainability is that polymers are artificial. Out of all of the word-pairs, only this one shows consistently above-midline perceptions. Perhaps this is why polymers made from and marketed as being made entirely from plant materials, such as Natureworks’ Polylactic Acid (PLA), have been so well received.

Both toxicity and degradability have consistent perceptions above midline, but not by nearly as much, nor as consistently outlying as artificiality. Perhaps toxicity does not appear as consistent as artificiality
because people know there are more and less toxic polymers, but do not feel able to differentiate them based on the samples provided. Perhaps the issues around toxicity and polymers are not vernacularly understood. Perhaps the people surveyed would assume that they would not be given highly toxic materials to assess.

While we commonly hear that polymers are not bio-degradable, perhaps people did not associate degradable with bio-degradable. Perhaps the word-pair of Degradable-Lasting was not a strong or clear enough positive (Degradable) to negative (Lasting) choice. Perhaps degradability is not the factor that most concerns people, as landfills may not be visible in the participants daily lives.

The remaining sustainability word-pairs showed results that can affect a conscious designer’s materials choice. The materials with the lowest impact factors: Natural Rubber, HDPE, PP, SAN TPE and HIPS all appear to be accepted in sustainability issues. HDPE has solid reasoning and emotional reception for products made with polymers. SAN TPE is a bit surprising in its reception. It should be further studies compared to natural rubber and Silicone for the nuances perceived between these materials. A comparable impact factor for Silicone should be provided. For strong, durable products, HIPS should be a strong option. While there are specific product markets in which it is used, it could be applied to a broader sustainable product array.

Further studies into peoples’ perceptions of materials will uncover distinct features of the materials that create perceptions of durability, toxicity or artificiality. These materials features, or material properties, may also be given to chemists for the development of polymer compounds and polymerizing processes that may be accepted more easily as ecologically sustainable materials. Partnering designers and chemists to create sustainable products from molecule through manufacturing and even marketing will provide the most highly sustainable products for clients, consumers, and everyone.

REFERENCES


