21ST INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED17
21-25 AUGUST 2017, THE UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA

USING LOCAL INVASIVE SPECIES AND FLORA TO MANUFACTURE COLLAGEN BASED BIODEGRADABLE PLASTIC TABLEWARE

Willett, Kathryn; Howell, Bryan
Brigham Young University, United States of America

Abstract

This paper explains how we designed, developed and tested a locally sourced; environmentally sensitive, biodegradable collagen plastic. It discusses the creation of simple moulds for manufacturing tableware and the accompanying workshop proving the viability of both the process and product. Tests were conducted using commercially available collagen materials to understand its attributes. A unique formulation was developed from hides of local agricultural vermin and powders derived from invasive flora. Plaster and concrete moulds were created for the manufacture of simple tableware. A workshop occurred were 12 participants tested the quality of the plastic, the robustness of the moulds, the simplicity of the manufacturing process and the aesthetics of the tableware. Finally, four of the bowls were successfully tested for bio-degradability and fully degraded within 12 weeks of contact with soil. The workshop demonstrated the success of all aspects of the process and how this development process could be used in emerging communities globally to encourage local manufacture of sustainable products.

Keywords: Ecodesign, Sustainability, Social responsibility, Bio plastic, Bio-inspired design / biomimetics

Contact:
Bryan Howell
Brigham Young University
Industrial Design
United States of America
bryan.howell@byu.edu

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 1: Resource-Sensitive Design | Design Research Applications and Case Studies, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

The field of sustainable bioplastics has experienced rapid growth in the past decade due to the public concerns regarding the environment, climate change and the depletion of fossil fuels (Shen, Worrell and Patel, 2010). By designing low cost, locally sourced, environmentally sensitive biodegradable plastic we can enable the manufacturing of products that can economically stimulate an emerging community. Collagen plastics utilize agricultural pests and dehydrated invasive plant species to create a robust plastic that is beneficial to the environment, before, during and after production.

2 CURRENT BIOPLASTIC RESEARCH AND DESIGN IMPACT

In the past few decades, sustainable design practices have begun to shift from making "less bad," namely a movement to limit pollution and wasteful manufacturing methods; to creating "more good," altering the definition of sustainability (Vezzoli and Manzini, 2008). Designers have begun to step past "stimulating desires to increase non-essential consumption" (Cooper, 1999) and are promoting new environmentally minded practices.

Hilton (2000) analyzes the findings of a study carried out in Germany, the Netherlands, and the United States, which suggests that sustainable design and manufacture practices could deliver 25-50% reduction in pollution and resource consumption per person. As sustainable practices and social considerations become more commonplace, they can assure economic growth and a sustainable future for communities and individuals alike.

Eco design, or ecological design, focuses on environmental aspects of sustainability to improve the quality of products, services, hybrids, or system changes that minimize negative and maximize positive ecological impacts (Charter and Tischer, 2001). Many designers and manufacturers already recognize eco-design as a viable ideology to drive production. Groups like Zuperzozial, who create plastics from sucrose and alternative biodegradable wares from compressed vegetation, have validated the use of new sustainable production methods—and consumers are increasingly supportive of environmentally conscious companies and products (Cone Communications, 2015). A group of students at Waikato University in New Zealand developed Novatein, a bioplastic made from blood meal and animal by-products, which would have otherwise been disregarded as waste (Verbeek et al., 2013). Another example is a chemical research institution in Japan that has industrialized a method for producing a thermoplastic using cardanol, a by-product of cashew nut processing, as a plasticizer with cellulose derivatives (Tanaka et al., 2015).

Even with the rise of these novel materials and methods, sustainable products are relatively uncommon as designers and manufacturers do not readily see financial benefits because of the typically increased cost of production. Reducing negative manufacturing impacts is not the only requirement for promoting sustainable practices; the community itself needs to adapt to the emerging sustainability needs and reconsider the way it lives, produces and consumes. Schumacher (2010) noted the need to maintain the society within natures carrying capacity, and unfortunately, this debate remains unresolved. Designers then, can promote sustainable products and systems through innovative and profitable products—thus promoting sustainable practices by association amongst manufacturers and consumers alike.

Sustainable design practices can also serve as a means of humanitarian aid. By crafting systems to assist specific communities designers can promote ecological benefits and methods for the well being of people in developing countries. The design firm IDEO in cooperation with Acumen has been involved in a program to bring clean drinking water to isolated communities in India and West Africa. Their designed system facilitates a responsive relationship between the local governing bodies, private water suppliers and those in need (Dolan, 2009). Karlsson, (2006) states "We must engage all stakeholders in envisioning and creating the sustainable societies we hope to achieve". Being that designers are often at the forefront of emerging projects, they should feel obligated to facilitate a sustainable lifestyle in their design efforts. Our project strives to bridge the gap between "less good" and "more good" by designing materials, products and manufacturing methods that will benefit both the environment and enable the economic development of a developing community.

3 METHODOLOGY

To promote sustainable practices in small scale manufacturing, we developed a series of biodegradable dinnerware consisting of a plate, small cup, and a large and small bowl. These vessels are made from a collagen-based material and utilize minimal manufacturing equipment, allowing for manufacture in budding communities. Emerging communities would be able to make these vessels from local invasive collagen and flora, thus curbing the effects of environmentally harmful plant species and other agricultural hindrances while creating valuable products that could be well received by consumers while requiring nominal manufacturing infrastructure.

3.1 Experimentation and Development

In the first series of tests, we experimented with hide glue to ascertain which brands of commercially available collagen exhibited properties necessary for durable and mildly heat resistant material, once it has set or cured. We tested four types of collagen at various mixture proportions: Behlen bovine hide wood glue granules, Great Lakes Gelatin Co. beef collagen hydrolysate, Titebond liquid hide glue, and Utrecht rabbit skin glue. All materials were heated to 60°C and then mixed in ratios of 1:6 by weight, collagen to water, as well as 1:1, 2:3, and 1:12 modifications. 35 ml of each medium was then poured into a 4x12 cm. aluminum tray. These samples were supported at a 5-degree incline, allowing for the resulting wedge-like samples to have similar variance in material thickness ranging from 0.5 mm to 4 mm thick. The samples were set overnight to ensure complete setting. Once dry the wedge like samples were removed from the aluminum trays and tested for heat and water resistance and flexibility, with gentle bending and mild heat provided by a hairdryer.

It was concluded that the 1:3 Great Lakes and 1:3 Utrecht rabbit samples were the most heat resistant and least fragile when bent. The Great Lakes product is intended for human consumption as a holistic remedy for a variety of health issues. It is unaltered beyond the original collagen extraction process and unfiltered with no perceivable additives, and thus laden with oils and other impurities from the animal. These granules saturated normally and dried with a greater resistance to water. The Utrecht product is intended to be rigid when set, due to being primarily used as a canvas sealer/stiffener for oil painters. This brand demonstrated a longer working time (5-7 minutes, as opposed to the approx. 3-5 minutes of the other brands tested) before setting and was less brittle than other samples when dried. The properties exhibited by these two brands differ starkly from the other varieties of collagen created as wood glue. Traditional hide glue becomes pliable at approximately the same 60°C temperature it was re-saturated and is manufactured to be water soluble, even after setting. The Great Lakes and Utrecht Rabbit products exhibited more favourable properties such as higher water resistance and greater flexibility when set, provided valuable insight on the adaptable properties of collagen and prompted further testing.

In the second series of tests, we tested only ‘unaltered collagen’—specifically proteins and oils extracted from the animal byproducts under controlled conditions with no preservative additives or treatments applied thereafter. These tests focused explicitly on the differences exhibited by the collagen composition of a specific animal. The strength, water, and heat resistant properties of dried samples derived from proteins from rabbit hide, dog hide, bovine hide, and bovine hoof/horn were tested. These samples were resaturated at a 1:3 ratio of water to dried collagen, by weight, at 60°C and were prepared in the same manner as the initial experiments. The 4x12 cm wedge-like samples were allowed to set overnight and tested in a similar manner as the first experiment samples. In terms of heat, water resistance, and flexibility, the rabbit collagen sample performed the best.

3.2 Product Production

In light if these preliminary results, we locally harvested 45 hides from black-tailed jackrabbits (Lepus californicus), which many considered a blight to crops and livestock in the western United States (Feldhamer, Thompson and Chapman. 2003). The hides were divided into three sealed 20-liter containers full of a 1:12 of pine/elm ash to water solution and soaked for 72 hours in an outdoor environment at a temperature between 0 – 15°C. This solution contains high percentages of lye, which prevents bacterial growth, and allows for the removal of hair and separation of the epidermis and subcutaneous tissue from the dermis, which contain the usable collagen. They remained in this solution for 72 hours outdoors (approx. 0-15°C) in a sealed 20-liter container. Once softened, stray flesh was removed, the hides were de-haired, and the collagen layer was separated and placed in a new container with a solution of 1L baking soda to 10L water. To increase its elasticity for stretching, the hides remained in this solution for 18 hours under similar environmental conditions. The hides were then removed, and stretched on traditional hoop rabbit skin stretchers. Once the hides were dry to the touch, they were removed from the stretchers and placed in a dehydrator overnight to remove excess moisture. These final dried hides are shown in Figure 1. The hides were then cut into smaller pieces and ground repeatedly in a food processor until they resembled fine granules. The granules were sterilized via dry heat sterilization at 160°C for 3 hours. Sealed in this dehydrated state, the powdered collagen can be effectively stored and transported.

Figure 1. Dried Lupus Californicus (Jackrabbit) hides prepared for grinding

To produce 1dl of collagen plastic medium, we combined 60ml of 10°C water with 40g of collagen granules and 3 ml 1% glycerol solution. (Glycerol solution was created by diluting 1 ml of glycerol in 99 ml of distilled water.) It was stirred and then left at rest for 4-6 hours or until gelatinous. The solution was kept at 60°C until the granules were dissolved and then the foam resulting from the heating process was removed. This process creates a desired putty-like consistency for the mixture. The mixture was then heated to 95°C and fortified by introducing a proprietary food safe wax; causing the substance to became more water resistant and its form more easily able to be altered as it cooled from a hot liquid state.

3.3 Sample Dinnerware

Plaster and concrete slip-casting moulds were created from thrown ceramic vessels to produce unified forms. These semi-porous moulds assist in the extraction of liquid rapidly from the cast collagen medium. To make a bowl sample, these moulds were dusted with vegetable starch and filled with its respective amount of medium—ranging from 75 ml to 150 ml depending on the form of the desired vessel. It was noted that by adding consistent pressure to the moulds while setting, the vessels were substantially more robust and uniform, without being brittle. This also cut the initial setting time for the vessels from 2.5 hours to 1. 75 hours for the largest form. This improved strength was observed in all alternates of the dinnerware, regardless of varying thickness.

The produced containers, made from collagen plastic medium with no additives, were a soft tan colour with a light separation between the heavy and light particles in the medium. In efforts to explore colour variations, a number of chemical and natural additives where explored. In one experiment, a 1:3 ratio of hydrogen peroxide to water was used to hydrate the granules. This mixture ‘purified’ the material into a translucent deviation but did not have any noticeable effect on the strength, or resistance to heat and water of the medium once cured. In another experiment walnut wood sawdust was added and it produced a darker material with significantly less translucency. These samples can be seen if Figure 2. Further experiments were conducted using locally found dehydrated invasive plant species. This added both colour variety and environmental value. For example, powdered dried salt cedar collected from the Wasatch mountain range as well as Russian thistle from the region surrounding Promontory, Utah, added subtle colours to the end product.

Figure 2. Tableware castings demonstrating how different additives affect colour and transparency. Additives from left to right, hydrogen peroxide, unaltered or original collagen plastic, and walnut wood sawdust

With the ability to sterilize the organic substrate, we continued to experiment with other dehydrated materials, like sawdust, soil, leaves and various fibres, as well as other invasive plant species. The addition of plant particulate shortened the setting time from 1.75 hours under pressure to approximately 1 hour. After this initial setting time, the collagen vessels can be easily removed from the moulds, due to minor shrinkage, and handled. The vessels were dusted with agar (powdered red algae) or a vegetable starch to eliminate any residual tackiness as they continue to set in open air. The vessels completely set in 2 days.

4 WORKSHOP VALIDATION

A workshop was designed to demonstrate the value of the new collagen plastic and production process. 12 volunteers were recruited to participate who possessed no knowledge of the project beforehand. For the workshop, we presented pre made finished sample pieces, and explained the 5 step manufacturing process with demonstrations on particular manual aspects, such as how to fill and clamp the molds. In the interest of time, we pre-saturated 2 liters of both the original and pure mediums. Following are the procedural steps as they were presented to the panel of volunteers.

- Mix the medium using a 2:3 ratio of collagen powder to cold water, add glycerol solution 3ml for every 100ml of mixture (pre-mixed).
- Warm to 60°C, remove foam and sit until gelatinous. Raise the gelatine to 90°C, stir in wax and remove from heat.
- Fill the molds up to the setline; add dehydrated inclusions under 50g mass.
- Clamp the two parts moulds and stack them inside the dehydrator.
- Let it set inside the dehydrator for 45 minutes.
- Carefully remove the top portion of the mould and dust the collagen plastic with starch, turn the mould upside down and dust the underside. Place in a cool, dry place and let set for the two days.

The volunteers successfully followed the instructions and each created their own piece of personalized biodegradable plastic dinnerware. As the pieces cured we took the opportunity to discuss their experience with the process, as well as the impact of sustainable manufacturing processed in plastics, and the origins of the dehydrated colorants they used in more detail.

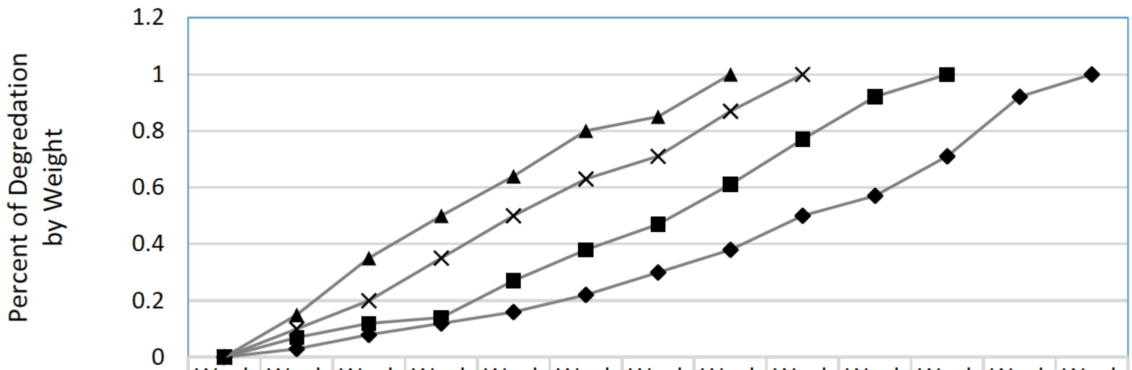
4.1 Product and Workshop Results

The collagen plastic products assist in curbing the populations of agricultural pest as well as the spread of environmentally harmful evasive plant species. They can be made with very simple tools and procedures with no harm to the environment or atmosphere. The collagen sets quickly, from 30-45 min depending on the size of the vessel, and cures completely in 2 days. The organic colouring additives worked well and did not chemically hinder the plastic curing. Each of the 12 volunteers successfully created their own personalized piece of biodegradable dinnerware as shown in Figure 3. Several participants inquired when another workshop would be held, as well as where to purchase additional pieces or dinnerware sets.

Figure 3. Photos taken of the initial workshop. Left; bowls of colour additives collected from dehydrated and ground local invasive plant species and local soil. Right; Results of the workshop. Manufactured cups showing different colour additives

5 COMPOST TESTING AND DECINTIGRATION

To test the biodegradability of the vessels upon disposal, a 15x50x15-cm planter was placed outdoors (5-15°C) and filled with seasoned compost. Four collagen plastic cups were placed in the planter; labelled A, B, C, and D respectively. Cups A and B were placed on top of the compost, while cups C and D were buried. Cups A and C received daily midday watering while cups B and D received no alternative treatment aside from the weather. The cups were tended daily and the buried samples were uncovered for observation weekly. The Compost Test duration was 12 weeks. The watered subgroup was tended to daily and all samples were examined weekly. All sample-composting results are charted and viewable in Figure 4 below.



	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
Sample A	0	7%	12%	14%	27%	38%	47%	61%	77%	92%	100%		
Sample B	0	3%	8%	12%	16%	22%	30%	38%	50%	57%	71%	92%	100%
Sample C	0	15%	35%	50%	64%	80%	85%	100%					
Sample D	0	10%	20%	35%	50%	63%	71%	87%	100%				

Figure 4. Assessing the deterioration of collagen plastic samples A-D by weight as measured over time

Of the above ground samples; watered sample A exhibited extreme wear and bore a consistency that resembled “baked oatmeal.” The sample was fragile and could not be handled without disintegrating

further. By week 10, sample A was unrecognizable. The above ground unwatered sample B, exhibited noticeable wear such as cracks and flaking. The area where the cup touched the compost was structurally delicate and misshapen. Sample B was noted as being ‘flakey and brittle’ as a result of being solely exposed to the elements. Both samples A and B had numerous unidentifiable insect holes measuring approximately 1.5mm. Buried watered sample C was rendered unrecognizable in 49 days, being reduced to a soft tannish mush. Buried un-watered sample D became unrecognizable in 56 days displaying the same characteristics as sample C.
We have not concluded a test of long-term water solubility at this time. Using a simple hand-squeezing test, the vessels retain their shape and integrity when containing cold to warm water, however, they become more malleable when containing hot water.

6 DISCUSSIONING THE WORKSHOP, PLASTIC AND THE NEXT STEPS

6.1 Workshop

The workshop lasted 1.5 hours from start to finish, including the time allocated to explain to the volunteer participants about the moulding process, plastic collagen material, various powdered colouring agents, and the eventual goals of the project. The workshop was a considered a success by all participants. Once the event ended several volunteers asked where and when the next workshop would be held, as well as how to purchase additional wares and make orders. When surveyed the day after the workshop, the volunteers stated that they would be interested to purchase this product when manufactured in a foreign country. The ease with which the participants were able to produce these collagen vessels supported our belief that they could be made by small rural communities with limited access to electricity or other public utilities. Exporting these collagen vessels would supply an effective source of income and the promise of growth in these communities. Once we have consolidated our production method further and verified deviations of the collagen plastic medium using other common farming pests aside from rabbits, we hope to conduct a case study of this project with a volunteer community for a trial period.

6.2 Collagen Plastic

The production of collagen plastic assists the immediate environment by reducing harmful agricultural pests and foreign plant species. Removal and use of these species will control the spread of disease within their community and livestock, potentially bolster local crop yields by removing ecologically detrimental invasive species, and provide a source of income for isolated rural communities. The elementary nature of the production process and longevity of materials—whether shipped or produced locally, allows for these vessels to be produced in remote areas with limited access to electricity and other utilities. Once discarded, these biodegradable wares are easily composted under standard weather conditions in less than 84 days. We plan on pursuing this project further by streamlining the production method further, modifying the properties of the set plastic for specific purposes, and exploring alternative inclusions and sources of collagen.

6.3 Continued Experimentation

We are continuing to explore other applications within the realms of agriculture, namely small biodegradable seedling pots. These thin vessels contain the seedling until it is large enough to be planted in its permanent location. When it does come time to relocate the seedling, the entire pot can be planted. We are currently exploring potential organic fertilizing agents with which to imbue the plastic, as well as various pot shapes to yield the best results. A four-month study is currently underway to determine the overall effect of the collagen itself as a fertilizing agent.

7 CONCLUSION

After these preliminary experiments and the resulting collagen based plastic material, we believe this process to be a viable mode of repurposing agricultural pests and invasive species--which would otherwise have been disposed of or burned. We also believe that this is a material that can be used as basic kitchenware and can easily decompose when needed. In its current state, this material has numerous potential applications, including possible financial benefits for developing communities. We intend to do more thorough testing involving potential strength, malleability, flexibility, reactivity to temperature, as well as solubility, in addition to our current seedling pot study.

REFERENCES

Charter, M. and Tischer, U. (2001), Sustainable Solutions: Developing Products and services for the future. Green Leaf Publishing. Sheffield, UK.

Cone Communications. (2015), Global CSR (Corporate Social Responsibility) Study, Cone Communications, Available at: http://www.conecomm.com/2015-cone-communications-ebiquity-global-csr-study-pdf. Accessed: Dec. 16, 2016.

Cooper, T. (1999), "Creating an economic infrastructure for sustainable product design". *Journal of sustainable product design*, Issue 8, pp.7-17.

Dolan, K. (2009), Getting Water To The World's Poorest, Forbes, Available at: http://www.forbes.com/2009/09/10/ideo-acumen-fund-technology-breakthroughs-water.html, Accessed Dec. 17, 2016.

Feldhamer, G. Thompson, B. Chapman, J. (2003), Wild Mammals of North America: Biology, Management, and Conservation, Second edition, John Hopkins University Press.

Hilton, M. (2000), "Design for Sustainable Development: Support Systems for small and Medium- Sized Enterprises", *European Foundation for the Improvement of Living and Working Conditions*. Available at: http://edz.bib.uni-mannheim.de/daten/edz-ma/esl/00/ef0072en.pdf. Accessed Dec. 17, 2016.

Karlsson, R. and Luttropp, C. (2006), "EcoDesign: what's happening? An overview of the subject area of EcoDesign and of the papers in this special issue". *Journal of Cleaner Production. Elsevier Press*. Vol.14, Issue 15-16, pp. 1291–1298, http://dx.doi.org/10.1016/j.jclepro.2005.11.010

Schumacher, E. F (2010), Small is beautiful: a study of economics as if people mattered. Harper Perennial, New York, New York.

Shen, L., Worrell, E. and Patel, M. (2010), "Present and future development in plastics from biomass". Biofuels, Bioprod. Bioref., Vol. 4, pp. 25–40. http://dx.doi.org/10.1002/bbb.189

Tanaka, S. Moon, S. and Iji, M. (2015), Cellulose Resin and Process for Producing the Same, US Patent no. 9181351 B2

Verbeek, C. J. R., Lay M. C. and Bier J. M (2013), "Plasticization of bloodmeal-based thermoplastics". Proceedings of Chemeca 2013: Challenging tomorrow, Brisbane, Australia. September 29 - October 2, 2013, Brisbane, Australia, Institution of Engineers.

Vezzoli, C. and Manzini, E. (2008), Design for Sustainable Development; Support Systems for Small and Medium-sized Enterprises, Springer-Verlog, London, http://dx.doi.org/10.1007/978-1-84800-163-3