MANUFACTURING PROCESS AND PRODUCT DESIGN FOR MASS PRODUCTION OF ENVIRONMENTALLY-FRIENDLY FISHING LURES AND WEIGHTS

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ABSTRACT

Manufacturing Process and Product Design for Mass Production of Environmentally-friendly Fishing Lures and Weights

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The current industry standard for the manufacture of recreational fishing tackle uses lead-based weights and PVC or silicone-based lures. Both materials have serious negative effects on those who handle these products, waterfowl, fish, and other animals that may consume this discarded tackle. The goal of this project is to find and design an environmentally safe process and product alternative for this industry. To do this, we researched a large amount of viable safe materials for weights and lures and used decision matrices to decide on the best one. We found that brass would be the most suitable alternative and created a die that could be scaled up to provide proof of mass manufacture. We were unable to find a perfect replacement for lures from our research, so we created our own materials and tested them to determine which material we should progress with. To test our materials, we fixed them in water for three days to see how long they take to degrade, and attempted to fish with the materials to see if they were strong enough to resist casting forces. We found that a gummy candy mixture of gelatin, sugar, and pectin is the most suitable for biodegradable lures. We created a small-scale prototype that involves pressing a die with multiple shapes of the lure into a bed of cornstarch to create a cavity to show proof of this environmentally-safe concept for mass production.

It was found that by comparison to the roughly five dollars per pound for the current lead-based weight products, brass weights will likely be in the twelve to fifteen dollars per pound. Even though brass weights and environmentally-safe lures would cost more to produce, it appears that the market is gradually shifting towards non-leaded and biodegradable products therefor making the switch over to this more environmentally safe alternative beneficial; as people would be willing to spend more money on a product that protects wildlife.
I would like to thank my parents and grandparents for supporting me throughout my college career, especially when things weren’t going so well. I would also like to thank Poly Escapes for creating an incredible community and giving me a real home here.

- Jake

Thank you to my parents Vartan & Siran Ichlokmanian, Bob Aboulafia, and my grandfather. You gave me the tools and support to be successful. I will not let you down.

- David
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1. Introduction

1.1 Subject Statement

This report will describe the problems with the current, environmentally-negative materials that are used in fishing lures and weights as well as our solution to produce environmentally-friendly fishing tackle.

1.2 Background

Fishing tackle is one of the critical components for fishing, it is used by any and all fishermen. Due to this widespread usage, you can imagine that there is a lot of waste that follows this usage; especially when tackle gets lost because of a fish breaking a line, a line getting caught on a rock or tree, or if someone is careless and leaves some behind. This leaves us with an interesting problem as most of this fishing tackle is not made with environmentally safe materials. The current materials will often sit in an environment for lifetime as they do not biodegrade. If the fishing tackle does degrade, some do so at the cost of the organisms living in that environment as the degrading material releases toxic chemicals into the surrounding area. The idea for this project originated with David’s interest in fishing as well as his discussion with a professor when a more simplified version of this product was used as an example in class.

1.3 Problem Statement

In today’s fishing world, there are many cases of fishing tackle being lost to the environment, the tackle on the market is made of non-environmentally safe materials. Our goal is to design an environmentally-safe fishing tackle manufacturing process with alternative environmentally-safe materials.

1.4 Purpose

The purpose of this study is to prove that there is a need for environmentally-safe, alternative materials for fishing tackle and to design a product and process to make the safer fishing tackle a reality. We hope to show that the current industry standard is causing harm to the environment and to create an easily adoptable process for creating better fishing tackle.

1.5 Objectives

- Provide environmental data to justify the need for better alternatives
- Determine alternative materials to use.
- Use a cost vs. environmental impact decision matrix to determine the best material
- Design the lure and weights
- Design an environmentally-safe manufacturing process which can be scaled to mass manufacture and adapted to current or new fishing tackle.
By the end of this project, we hope to deliver prototypes for the lures and the weights, an alternative way to adapt current machinery to be able to produce our product, an economic analysis for our project, a literature review that details other processes and materials that we have considered and the effects of current materials on the environment. In order to accomplish this problem, we will need to pick the best material for our environmentally safe tackle and ensure that the mass production process is equally environmentally safe.

1.6 Approach Solution

In order to find the best solution to our problem, we have done research to determine the best material for our fishing tackle. To figure out which is best, we will look at all of the advantages and disadvantages of each material, compare costs, weights, densities, and how they degrade. After analyzing all of the options, we will have come to our conclusion on which will be best. Once we have chosen our material, we plan on creating a prototype of the tackle and testing it. We will test our prototype to find out the rate at which it biodegrades, how reusable it is and if it is effective in real life. Our product needs to be environmentally-friendly and effective. Fishermen will not use the safer alternative if it doesn’t catch fish. We also need to test that the alternative material act in the same way as current standards, for example, when moving through the water, does the tackle ‘swim’ as it should.

In order to meet all of our objectives, we will have to do a lot of design work in Solidworks to make our lures, weights, and molds. We will research the economic and environmental benefit of using our lures and if there is room in the market for a product such as ours.

1.7 Report Organization

The rest of this report will have data and background information on processes and materials that we considered but will not use as well as information on the damage that fishing tackle causes on the environment. There will also be information on the fishing market and where this product will fit. After, we will go over our design and choices we had to make to produce the best result for our product and process. Lastly, we will then present how we tested our designs and processes and our conclusions from those tests.

In the next section, we will go over background information on our project and discuss many of the technical aspects of our project.

2. Background

There are many types of lures available on the market such as jigs, spoons, flies, spinners, swimbaits, and soft plastic lures (SPLs) to name a few. Among the many types of lures available there is an ever-growing assortment of styles, shapes, and color schemes being released to the market every year. Alternatively, sinkers and weights are far more simple in design, with certain shapes being preferred. The variety and differences among the competing manufacturers is limited. The most common of these shapes include egg sinkers, split shot, cannon balls, disk, pyramid, and drop shot styles. Until recent years, lead has been the material of choice in the production of weighted hooks/lures, weights and sinkers.
According to an article from 2003 published in the Canadian Wildlife Service Occasional Paper it is estimated that 500 tons of fishing tackle, specifically weights and lures, are deposited into the environment that year. (Franson et al., 2003) The main concern with the use of lead in these products are the health risks to those handling the products, and their impact on wildlife and the environment. According to a study published in The Annals of Occupational Hygiene in 2015, using lead fishing weights as the source of contamination, they determined the skin to saliva transferability of lead after handling the sinkers was in the 12 to 34% range. Couple this transferability with data gathered by the EPA in 2002 stating their finds that for both children and adults there are approximately 9-15 hand to mouth contacts per hour (Sahmel et al., 2015). The results of these studies are similar to those which lead to the ban of leaded fuels in the 1980’s, as well as paints containing lead in 1978, which showed the damaging effects to those in contact with or using these products. In a study titled Fish and Wildlife Issues Related to the Use of Lead Fishing Gear published by the Washington Department of Fish and Wildlife in December 2006 detailed the environmental impact of lead fishing gear on local wildlife with the focus being bird species which become susceptible to lead poisoning by ingesting the lost or discarded fishing (Michael, P., 2006).

There are currently many different methods being used to produce the vast variety of lures and weights. Though the most popular methods for weighted products and SPL’s appear to be spin casting into molds and injection molding respectively. These processes utilizing the current materials allow for mass manufacturing at relatively low costs, and rather simple and inexpensive equipment. With the exception of the toxicity to exposure the properties, availability, and cost of lead unfortunately make it a rather ideal choice. A similar situation applies to the use of silicone and PVC-based plastics in SPLs, their relatively low cost for materials, tooling and equipment also makes the ability to mass produce these products cost effective and rater simple to implement.

In recent years, a few materials and alloys have gained popularity in replacing lead as the weight component for fishing products. Since the passing of legislation to ban the use of lead in all products in the European Union, as well as the ban of sale or use of fishing tackle containing lead in many U.S. states, and national parks, many materials including tin, bismuth, stainless steel, Copper alloys, machined tungsten nickel alloys, and tungsten composites have been used in an attempt to replicate the high density and/or ease of manufacturing of lead in fishing products. Though some of these materials have been sufficient in specific applications i.e. tin and bismuth split shot and small weights none have yet to be successfully implemented in many larger sized fishing tackle without a significant increase in manufacturing or final product cost.

Many of the above listed materials such as steel (7.6 g/cm³), tin (7.3 g/cm³) are limited in their function when considering medium to heavy lures and weights due largely to their relatively low densities by comparison to lead (11.3 g/cm³). The other factors to consider for these materials are the methods required to produce equivalent products. Steel has a considerably high melting point (1300-1500°C depending on composition) meaning casting would require a considerable investment, and the machining of steel into complex shapes is also quite time consuming and expensive process. Tin and bismuth have melting points far closer to that of lead
(231.9°C, 271.4°C and 327.5°C respectively) due to this casting is a viable option for developing products with these materials, although as previously stated these materials have relatively low densities. However, the low-density results in far larger sized tackle at the higher weights which is an undesirable trait when considering fishing tackle. In order to combat the issue of low density, materials such as tungsten (19.25 g/cm$^3$) and brass (8.4-8.7 g/cm$^3$, melting point between 900-940°C depending on composition) have been used. Tungsten and brass based fishing tackle are typically sold as higher end fishing tackle due to the higher density of the material, higher cost of materials, and the higher cost of manufacturing.

Even at higher prices tungsten composites have been utilized in a niche fishing tackle market developed for the sport fishing community. Due to the very high melting point of tungsten (3400°C) casting is not a viable option for mass production, however there have been sinkers and lures made by sintering nickel and tungsten powder, but the more common practice is the use of a tungsten infused putty. This tungsten putty is typically molded and hardened in the desired shape. The raw material is however quite expensive which translates to a much more costly final product. However copper alloys such as brass have been used in a limited capacity in the market. Thanks to the relative softness, reasonable cost, density, and melting point of brass makes casting and machining viable options to study.

2.1 Literature Review

The subjects that will be reviewed within the research for this project will include; the effects on the environment and those in contact with the materials currently used in fishing equipment, along with manufacturing techniques for large production of lures using alternative materials. The materials of specific concern are, lead which is used to sink the lure and line and the polymers typically used as bait. These materials are known to have adverse side effects on those who handle them, as well as the environment when discarded or lost. We are designing fishing lures and weights that will be more biodegradable and environmentally friendly than the current industry standard. We aim to make the lures out of a biodegradable and environmentally-safe substance and we plan to make the weights out of a safer, non-toxic metal. Our articles will focus on how to produce these products efficiently, sustainably, and affordably. We will also be researching the effects of the current industry standard in order to see the effect our safe lures and weights will have. We will also review techniques available within industry to produce our lures.

2.1.1 Weight Considerations

**Evaluating Non-toxic Substitutes for Lead Shot and Fishing Weights**

This article is about creating the evaluation process for the material fishing weights and shot. It discusses what the material limitations and testing procedures for these products as lead should be replaced with something less toxic. This is relevant to our project because we are working on creating a non-toxic, biodegradable fishing lure and weight system. Our product and manufacturing process will have to meet these requirements if we wish for our project to be successful and usable. (Thomas et al., 2003)
Lead in Fishing Tackle

This article by the The American Sportfishing Association (ASA) which states their opposition to the legislations and bans of lead in fishing tackle, gives detailed summaries of legislation passed concerning the use of lead in fishing tackle. There is also a large amount of background information regarding the rules associated with these laws.

Estimation of Hand-to-Mouth Transfer Efficiency of Lead

To help evaluate the potential damage of the current materials in use for the manufacture of the current fishing tackle on the market, this article was a study published in 2014 by Oxford University Press on behalf of the British Occupational Hygiene Society. This study used 100% lead fishing weights as the source of metallic lead to test the effectiveness of transfer from hand to mouth. This directly ties into the purpose of the development of our product. Their study was able to determine that there was a range of transferability from 12-34% (Sahmel, J., et al.,).

Ecomass High-Density-Composites

The ecomass technologies company have developed a nontoxic composite as an alternative to lead alloys used in the fishing tackle industry. By utilizing a mixture of plastic and metal particles they are able to offer a product which is designed to be used in an injection molding process that has the same density of lead but is considerably more eco-friendly.

Synthesis and Densification of Tungsten-Brass Composite by Mechanical Alloying

This article describes the process required to produce a copper-zinc-tungsten alloy which was developed as a cheaper alternative to copper tungsten composites. This material became a viable choice as a lead substitute due to the similarly high density of tungsten, and the claims of the materials ease of machining and shaping. (Mohammed, K.S. et al., 2015)

Release of Copper from Sintered Tungsten-Bronze Shot

After discovering the material and its properties, we searched the database to find more information regarding the tungsten-brass composite. This authors studied the possible risks to the aquatic life and the environment in general. The results of this study show that sintered W-brass does not pose a risk to the environment or aquatic life. (Thomas, V.G., et al., 2007)

2.1.2 Lure Considerations

Degradable Materials in a Marine Environment

This article is about the degradable materials in a marine environment and their effect on that environment. The article also talks about historical amounts of debris that have been dumped and left in the oceans and other bodies of water. This article estimates that there a loss of 150,000 tons of fishing gear in the past. We assume this estimate includes more than just lures and
weights, however, that is a very sizable amount of waste being left in the oceans and we think that our product can help reduce that amount. Lastly, the article discusses testing and creating alternatives for fishing gear that will be more environmentally friendly. This relates to our project as it describes the effects of lost fishing gear and the damages it causes, which is something that we are trying to combat. The research done on other plastics used in fishing gear is also extremely valuable to our project as it can narrow down our search for a safer lure. (Gonsalves et al, 1990)

**Potential Effects of Lost or Discarded Soft Plastic Fishing Lures on fish and the Environment**

This report relates to our project is about the effect of soft plastic lures (SPL) on the environment and how well they decompose. This article found that SPLs do not decompose at all and that they actually grow in size over time. That effect being more intense in warmer climates. The article also discusses the rate at which SPLs are consumed by local fishes. The article also discusses the need for a replacement for the current standard or better education of fishermen on not losing their lures. The information is critical for our project as it shows the damage that is done by current non-biodegradable fishing lures. Our project aims to remove this problem by using a degradable substance to make the SPLs, removing the lasting effects of discarded and lost lures. (Raison, 2014)

**Starch Blends**

The effects of discarded polymer packaging on marine environments is part of the reason why we are performing this study, we want to see the effects of polymers in fishing tackle. We will look at many different materials, one of which is similar to the research done in this article about the process of developing a new starch based polymer that would be a more biodegradable than currently used polymers. This article is extremely relevant to our project as it discusses the creation of a new polymer that would be degradable in water. The process that it goes through will be similar to how we develop the polymer that we would like to use for our biodegradable fishing lures. (Guzman-Sielicka, 2013)

**Mixed Agarose and Gelatin Gels**

Mixing gelatin and agarose in different concentrations and seeing their effect on the gelatinization, the elastic modulus, melting point, and swelling is a critical aspect to our project as we plan on using both of these as potential materials. We will need to make a compound that is biodegradable in water, does not swell, but can also be reused multiple times. (Gotlib, 1989)
Elastic and Viscoelastic Characterization of Agar

Agar is going to be a very important part of our project as it is one of the materials that we are considering using to make our lures. This article describes what agar is and how it is used in many other ways, typically used in engineering research. It is a biological material so it will be able to decompose in a natural state. It also discusses the elastic modulus of this substance depending on concentration and goes over other aspects of this material. We will need to decide if we want our lures to be a mix of agar, gelatin, and other materials or if we want it to be a more chemically pure product. (Nayar, 2012)

Functional Properties of Films Based on Soy Protein Isolate and Gelatin Processed by Compression Molding

Researchers made an attempt to compression mold a mixture of soy protein isolate and gelatin. This article falls in the same category as the previous two articles as it is very important in determining what kind of material we want to use for our lures. A critical aspect of whatever material we choose is that it needs to be able to be injection molded or compression molded. This article also describes that the main purpose of this experiment was to find more environmentally friendly packaging. Knowing that both of these materials are environmentally friendly is a huge part of choosing which material we would like to use. Seeing other uses of gelatin in molding shows that it is a viable material for mass production. (Guerrero et al, 2011)

2.1.3 Manufacturing Considerations

Automation in Brass Die Casting

This article is about a new type of brass casting that increases efficiency and effectiveness. It allows for higher quality parts due to the machine taking brass casting parameters into consideration which allows the operator to do a better job. Allowing the operator to focus on other aspects of the casting prevents defects and increases efficiency. This is relevant to our project as it goes over the process to create and new casting process and how to create a higher quality casting. We can use this information when developing our process to cast weights, this includes the machinery and the facility floor plan. (Karni, 1986)

Copper Alloy Casting

This article goes over the casting of marine brass and what that entails. The article also describes the history of marine brass and its durability. The marine brass will not degrade while in use and if a weight is lost then they will not release toxic chemicals like lead does. The article also discussed different types of bronze alloys for different uses including what is necessary for fishing or boating. This articles relates to our topic because we will need to select the proper type of marine brass for our product so that it either does not degrade and does not release toxic chemicals or that it does degrade in an environmentally safe way. This article also provides information on how marine brass is produced which is necessary for designing the manufacturing process. (Lindberg, 1986)
Malleable Iron Dies Pressure Die Casting Brass Fittings

This article was about developing steel inserts for the production of brass disk for gasoline gate valves. The authors were exploring the effects on surface finish between the use of a steel or ceramic dies for the production of iron based cores for a production process. We were able to determine from some of the information provided in this article that the use of ceramic dies may be a viable option for casting brass, as well a brief overview of the process and materials used to produce them. (Timofeev, et al., 1983)

Rapid Casting Solutions for Lead and Brass Alloys using 3D Printing

The focus of this article was to develop a procedure utilizing additive manufacturing to develop a cost effective process for thin walled castings of lead and brass alloys. This article gave us an example of the capabilities of additive manufacturing in producing investment castings. (Singh, et al., 2009)

Permanent Mold Composite for Brass Casting

This article covered the testing of a yttria-zirconia composite as a suitable material to produce permanent molds for the casting of high melting point alloys such as brass. By testing different concentrations of zircon within the composite to determine thermal shock resistance. The authors were also able to determine the necessary sintering temperature to develop reusable molds capable of producing more than 200 castings. This composite was considered as a mold material for our process, however the costs, sustainability of the materials and potential environmental impacts must be considered as well. (Jin, et al., 1996)

Casting with Graphite Molds: Economical Precision Parts

In the search of alternative materials to develop reusable casting molds for production we discovered this article which described the efficiency and cost effectiveness of the implementation of graphite as the mold material for the mass production of zinc-aluminum alloys. Due to the large number of parts these molds can produce 40,000 parts per this report, and this made graphite molds a very attractive mold material option. (Zanchuk, 2006)

Gummy Candy Manufacture

After much research of manufacturing process for fishing weights, we moved onto research ways to produce our lures. The process that current gummy candies are made came to mind. They use a cornstarch base that acts as a base for a die to punch into creating a mold. After the gummies are poured and allowed to cool, the cornstarch is filtered out and reused. This
process produces very little waste and is safe for animal and human consumption. ("Manufacturing Process of HARIBO Gummies", 2017)

2.1.4 Other Considerations
Reclaiming and Recycling of Discarded Plastic Fishing Gear

One of the reasons why we are doing this project is because it is very difficult to recover all the discarded plastic fishing gear that is left annually. Most of the plastic gear will never be recovered and will stay in the environment for years. This study describes an attempt to recover and then reuse and recycle found fishing gear. The study focuses on the feasibility of the recovery and they found that it would use more energy and resources to collect and recycle the plastic fishing gear. This is a further reason why our product needs to go into production as it would alleviate this massive problem. (Dagli, 1990)

3. Design

3.1 Customer Requirements

Our project does not belong to a specific customer as it was originated by David Ichlokmanian, due to this, we do not have specific requirements from a company or individual. Instead, we will list what we believe to be the requirements that our target consumer would want. We will also base this off of our own requirements for our project.

Our customer requires that the weights used on our lures and weighted hooks be made of something other than lead. This new substance should be durable and reusable while also being nontoxic to the environment. The metal either needs to biodegrade or to not release harmful chemicals into water sources. The material used for the soft plastic lures need to fit the same parameters. They need to biodegrade in a nontoxic way and be safe for a fish to consume. Fish need to be able to consume the lure as they are often lost after a fish has been hooked. In our research, we found that many lures actually increase in size over time due to water absorption, the material that we choose needs to get smaller and eventually degrade into the environment. The lure also needs to be reusable, however, less so than the weights. The lures should be able to enter an aquatic environment and then leave while still maintaining shape and not beginning to degrade. One of the keys to our products success is the functionality of the final product. Our lures need to not only work, but they need to work well. The lures that we make need to be able to catch fish as well as lures that are on the current market. This is because a fisherman won’t buy a lure that doesn’t work. The final customer requirements revolve around the manufacturing process of our product. The manufacturing process needs to be environmentally friendly and produce as little waste as possible. If our product is to be environmentally friendly, the process to make the product needs to be as well. The process needs to be able to produce our product quickly and en masse.

3.2 Weight Material

The first thing that we needed to consider when creating our fishing weight was to figure out the appropriate material. In order to do this, we created a decision matrix that listed our potential materials that we found during our background research and literature review. Once the
potential materials were chosen, we decided on the factors that we determined to be the most important for manufacturing our environmentally friendly weights. Many of these criteria were decided on to determine the environmental impact of each material as well as its price and manufacturing ease. Each criterion was weighted with an importance ranging from one to five; five being the most important. After rating each material based off of information taken from the Granta CES Material Database from the materials engineering lab. (This data can be found in chart form in the appendices.) We found that lead is still the best material for this job. This would explain why it is currently the industry standard for lead shot and weights despite its toxicity to animals. Since the best option is the material we are looking to replace, we decided to move forward with the second-best option, brass, for our fishing weights.

### Table 1: Decision Matrix For Weight Material Selection

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<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>93</td>
</tr>
<tr>
<td>Granite</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>82</td>
</tr>
<tr>
<td>Nickel</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>63</td>
</tr>
<tr>
<td>Tin</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>79</td>
</tr>
<tr>
<td>Tungsten</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>71</td>
</tr>
</tbody>
</table>

3.3 Weight Design

After we had decided on the material, we moved forward with designing the weight itself. Before designing the part, we decided that this product should be die cast. We chose to go with this process as opposed to brass’s typical process of sand casting as die casting will produce less waste and is better for mass production. The material we chose for the die is graphite. This was chosen due to its low environment impact, abundance, and high melting temperature.
3.4 Weight Manufacturing Process

When designing the weight, we wanted to mimic current designs that are on the market so that fishermen would feel comfortable when trying a new product. We designed the weight to appear like a fish head. It has a protrusion off of the back with two spines to help keep the lure attached to the weight. We also applied three degrees of draft to the weight to facilitate die molding. Below you can find Solidworks screenshots of the fish head weight and mold. You can also find a copy of the engineering drawing in the appendices.
3.5 Lure Material

Once the design for the weight was finished, we needed to figure out what material our lure should be made from. We applied the same procedure as before for the lure. Using data obtained from our literature review, we found materials that would work well as biodegradable lures. Again, using the same technique as before, we chose properties that are important for fishing lures to have and weighted them by importance. However, after completing this decision matrix, we found that we had to make far too many assumptions about each material due to a lack of available information. In order to combat this, we decided to make our own lures with varying amounts of each component and then test them. We plan on testing all of the materials listed below except for Bioplastic due to its higher cost and low availability. This will be further discussed in the next section and in the methods section of this report.

<table>
<thead>
<tr>
<th>Material</th>
<th>Strength (5)</th>
<th>Flexibility (5)</th>
<th>Water dissolution rate (3)</th>
<th>Availability (5)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gelatin Based</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>72</td>
</tr>
<tr>
<td>Agar Based</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>34</td>
</tr>
<tr>
<td>Agar -Gelatin mix</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>47</td>
</tr>
<tr>
<td>Bio Plastic</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>46</td>
</tr>
<tr>
<td>Gummy Candy</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>77</td>
</tr>
</tbody>
</table>

3.6 Lure Manufacturing Process

In order to mass produce our lures, we decided to apply an already accepted industry standard. We chose to adjust the process that is used by gummy candy manufacturers. Currently, gummy candy manufacturers take a die with multiple copies of the candy and press it into a bed of cornstarch to form a large series of molds. These molds are then filled with the gummy material, allowed to cool and harden, and then are filtered out of the cornstarch. Afterwards, the cornstarch is then reused for other gummy candies. This process is extremely environmentally friendly and little of the cornstarch is wasted during manufacture and it produces a product that is even safe for human consumption. In order to make a small-scale prototype of this process for our purposes. We designed a plate that would be attached to multiple copies of our lures which could then be hand pressed into a small bed of cornstarch.
3.7 Lure Design

Since the materials will all have the same manufacturing process, we moved forward with designing. We designed two types of lures. One shaped more like a worm that could be easily applied to standard hook and one that is meant to be attached to the fish head weight. The worm design was made to look as similar to a worm as possible while still applying design for manufacture which involved applying a three-degree draft on the sides to help remove it from the cornstarch bed. The same principles were applied to the fish lures. The fish lures were also modeled more closely to industry standard lures so that, again, fishermen would not be wary of trying a new product.
Figure 5: SolidWorks Screenshot of Soft Plastic Lure Fish Body

Figure 6: SolidWorks Screenshot of Soft Plastic Lure Worm Body
4. Methods and Production

We wanted to test our manufacturing processes and our design so in order to do that we made small scale versions of both. In this section, we will go over how our production of the molds and prototypes went as well as how we tested to find the best lure material.

4.1 Mold Production

With the designing the out of the way, we needed to machine our graphite to make the molds for our weights. This proved to be a problem when we were told that we could not machine in the Industrial and Manufacturing labs. We were unable to produce on the machines as graphite is very hard on the tools and creates a large amount of debris that is extremely difficult to clean out of the machines. Due to this, we had to send our graphite to a machine shop where it could be milled. This also caused us to make some minor redesigns to adjust to the machinist’s mill.

To produce our lures, we chose to use 3D printing to rapidly prototype our die plate. This was done in the Industrial and Manufacturing net shape lab using Monoprice Maker Select v2 3D printer. This process took an extremely long time and required a lot of minor adjustments and failed attempts. The PLA plastic that was used would often get stuck to the extruder and force us to restart the operation. We also ran out of a plastic on one attempt, again, forcing us to start over. The 3D printer took 11.5 hours to finish a single plate from start to finish. In the end, we had successfully made two plates, one with worms and one with fish, that were ready to start making molds.

4.2 Weight Production

Once the finished mold was received from the machinist we were able to cast our weights. We ran into a few problems when doing this, to start, we found out immediately that the gates into the mold cavities were too small for the molten brass to get through. Even after heating the molds through repeated castings a successful fill was not achieved. While reviewing the mold with a jewelry casting professional, adjustments were made to the runners and gates into the mold cavities. After the gates and runners were widened, changed from 90° to roughly 45° from the sprue, and the addition of an insert placed under the top set of mold cavities we were able to successfully cast our weight. However, it is worth noting that the first casting attempted after the adjustments resulted in a small explosion within the mold. While most of the damage was concentrated around the bottom two cavities, this could have been a result of either moisture introduced into the mold material or from a build-up of graphite powder which was not sufficiently cleared away during the rework of the mold. After clearing out the imbedded brass pieces and remaining graphite dust, the molds were heated then air cooled to remove any moisture. Once cast and removed from the mold, cut from the sprue, the flash developed at the parting line of the mold must be cleared, followed by a light polish on a buffing wheel. For larger production, the final two steps can be done with a tumbler and polishing stones.
4.3 Lure Production

With the completed PLA lure plates, we were able to begin production of the lures. This entailed filling metal containers with cornstarch, creating a flat, even surface and the pressing the dies into the cornstarch. We ran into some issues during this process as occasionally the cornstarch would stick to the plastic when the die was removed, thus ruining some of the potential molds. After we finished production of the molds, we moved on to filling them with different mixtures of gelatin and agar-agar. The ratios we used are as follows:

**Table 3: Lure Material Mixture Ratios**

<table>
<thead>
<tr>
<th>Water (Cups)</th>
<th>Gelatin (Teaspoons)</th>
<th>Agar-Agar (Grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>3.5</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

We had some issues creating the lures with this method. When we would pour the material into the mold, we found that the cornstarch would absorb most of it, rendering that mold useless. We realized that this was due to the high temperature of the liquid material; after allowing it to cool slightly before pouring, we yielded much better results. After all the molds had been filled, they were left in a refrigerator overnight to harden. We also poured any leftover material into plastic containers in order to maximize our number of potential lures.
4.4 Tests for Lures

**Water Durability/Degradation Test:**

We need our lures to be able to degrade over time if they are left in water, however, they also need to sit in water for extended periods of time and be reused at least one time. In order to test for this, we left all of our different materials in water filled jars and recorded how long it took for them degrade. The main thing that we were looking for in our material was to see that it had not dissolved over the course of two hours, which we determined to be a good minimum time for fishing lures left in the water, however, we also looked for the lures to be completely dissolved in under three days to confirm that they will degrade in a reasonable amount of time. We also were able to test this aspect of our lures during our castability test which is described next.

**Castability Test:**

Another important thing for our lures to be able to withstand are the forces that are associated with casting out into the water. When a fisherman casts his lure into the water, if the lure is not strong enough, it may fly off, rendering the cast useless and forcing the fisherman to reel the line back in and try again. Our lures need to be able to withstand those forces and be able to be cast multiple times after sitting in the water for a short period of time. We tested this by doing exactly that. We took our prototypes, attached them to a hook and cast them repeatedly into the water. We did this five times with each type of lure and recorded whether or not it was
successful, landed safely in the water and stay attached, or failed, did not stay attached to the hook.

**Functionality/Fishing Test:**

One of the biggest concerns with this product will be its final ability to catch fish. Even if we create a more environmentally suitable alternative, fishermen will not use this product if it is unable to catch fish. The only way to test this is to take our product into the field and test it in real life. This test is an extremely small scale test and may not prove to be fruitful due to the luck based nature of fishing. In order to see if fish would actually bite on our weights and lures, we took our prototypes out to Lake Nacimiento and attempted to fish.

5. Results and Discussion

Upon removing the lures from their cornstarch molds, we immediately realized that the cornstarch created very questionable lures. The cornstarch had gotten stuck to a lot of the mixtures making them very difficult to remove and rendered many of our lures useless. We were unable to test many of the lures that were created in the cornstarch molds, however, we were still able to complete full tests because of the left-over material that we had poured into plastic molds.

**Water Durability/Degradation Results**

**Table 4: Water Degradation Test Results**

<table>
<thead>
<tr>
<th>Material</th>
<th>Greater than 2 hours</th>
<th>Less than 3 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 tsp Gelatin</td>
<td>Success</td>
<td>Success</td>
</tr>
<tr>
<td>15 tsp Gelatin</td>
<td>Success</td>
<td>Success</td>
</tr>
<tr>
<td>10g Agar</td>
<td>Success</td>
<td>Success</td>
</tr>
<tr>
<td>10g Agar/ 3 tsp Gelatin</td>
<td>Success</td>
<td>Success</td>
</tr>
<tr>
<td>10g Agar/ 6 tsp Gelatin</td>
<td>Success</td>
<td>Success</td>
</tr>
<tr>
<td>Store Bought Gummy Worm</td>
<td>Success</td>
<td>Success</td>
</tr>
</tbody>
</table>

We found that all our mixtures performed to our expectations. All of our different lure material mixtures were able to last longer than two hours in the water and were dissolved in under 3 days. However, we did find that many of the lures had swollen in size after six hours. The swollen lures also did not seem as structurally sound as they had been previously, some breaking apart with a light touch.
Castability Test:

**TABLE 5: CASTABILITY TEST RESULTS**

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Attempt 1</th>
<th>Attempt 2</th>
<th>Attempt 3</th>
<th>Attempt 4</th>
<th>Attempt 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 tsp Gelatin</td>
<td>Success</td>
<td>Success</td>
<td>Success</td>
<td>Fail</td>
<td>Fail</td>
</tr>
<tr>
<td>15 tsp Gelatin</td>
<td>Success</td>
<td>Success</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
</tr>
<tr>
<td>10g Agar</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
</tr>
<tr>
<td>10g Agar/ 3 tsp Gelatin</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
</tr>
<tr>
<td>10g Agar/ 6 tsp Gelatin</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
</tr>
<tr>
<td>Store Bought Gummy Worm</td>
<td>Success</td>
<td>Success</td>
<td>Success</td>
<td>Success</td>
<td>Success</td>
</tr>
</tbody>
</table>

As you can see from the table above, we had relatively varied but mostly unsuccessful results with our prototypes. We found that gelatin is one of the more important ingredients when creating strong and durable lures. Any mixture that contained Agar-Agar was a complete failure. The Agar-Agar makes the material much too brittle to be used in any way; we even struggled to place the Agar mixes on the hooks. The hooks would pierce through and essentially tear the lures apart. We had limited success with the pure gelatin mixtures however after they had been cast a few times, they began to lose their structural integrity and would fly off the hook after the first few tests. The most successful of our tests came from the store bought gummy worms that we used. This lead us to believe that the other ingredients in the store bought gummy worms are more critical to their strength than just gelatin.

**Functionality/Fishing Test:**

When we were not testing the castability of our the lures, we attempted to simply fish at Lake Nacimiento with our prototypes. However, on the day and time that we were fishing, we were unable to catch any fish. This could have been due to the lure or it could have just been an unlucky day. In order to truly test this aspect of our lure and gain reliable results, we would have
to mass produce the lures and distribute them to many fishermen. Then after gaining results from a large, random amount of locations and times would be able to guarantee that our lures have the ability to catch fish.

5.1 Post Test Redesigns

After initial testing, further research was done via confectionary and baking discussion boards following many of the suggestions adjustments to the formula of the lures were made, the key additions were pectin and sugar to try and match the store bought gummy worms recipe. When heated with sugar the pectin, a polysaccharide most commonly used in jams and found in fruits and berries, congeals and acts as a thickener. This less viscous gelatin solution allowed the cornstarch to retain its shape by significantly reducing the availability of the water within the gelatin mixture. This resulted in decreased water absorption by the cornstarch allowing for greater success in producing functional lures. This yielded far better results as the new recipe resulted in much more elastic lures than the initial test batch. Testing of the new lures was done at Castaic lake thirty minutes north of Los Angeles. The lures were on average capable of being cast out five to eight times, with a total submerged time of ten to twenty minutes for each lure, before replacement was necessary. During this set of testing over the course of three hours we were able to successfully catch a fish. As stated earlier the success of a fishing lure cannot be determined based on such few tests, however these results show that it is possible.

6. Conclusion

6.1 Project Summary

The main goal of our project was to design a manufacturing process to create environmentally friendly fishing lures and weights. In order to do this, we needed to research and apply new materials to our version of an already accepted industry standard. We set out to find a set of new possible materials for weights, determine the best for our purpose, and design a manufacturing process that could be scaled up to mass production. To accomplish these goals, we determined the best material for the weight and then created a die in order to cast our brass weights. After, we needed to find the best material for our soft plastic lures but found that we had to make far too many assumptions about each material. To further decide the best material, we created prototypes and tested them in real life, practical settings.

6.1.1 Results Summary

- Waterfowl and other animals are deeply affected by lead and soft plastic lure ingestion every year, thus creating a need for an environmentally safe alternative. (Franson et al, 2003)
- Lead is still the most ideal material for mass production, this explains why it is the industry standard.
- Brass proved to be a successful and usable alternative.
- Exclusively gelatin and agar-agar mixes are not capable of being produced in a cornstarch mold
- Exclusively gelatin and agar-agar mixes do not make suitable lure replacements.
- The addition of pectin and sugar to gelatin based materials allow them to be produced in a cornstarch mold.
- The addition of pectin and sugar to gelatin based lures increases durability significantly allowing this mix to be a suitable replacement.
- Graphite die casting and cornstarch casting are both proven mass manufacturing techniques and could be scaled up from our prototypes for true production.

6.2 Business Case and Economic Analysis

In order to produce this product there are more factors to consider than can be covered in this paper, to develop a simple business case, the cost of the raw material for lead was compared to the retail price of the weights currently available at a large retail store. It was found that at the time of this paper; a one pound package of lead weights- molded into sixteen one-ounce egg shaped sinkers retailed for about five dollars. This results in approximately a 4.7 time markup of the material cost. With this figure, we could assume a slightly larger markup would be necessary for the brass alternative, due to the higher energy costs associated with the casting process, as well as the higher cost in mold materials. We can estimate a final retail cost for our alternative between the twelve and fifteen dollar range. Although economically the use of lead makes the most sense, more areas within the US are restricting the use of lead, and with rising trends in environmental protection and conservation the greater cost of the product is not likely therefore in order to stay competitive within the market our product and manufacturing method is the better of the alternatives.

6.3 Recommendations

Based off our results and economic analysis, we think that there is definitely a place for brass-based, environmentally friendly weights and gummy candy based lures. We think that companies could easily switch gummy based lures as they could outsource to candy factory and simply install a new die plate with the desired shape lure. Companies could also switch fully to brass as it is close to lead from a consumption perspective even though it is slightly more costly. One drawback for brass is the need for more expensive tooling due to its higher melting temperature. To conclude, using a gelatin, sugar, and pectin based alternative could be easily implemented at current candy factories allowing for lure companies to easily outsource production to create safe lures while they update their own facilities. Our weights, however, may be slightly more difficult to adopt immediately for an existing company, with this being said, it might be easier for a new company to start with brass weights as their primary product.

6.4 Impacts

As a whole, this project, if implemented on a grand scale, could have great societal and environmental impacts. First, if all lead weights were outlawed and replaced with our brass alternative or another environmentally friendly alternative; wildlife in fishing areas would greatly benefit. This would remove most, if not all, lead related deaths to waterfowl and fish. Replacing PVC-based soft plastic lures would also decrease or remove the amount of dead fish that are found with one inside their system. This decrease in death could also have a great impact on species that are not directly affected lead weights and discarded soft plastic lures as species that prey on animals that accidentally consume lead would no longer be a problem. A change in
regulation or product could also affect the way society views the environment further encouraging them to protect and create newer ways of being green. One change in one industry can lead to much larger changes across all industries hopefully leading towards a much brighter and greener society.

6.5 Next Steps and Future Works

With this project coming to a close, we found that there is a lot of room for improvement in this industry. For a group with more time and funding, we would suggest further research into bioplastics to replace PVC-based soft plastic lures. Bioplastics may be far superior than simple gelatin and pectin based lures. Another project of interest could be to look into coating lead weights with an environmentally safe material. This would allow for animal ingestion while still maintaining high density and low consumption manufacturing. Lastly, another project that would greatly help the environment and is directly related to the recreational fishing industry would be to find a biodegradable replacement for fishing line. Fishing line is currently one of the more dangerous and frequently lost pieces of lost outdoor recreation equipment and finding a replacement would be a massive success for protecting wildlife.
References


# Appendices

A: Raw Material Data

## Table 6: Raw Material Data

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% USD/kg kg/m³ MJ/kg kg/kg l/kg MJ/kg kg/kg l/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>Pb 99.9-100</td>
<td>2.20 to 2.35</td>
<td>11300 to 11400</td>
<td>26.9 to 29.6</td>
<td>2.15 to 2.37</td>
<td>328 to 362</td>
<td>5.14 to 5.68</td>
<td>0.386 to 0.426</td>
<td>9.73 to 14.6</td>
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<tr>
<td>Bismuth</td>
<td>Bi 99.9-100</td>
<td>24.10 to 29.50</td>
<td>9740 to 9800</td>
<td>138 to 152</td>
<td>8.63 to 9.51</td>
<td>2800 to 3090</td>
<td>5.27 to 5.83</td>
<td>0.395 to 0.437</td>
<td>9.98 to 15</td>
</tr>
<tr>
<td>Brass</td>
<td>Cu 58 to 64, Zn 36 to 41</td>
<td>5.23 to 5.70</td>
<td>8020 to 9460</td>
<td>51.2 to 56.5</td>
<td>3.45 to 3.8</td>
<td>307 to 339</td>
<td>8.28 to 9.15</td>
<td>0.621 to 0.686</td>
<td>15.7 to 23.5</td>
</tr>
<tr>
<td>Bronze</td>
<td>Cu 86 to 90, Sn 10 to 12</td>
<td>8.53 to 9.44</td>
<td>8800 to 9220</td>
<td>72.5 to 79.9</td>
<td>4.61 to 5.08</td>
<td>1300 to 1440</td>
<td>8.49 to 9.39</td>
<td>0.637 to 0.704</td>
<td>16.1 to 24.1</td>
</tr>
<tr>
<td>Silicon Bronze</td>
<td>Cu 92, Si 3 to 4, Zn 2, Fe 1.5, Mn 1</td>
<td>6.41 to 7.11</td>
<td>8520 to 8970</td>
<td>57.5 to 63.4</td>
<td>3.47 to 3.82</td>
<td>280 to 310</td>
<td>8.7 to 9.62</td>
<td>0.653 to 0.722</td>
<td>16.5 to 24.7</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>Fe 93, C 3, Si 1.7, Ni 1.1, Mn 0.6, Cr 0.5</td>
<td>0.58 to 0.64</td>
<td>7200 to 7300</td>
<td>30.8 to 33.9</td>
<td>2.26 to 2.49</td>
<td>46.1 to 50.9</td>
<td>10.1 to 11.1</td>
<td>0.755 to 0.835</td>
<td>19.1 to 28.6</td>
</tr>
<tr>
<td>Granite</td>
<td>Al2O3, SiO2</td>
<td>1.04 to 6.22</td>
<td>2630 to 3200</td>
<td>10.5 to 11.6</td>
<td>0.667 to 0.735</td>
<td>3.23 to 3.57</td>
<td>11.4 to 12.6*</td>
<td>0.858 to 0.949*</td>
<td>N/A</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni54to 64, W12to14, Co9to11, Cr 8to 10, B 10, Al 4.8to 5.2, Ti 1.8to 2</td>
<td>34.10 to 38.9</td>
<td>8450 to 8600</td>
<td>264 to 291</td>
<td>16.2 to 17.9</td>
<td>308 to 340</td>
<td>10 to 11.1</td>
<td>0.75 to 0.829</td>
<td>18.9 to 28.4</td>
</tr>
<tr>
<td>Tin</td>
<td>Sn 99.8 to 100</td>
<td>21.10 to 23.30</td>
<td>7280 to 7310</td>
<td>217 to 239</td>
<td>15 to 16.6</td>
<td>10400 to 11500</td>
<td>5.24 to 5.99</td>
<td>0.407 to 0.45</td>
<td>10.3 to 15.4</td>
</tr>
<tr>
<td>Tungsten</td>
<td>W 80, Cu 13, Ni 7</td>
<td>44.80 to 54.50</td>
<td>15200 to 15400</td>
<td>458 to 505</td>
<td>30.2 to 33.3</td>
<td>171 to 189</td>
<td>8.73 to 9.65**</td>
<td>0.655 to 0.724</td>
<td>16.5 to 24.8</td>
</tr>
</tbody>
</table>
B: Drawings

Figure 8: Fish Head Weight Engineering Drawing
FIGURE 9: GRAPHITE MOLD ENGINEERING DRAWING
FIGURE 10: FISH BODY ENGINEERING DRAWING
Figure 11: Worm Body Engineering Drawing
C: Project Photos

**Figure 12: Explosion Aftermath**

**Figure 13: 1st Successful Test Casting**
Figure 14: 2nd Successful Casting with Hooks

Figure 15: Fish Head Mass
**Figure 16: Corn Starch Molds**

**Figure 17: Worm Body Lures Solidifying**
FIGURE 18: FAILED CORN STARCH LURE CASTINGS

FIGURE 19: TEST SET UP WITH SUCCESSFUL AND FAILED LURE CASTINGS