Team 9: World’s Strongest CAN
Process of ALON Production

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Project Proposal and Feasibility Study

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Executive Summary

Aluminum oxynitride, produced via numerous chemical reactions and multiple physical manipulations, is an optically transparent ceramic that is mechanically very durable. So durable in fact, that it is being used more and more by the military, as well as other defense corporations as a lightweight substitute for bulletproof glass. This material has the potential to revolutionize defense applications. The current implementation of AlON into the commercial market is an area that is on the rise, with a plethora of benefits related to further integration of this product into the market. The applications for this product are vast, however the price at which it is available is significantly higher than alternatives, with a price tag more than 250% higher than traditional transparent ceramic equivalents.

The goal of this project is to design a process capable of transforming aluminum used beverage cans (UBCs) into AlON in powder form. The decision for the outcome of this project is to market this powder to various companies who will be able to create the transparent ceramic AlON via hot isostatic pressing. The feedstock for this process will be, as mentioned above, recycled aluminum beverage cans, which will be stripped and purified at the beginning of the process to acquire pure aluminum to be reacted further, and transformed into AlON powder.
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Introduction

1.1 Course Introduction

Calvin College Engineering Program uses a senior capstone project as the culmination of learning throughout the past four years. This project includes two separate courses: ENGR 339 and ENGR 340 combining for a total of six credit hours, both of which are required in for graduation. The fall semester course, ENGR 339, focuses students’ attention towards team formation, project development and identification, and project feasibility. The spring semester course, ENGR 340, delves into the process of fulfilling the requirements of the proposed project set forth in the fall semester. Throughout both courses, Christian design norms and broader worldviews are incorporated into the curriculum through multiple lectures and mentorship. The culminating result of this project is the successful deliberate application of the technical aspects of the engineering design process, with a tangible and practical outcome.

1.2 Problem Statement

AlON ceramic is a highly utilizable material on the commercial market. With material properties such as high hardness and good transmission, AlON has been found to be superior in protection to the currently employed bulletproof glass. This material has the potential to revolutionize the defense industry in both military and civilian applications, giving people the ability to provide a higher level of protection. The current production of AlON is an up and coming process, currently only being produced by one company, Surmet due to the recent discovery and development of AlON as a mass production marketable item. Due to the monopolization of this field, and the methods and raw material costs of producing the AlON, the market price for the consumers is extremely high.

1.3 Project Proposal

The World’s Strongest Can design team is proposing a process to produce aluminum oxynitride through a method that is cheaper and more readily available for implementation for defense and protection corporations. To achieve the cheaper production, the aluminum used for the synthesis of AlON will be
acquired through recycling of used beverage cans (UBC’s). The initial goal for this project is to design a process for the production of aluminum oxynitride powder, which can later be physically manipulated into the final product, the hard and optically transparent ceramic. Feasibility plays a huge role in this project, in that once the process for producing the powder has been finalized, three separate options for what to do with that process arise. First, the process idea could be marketed to a company with the desire to produce the AlON powder itself. The second and third options include, the proposal of the creation of an industrial production facility to produce the powder by its own means. The second option would be to market the powder to other companies for final production implementation, and the final option would be to propose a design for the AlON ceramic in the team’s production facility.

1.4 Design Norms

During this design project, 3 specific design norms will be kept in mind as guidelines for ethical focus: stewardship, caring, and trust. Stewardship will be displayed through this design since this process will use the recycling of aluminum which will reduce aluminum being wasted. Caring will be displayed through the impact that the final product will have on the consumer. The product being made in this design process has the ability to save lives, and furthering the production of this product shows care for the people who would benefit from it. Finally, this design team will strive to display trust throughout the project. We want the companies who purchase our intermediate powder to know with certainty that it is a quality product that will be used to create the AlON transparent ceramic.

1.5 Project Management

To effectively and efficiently accomplish the desired goals of this project, the team below focused on dividing responsibilities among team members, time management, and team communication throughout the course of the project.
1.5.1 Team Members

Brandon Pott

Brandon Pott was born and raised in Grand Rapids, Michigan. Although he has gone to school in Grand Rapids his entire life, Brandon enjoys travelling, specifically to the mountains. When Brandon is not busy studying Chemical Engineering, he enjoys playing and watching sports, especially if the sport is football. Brandon also boasts about his loyalty to the University of Michigan athletic teams.

Galen Wood

Galen Wood was born in Andrews AFB Maryland, and spent his childhood moving around the country (and world) as a dependent of the United States Air Force. Galen enjoys long walks on the beach, playing ice hockey, and attending music festivals around the world. Galen is studying chemical engineering, however he plans to join the United States Army as an officer upon graduation in May 2016.
**Zhihong Zhang**

Zhihong Zhang is a senior chemical engineering student from Shanghai, China. He serves as the team web editor and is charge of the management of the team websites and researching process of recycling. He is studying to become a chemical engineer and is passionate about project analysis. After graduation, Zhihong plans to find a job working in the chemical engineering field.

### 1.5.2 Team Responsibilities

As a team, ongoing responsibilities throughout the semester were divided among the team according to everyone’s strengths and weaknesses. In addition to ensuring that these activities get accomplished, this method of dividing responsibilities allowed tasks to be accomplished in the most efficient manner. In addition to the following roles filled by each team member, all team members contributed to researching throughout the course of the project. Constant status reports and meetings kept all members accountable in their responsibilities. Reports and presentations were conducted by all team members, dividing the work amongst ourselves evenly.

**Team Webmaster:**

Based on his keen knowledge of computers, writing code, and simulation software, Zhihong was appointed to the position of Team Webmaster. In addition to creating and managing the team website, Zhihong is responsible for running and troubleshooting any software which is used in this project. This includes Unisim, Polymath, or any other program used in this design project.
**Project Coordinator:**

As an active member of ROTC in the United State Army, Galen studies the art of leadership on a daily basis while conducting his officer training. This special skillset is carried over into other group work, where Galen exercises his knack for being a leader. During this design process, Galen was appointed the project coordinator. As project coordinator Galen gets a chance to utilize his leadership background, and is responsible for scheduling meetings, focusing meeting topics to align with upcoming due dates, and delegating work among the team. Galen also led the effort to create the overall project schedule.

**Quality Check Specialist:**

Having produced excellent results on past design projects, Brandon has shown an ability to understand the project goals and to make sure the team meets those goals, and meets those goals in a professional manner. As the quality check specialist Brandon is responsible for reviewing every document that is submitted, and making sure the ideas and designs developed by the team meet the goals of the project, as well as the standards set by the Calvin College Engineering Department.

1.5.3 **Time Management**

A crucial component in any successful project is time management. A design team must estimate the amount of time necessary to complete tasks and plan accordingly in order to meet project deadlines. Once the scope of this design project had been defined, a schedule was constructed allowing all progress to be tracked and evaluated. This schedule (Figure 1) includes all major milestones to be completed this semester, and the dates on which they should be done.
Creating such a schedule is critical to keeping the project on track and meeting the final deadline. This schedule is a “fluid schedule” and often adjusted to incorporate unforeseen obstacles and challenges, as long as critical deadlines are still able to be met.

### 1.5.4 Team Communication

Much like time management, communication is imperative for design teams. Once work was divided among team members, weekly meetings were held to make sure every team member was staying on schedule and adequately performing the required tasks. Weekly meetings serve as a time to voice any concerns as well as discuss overall project topics.
In addition to the weekly meeting with just the team, a bi-weekly meeting was scheduled with Professor Jeremy Van Antwerp. This is a time when Professor Van Antwerp would offer guidance and technical advice, as well as answer any questions the team may have come across.

2 Project Overview

The following sections will provide a more detailed description of the scope of the project, and the details in which it will entail.

2.1 Purpose

The World’s Strongest Can design team has identified and selected the proposed project as a primary focus because we feel the protection of human life is important, and we want to do our part in adding to the safety and preservation of such life. As engineers, World’s Strongest Can’s members feel called to do provide a cheaper and more accessible bulletproof protection through the widening of the market for AlON ceramic. By conducting this project, citizens around the globe will have the ability to be better equipped against harmful and life-threatening encounters.

2.2 Background

With a military defense budget higher than any country in the world, the United States military is always attempting to provide the best of the best for both offensive weapons, and defensive equipment. One such area that the military has been conducting research in is the field of transparent aluminum oxynitride as a substitute for traditional glass surfaces. With applications ranging from transparent armor for helicopters, aircraft, and ground vehicles, to domes for infrared guided missile systems, aluminum oxynitride has the capacity to revolutionize the safety

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components military wide. With substantially superior performance against conventional ballistics, as well as high performance against improvised explosive devises,\textsuperscript{2} AlON transparent armor is a much safer alternative to its glass-based counterpart. While the benefits of the evolution from a fully glass-based armor for all military defensive equipment are vast and evident, the downside to this transformation is its cost. The current production of currently implemented glass based armor ranges around $4 per square inch, where an equivalent chunk of aluminum oxynitride armor would be upwards of $10 per square inch.\textsuperscript{3} With such a higher price, the AlON has not yet been able to penetrate its way fully into the military just yet.

In addition to the military market, bullet proof protection is a high commodity in commercial applications as well, including home defense or business defense. Examples of civilian applications include armored truck companies, banks, hospitals, and many other areas where protection and safety is of an utmost importance.

AlON ceramic is a new, technology, without much widespread knowledge of its capabilities. Currently only being produced by one company, Massachusetts based Surmet corporation, the availability of this product is limited, and as previously mentioned, the costs are extremely high.

\textbf{2.3 Project Constraints}

The only constraint for this project is that the original raw material aluminum that will be used in the chemistry must be acquired from the recycling of the used beverage cans.

In the team’s attempt to lower production costs, and therefore selling costs of the AlON powder, the utilization of recycling methods will be a huge stepping stone. With this constraint in mind, the

\begin{footnotesize}
\textsuperscript{3} “Live Science Staff” \url{http://www.livescience.com/420-military-aluminum-windows-stop-50-caliber-bullet.html} Retrieved 2015/11/12
\end{footnotesize}
rest of the optimization decisions are free from constraints or limitations.

2.4 Approach

The steps taken to determine the feasibility of the project are discussed below. The feasibility of this project as a realistic business venture is an important part of conducting this research.

2.4.1 Initial Research

To initiate movement beyond the idea for this project, initial research was conducted in order to determine what exactly the team was trying to produce, and how we would go about doing so. While keeping the project goals, and project constraints in mind, the main topics of initial research included the research of recycling and aluminum stripping of used beverage cans, the chemical reactions used to turn aluminum into aluminum oxynitride powder, the hot-pressing of the powdered substance into the transparent ceramic, and finally, the marketability of the substance, both as the intermediate powder, as well as the end product ceramic. The research was conducted primarily through the use of the research database SciFinder Scholar, and also through researching various patents relevant to the material.

During the initial research phase of this project, numerous different alternatives for how to conduct this project were discovered. The process of recycling the used beverage cans can be performed multiple ways. The portion of the project regarding the chemistry needed to go from molten, recycled aluminum to AlON powder contained the most potential alternatives. With numerous routes to produce AlON, each design alternatives had to be analyzed in depth to determine the optimal production process.

2.4.2 Analysis of Design Decisions

The main purpose of this project is to develop the optimal process to allow for cost effective production of AlON. This can be accomplished by analyzing all possible design alternatives for
each portion of the project as discussed above. The best alternative for each portion of the project will be chosen, and this best case design will be analyzed for feasibility.

2.4.3 Project Feasibility

The feasibility determination of this project consisted of the analysis of the data discovered during the research, and the design alternative phases. The feasibility study laid the framework for what steps would need to be accomplished throughout the project. With the goal of producing a process to create the AlON powder, the feasibility study helped set the limits for what to do after the powder process was defined. The analysis of self-production of AlON ceramic versus marketing the powder was a large portion of the feasibility study, as the implications of this decision held a heavy weight on the scope of the project as a whole, and this section contains these decisions along with their corresponding discussions. In addition to this debate, a business model for the decided route is included, which contains a market analysis and marketing strategy used to uncover the question of whether this process would result in a profitable business venture.

3 Initial Research

3.1 Aluminum Extraction

Aluminum extraction from new cans is not a new process, and has been utilized for years. There are, however, different ways of doing this. Before the aluminum cans are melted, they must first be either mechanically or chemically stripped in order to remove paint, dirt, and other contaminants. These alternatives found during research will be analyzed to determine the best process of extracting aluminum from the cans.

3.2 Synthesis Options

Knowing the final product required and the feedstock, it was possible to determine many viable
series of chemical reactions that would fulfill the requirements of this project. The initial research conducted led to 9 different synthesis routes, seen in Table 1 below.

Table 1- Chemical Reactions known to produce aluminum oxynitride⁴

<table>
<thead>
<tr>
<th>Synthesis equation</th>
<th>Required temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Al}_2\text{O}_3 \ (s) + \text{AlN} \ (s) \rightarrow \text{AlON} \ (s) )</td>
<td>( \geq 1650°C )</td>
</tr>
<tr>
<td>( \text{Al}_2\text{O}_3 \ (s) + \text{C} \ (s) + \text{N}_2 \ (g) \rightarrow \text{AlON} \ (s) + \text{CO} \ (g) )</td>
<td>( \geq 1700°C )</td>
</tr>
<tr>
<td>( \text{Al}_2\text{O}_3 \ (s) + \text{C} \ (s) + \text{Air} \rightarrow \text{AlON} \ (s) + \text{CO} \ (g) )</td>
<td>( \geq 1700°C )</td>
</tr>
<tr>
<td>( \text{Al}_2\text{O}_3 \ (s) + \text{Al(l)} + \text{N}_2 \ (g) \rightarrow \text{AlON} \ (s) )</td>
<td>( \geq 1500°C )</td>
</tr>
<tr>
<td>( \text{Al}_2\text{O}_3 \ (s) + \text{Al(l)} + \text{Air} \rightarrow \text{AlON} \ (s) )</td>
<td>( \geq 2045°C )</td>
</tr>
<tr>
<td>( \text{Al}_2\text{O}_3 \ (s) + \text{NH}_3 \ (g) + \text{H}_2 \ (g) \rightarrow \text{AlON} \ (s) + \text{H}_2\text{O} )</td>
<td>( \geq 1650°C )</td>
</tr>
<tr>
<td>( \text{Al(l)} + \text{Air} \rightarrow \text{AlON} \ (s) )</td>
<td>(-1500°C)</td>
</tr>
<tr>
<td>( \text{AlCl}_3 \ (g) + \text{CO}_2 \ (g) + \text{NH}_3 \ (g) + \text{N}_2 \ (g) \rightarrow \text{AlON} \ (s) + \text{CO} \ (g) + \text{N}_2 \ (g) + \text{HCl} \ (g) )</td>
<td>( 900°C )</td>
</tr>
<tr>
<td>( \text{Al}_2\text{O}_3 \ (s) + \text{BN} \ (s) + \text{N}_2 \ (g) \rightarrow \text{AlON} \ (s) )</td>
<td>( \geq 1700°C )</td>
</tr>
</tbody>
</table>

As can be seen in the table above, there are many different reactants that can be used in order to create aluminum oxynitride. This table does not show balanced reactions, rather a demonstration of the required reactants and the phases of these reactants. Another additional note from this table is the required temperature for each reaction, almost all of the reactions require different temperatures. These temperatures are directly related to operating costs through the energy required to reach the specific temperatures, resulting in an additional design parameter.

### 3.3 Structure and Properties

The structure of the AlON powder produced has a large impact on the properties of the resulting ceramic made from it. In order to ensure the process developed in this project will produce powder meeting the necessary requirements, the different structures of AlON and the properties which they

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affect had to be determined.

3.3.1 Structure and Properties of AlON Transparent Ceramic

If a powder with the correct grain size pressed to make the ceramic, the transparent aluminum ceramic should have a cubic, spinel structure. This structure gives the ceramic its strength. As seen in Table 2 below, AlON transparent aluminum has strength and hardness properties much greater than average materials such as silica, which is used to make glass. Also, it can be noted that AlON has relatively comparable properties to sapphire, which is known to be an extremely strong material. In addition to its strength, AlON ceramic has good thermal properties.

<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>Conditions</th>
<th>UNITS</th>
<th>ALON™</th>
<th>Sapphire</th>
<th>Quartz (fused silica)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>g/cc</td>
<td>3.69</td>
<td>3.97</td>
<td>2.21</td>
<td></td>
</tr>
<tr>
<td>Grain Size</td>
<td>Micrometers</td>
<td>150-250</td>
<td>single crystal</td>
<td>amorphous</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td></td>
<td>Transparent</td>
<td>Transparent</td>
<td>Transparent</td>
<td></td>
</tr>
<tr>
<td>Fracture Toughness</td>
<td>MPa (ksi)</td>
<td>379 (55)</td>
<td>742 (107.7)</td>
<td>48 (7)</td>
<td></td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>25°C MPa (ksi)</td>
<td>2677 (398) (see note 1)</td>
<td>650 - 1100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>Knoop, 200 g load, 25°C</td>
<td>(kg/mm²)</td>
<td>1850</td>
<td>2000</td>
<td>460</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>GPA (psi x 10⁶)</td>
<td>334 (48.4)</td>
<td>344 (49.8)</td>
<td>70 (10.1)</td>
<td></td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>psi x 10⁶</td>
<td>135 (19.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td></td>
<td>0.239</td>
<td>0.27</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>W/m-K (cal/cm-sec-°C)</td>
<td>9.5 (0.023)</td>
<td>36</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>TCE (30-900°C)</td>
<td>10 e°C</td>
<td>7.5</td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific Heat</td>
<td>(J/kg-K) (Cal/g-°C))</td>
<td>0.77 (0.22)</td>
<td>0.75 (0.21)</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Thermal Shock T (°C)</td>
<td></td>
<td>N/A</td>
<td>200</td>
<td>&gt;1400</td>
<td></td>
</tr>
</tbody>
</table>

The final property that makes this ceramic appealing is its transparency. As seen in the graph below, AlION ceramic allows approximately 90% of light through at a wide range of wavelengths.
Visible light has a wavelength around 550 nm, which equals 0.5 microns. The graph shows that at this wavelength AlON ceramic lets about 85% of light through a 2 mm thick sample. These transparent and strength properties are what make this material a great choice for armor and defense applications.

4 Analysis of Design Decisions

4.1 Aluminum Extraction Method

Aluminum cans collected from collection sites will first be shredded into small pieces. After shredding, these scraps must be cleaned and stripped of contaminants by one of the following methods. The first option for cleaning the scraps involves a mechanical process which physically scrapes and rubs the contaminants off of the scraps using friction. This process would be carried out in a large rotating drum. The second method for cleaning the scraps is using a chemical bath to remove
and paint or contaminants. Once the scraps have been cleaned and stripped of paint, they will be fed to a furnace to melt them. The aluminum can then be extracted from the liquid metal mixture based on differences in density between the different metals in the can.

### 4.2 Production Process

The production of AlON powder can be performed in many different ways as discussed above. The design alternatives were analyzed in order to determine the optimal route for producing the AlON powder. This section outlines the major design decisions, and the processes that will be used as a result.

#### 4.2.1 Synthesis Route

After discovering the numerous pathways of producing the aluminum oxynitride, choosing the optimal route for production was a key decision in this design project. A table showing all of these various pathways can be seen in Table 1. The decision for the optimal chemistry route comes down to factors such as availability and cost reactants, required temperature (and therefore energy) for each particular chemistry, the waste products produced, and the phase of the reactants in each chemistry. It was determined that reaction number 1 seen in Table 1 was the best synthesis route to produce AlON. Not only is this the route used in current manufacturing of AlON, it also

In this reaction, aluminum oxide reacts with aluminum nitride following a solid state reaction route. This reaction must take place at high temperatures, above 1600 C, in order to occur although the exact temperature necessary depends on the ratio of the reactants. As seen in Table 3 below, varying the ratio of the reactants will produce a different form of AlON with a different structure.
In order to achieve the necessary spinel structure with the desired properties, the gamma (\( \gamma \)) version of AlON is needed. This structure requires the starting reactants to be present in approximately 36 mol % aluminum nitride and 64 mol % aluminum oxide. When the correct ratio of these reactants is obtained, the two reactants need to be mixed prior to entering the reactor. Since this reaction occurs in the solid phase, the powders must be mixed in order to maximize the contact between the two. The reactor will be blanketed with nitrogen.

### 4.2.2 Producing the Reactants

The reaction chosen to make AlON for this project requires aluminum oxide and aluminum nitride as reactants in powder form. Both of these reactants will be made from the aluminum recovered from the recycled beverage cans. These reactants can be made through a process called atomizing.
Atomizing allows for the molten aluminum leaving the recycling process to react to the desired reactant and take a powder form simultaneously. A diagram of this atomizing process can be seen below in Figure 3.

![Figure 3-Atomizer Diagram](image)

Team 09 will have 2 apparatuses as seen above; one to produce aluminum nitride powder and one to produce aluminum oxide powder. The molten aluminum exiting the recycling process will be dumped into each atomizer from the top. To produce the necessary amounts of each reactant, 47% of the recovered aluminum will be poured into the nitrogen atomizer and turned into aluminum nitride while 53% will be poured into the oxygen atomizer and turned into aluminum oxide. Once the aluminum is poured into the atomizer, the lid (5) will be closed and the space above the molten aluminum (1) as well as the atomizing chamber (7) will be filled with pressurized pure nitrogen gas.

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in the AlN atomizer and pure oxygen gas in the Al₂O₃ atomizer. The gas in each atomizer system must be pressurized in a compressor (12) prior to entering. The pressurized gas will enter the atomizing chamber through a nozzle (6) which forces the gas at high velocity to flow by the aluminum entering the chamber through the spout (4). This interaction between aluminum and the gas allows the reaction to take place. In the case of the AlN atomizer, the nitrogen gas in the atomizing chamber (7) must be heated to a temperature of 1200 C prior to entering in order to obtain the maximum conversion of aluminum to aluminum nitride. The nitrogen must be at least 800 C for any reaction between nitrogen and aluminum to occur since nitrogen is a very inert molecule. Increasing the nitrogen temperature beyond the 800 C to the desired 1200 C increases conversion of aluminum to aluminum nitride from 60% to approximately 99%. It was determined that increasing the aluminum nitride yield was preferred despite the increased energy costs of the nitrogen heater, since aluminum is the most expensive raw material in this process. In the case of the oxygen atomizer, the oxygen does not need to be heated since aluminum oxidizes very readily at normal temperatures. This also allows for essentially 100% conversion of aluminum to aluminum oxide since this reaction occurs very easily. When the material reaches the bottom of the chamber, it will be swept into a cooling compartment (9) by the flow of the gas. In this compartment the material will be cooled, producing AlN or Al₂O₃ powder with an average particle size of 0.1-0.2 microns.

4.2.3 Pre-Reactor Mixing

The AlN and Al₂O₃ powder leaving the atomizers will travel to a ball mill, where the two reactants will be adequately mixed. The proposed mixing mechanism, a ball mill, can be seen in Figure 4 below.
This style of mixer is very effective and commonly used for mixing powders, which is why it was chosen. Since the two reactants are already present in the correct amounts, once they are mixed they are ready to enter the reactor. A detailed design of the reactor will be completed in the upcoming semester. This reactor will take the mixture of the two powders, and result in the AlON powder that is desired.

4.2.4 Process Flow Diagram

The overall process discussed above can be seen below in the process flow diagram. For the sake of simplicity, non-critical items were left out such as gas recycle streams around the atomizers and compressors.

Figure 5-Process Flow Diagram of Proposed Design
5 Project Feasibility

5.1 Implications of Three Project Outcomes

The three design options after the initial process design for the production of AlON powder include: the sale of the design process, the production and sale of AlON powder itself, and the production of powder as well as the production of end-product transparent ceramic. By choosing the first option, the design team would make profits solely based off of the sale of the idea. This option provides limited profits, and minimal effort. The second option including the production of AlON powder involves the design and implementation of an industrial production facility, and the marketing of the powder to companies with the resources and capabilities to continue the process and produce the AlON ceramic themselves. This option involves creation of an industrial facility, and implementing the process laid out in the powder production process. A detailed market analysis and marketing strategy will need to be performed in order to find buyers for the powder, and determine whether or not this venture will be financially sustainable. By selling the powder to other companies with the ability of hot isostatic pressing, the physical manipulation of the powder will be performed by these companies, who will produce the ceramic for commercial sale. By creating the intermediate step in this process, and enabling more companies to enter the AlON market, production of aluminum oxynitride will become more widespread, and the price will be driven down, resulting in larger implementation of the product worldwide. The final option includes the same implementation of the industrial facility and production of AlON powder, with the additional design and implementation of a new process for the physical manipulation of the powder into the AlON transparent ceramic. This will require a much more detailed design of the equipment and process, and will require a much broader focus for the industrial production facility. This will require larger equipment housing meaning a larger and more costly facility, as well as a
larger facility scope, giving attention to not only the recycling and powder production processes, but also now the isostatic hot pressing, molding, and shining of the AlON. While this route does require more work, it would allow for the marketability of the end product to the consumers as opposed to intermediate companies. Either way, the larger implementation of AlON production will meet the design team’s goal of further improvement for defense capabilities of militaries and individuals around the globe.

5.2 Analysis of Project Outcomes

After analyzing the three different methods listed above, it was determined that the most optimal outcome for the project would be to propose the process to create the AlON powder in an industrial facility and market that powder to other companies. The project’s goals in regards to scope eliminated the first option of selling the process to another company. This route does not include much for design, and results in too small of a profit to be a viable and feasible option. The option of producing the AlON ceramic was eliminated for a few reasons. Firstly, it would create countless new design optimizations and specifications for all of the equipment required. A much larger industrial facility would need to be produced, with goals of each sector of the plant being even more varied in function. This would double the workload for the project scope, and be a significant challenge to overcome. Instead, the option to produce the powder for marketing seemed to be the most viable. This option allows for the design optimizations for the recycling process as well as the AlON synthesis chemistry. With a more focused industrial facility, and a more reasonable scope for the project, this was the best option.

5.3 Quantity of Feedstock

Taking used aluminum beverage cans for the feedstock in this process is the most significant way in which the cost of producing AlON can be lowered, assuming these cans are cheap and readily
available. In order to determine if this is in fact a feasible starting material, a study was performed which estimated the number of cans necessary to produce a given quantity of AlON. With production goals being to produce approximately 100 gallons of AlON powder per day, the amount of cans recycled in the Grand Rapids area was used as a basis for production calculations\(^6\). Every year in Grand Rapids, roughly 33 million cans are recycled. At approximately .95 grams Al/gram, there is on average 11.9 \(^7\) grams of pure aluminum in every can. This equates to 390,000 kg of aluminum that could potentially be recovered from recycled cans every year in the Grand Rapids area. Assuming a basis of recycling 60\% of the total recycled cans in Grand Rapids, this results in an amount of 236,000 kg aluminum to be used for production into AlON. The AlON powder which will be produced in this process is 56\% aluminum by weight. With the basis of 236,000 kg of aluminum recovered, 422,000 kg of AlON powder can be produced from these cans. Using 422,000 kg of AlON powder equates to approximately 450 tons, which will be used as the initial goal for production. 450 tons of AlON powder per year broken down, is approximately 100 gallons of powder per day. This value is a very feasible daily and yearly amount, attainable in an average industrial production facility. These calculations show that it is in fact feasible to begin this process with aluminum cans. The usage of a sustainable percentage of the cities recycled cans shows not only room for growth within the city, but also that there could be potential growth from bringing cans from surrounding cities.

\(<\text{http://www.kab.org/site/PageServer?pagename=recycling_facts_and_stats}>\).

\(<\text{http://www.bordersteelandrecycling.com/ALUMINUM_RECYCLING.html}>\).
6 Business Plan

Simultaneous with this project, Team 09 worked on a business plan simulating the startup of a new company named World’s Strongest Can. This plan assumed that the company’s fiscal endeavors would be both successful and repeatable. A succinct summary of this report is included in the following section.

6.1 Vision and Mission Statement

6.1.1 Entrepreneur’s Vision for the Company

World’s Strongest Can’s vision is to produce Aluminum Oxynitride powder with a high level of quality while reducing the current production costs required to make this product. In addition, this company will recycle aluminum beverage cans at our facility not only to reduce production costs, but to also reduce the heavy price paid by our environment in this industrialized culture. We aim to stay at the forefront of the defense industry, while remaining open to the idea of entering other markets in which we are well suited to excel. The engineers employed with us will not only be responsible for current production, they will also research other products and markets in which we may compete in.

6.1.2 Values and Principles on Which Business Stands

World’s Strongest Can is built on the foundation of three core values; stewardship, caring, and trust. It is imperative that we as a company strive to incorporate each of these values into our everyday business. Stewardship will be achieved by recycling cans, as well as reducing energy consumption during the energy intensive processes conducted at our company. Caring and trust will also be displayed in our company not only in the way we treat our employees, but also in how
we conduct business with suppliers and consumers. Products made by our company may be used in life and death situations, and it is necessary that we provide a quality and trustworthy product.

6.2 Industry Background and Overview

The production of AlON ceramic is a new process, beginning in the recent decades. Surmet, a ceramic company founded in 1982, started to produce this ceramic once it acquired AlON Technology from Raytheon in 2002. The greatest amount of development in the industry has happened in the past couple of years. These developments have increased not only the feasibility of the process, but also decreased the cost of the production. However, the process of producing AlON powder, the material from which the ceramic is made, still costs a lot. The price of the powder in combination with the technology required to produce it keeps many companies from entering this market. This also is a product that requires extremely high purity, which the industry has traditionally defined in terms of optical properties, affordability, and strength. With the focus on these aspects, company can be competitive in the industry.

6.3 SWOT Analysis

SWOT is a type of analysis which aids in the production of a business plan, which stems from the mission vision and goals of the particular company. This analysis includes a highlight of the Strengths, Weaknesses, Opportunities and Threats to the company both internal and external.

6.3.1 Strengths

The main strength of the company is the widening of a previously monopolized market. By supplying the intermediate for the aluminum oxynitride production, more companies are now able to join the market and compete with the one and only aluminum oxynitride producer, Surmet. In addition, the company is utilizing environmentally friendly methods of production resulting in a
positive public image, as well as a lower cost for production. The company is beginning production at a reasonable annual output, resulting in substantial room for growth and expansion if the demand for the product meets the supply goals.

### 6.3.2 Weaknesses

While the introduction of the new market is viewed as a strength as there is no competition, it can certainly also be viewed as a weakness too. While the lack of competition is an immediate plus, the fact that there has never been competition to Surmet can possibly intimidate other companies away from purchasing our intermediate product. With zero precedents, other companies would feel like their abilities to hot press powders could be more safely used producing other products. In order to eliminate this fear, the product and the potential profit that can be gained by furthering the aluminum oxynitride production process must be stressed severely. If companies were to understand that the risks heavily outweigh the risks in this market, the demand for our intermediate product would become significantly larger.

### 6.3.3 Opportunities

The company has the opportunity of growth in regards to the amount of raw materials it brings in for product development. With the basis for the used beverage cans utilized as the main raw material for production, and the number of cans available used on the basis of the amount of recyclable cans available in the Grand Rapids, Michigan area, the amount of powder that the company has the potential to produce has the ability to rise as the ability to accumulate cans rises. The raw materials would be able to be increased by raising the percentage of cans accumulated within the Grand Rapids area, or even outsourcing to neighboring areas. This expansion would be further pursued once the demand for the company’s product rises due to customer acceptance and approval of the furthering of aluminum oxynitride production. World’s Strongest Can is confident
that the customer approval will be high, and therefore the demand will rise, and expansion will be inevitable.

6.3.4 Threats

The major threat to World’s Strongest Can’s operations is the lack of demand for our product. This could be a result of potential customers being too afraid, or even the large current corporation Surmet bullying potential customers out of the market. If Surmet were to lower their costs significantly, that would result in our potential customers not being able to sell the final product for a profit, based on the sale price that our company is basing for our company to make a profit. In addition to this significant threat, there is the ever-prevalent threat of other startup companies with a similar idea and business plan. Depending on the success of our company, other entrepreneurs would want to emulate the success and enter the business. In order to mitigate this threat, the company will need to patent the process, as well as continually develop new and innovative ways to produce our product in order to stay ahead of anyone trying to compete.

6.4 Target Market

World's Strongest Can’s target market is a facet of companies that contain the resources, capabilities, and desire to conduct hot isostatic pressing. With this ability, these companies will be able to take our product, the AlON powder, an intermediate in the production of AlON transparent ceramic, and actually produce it. This requirements for entry into this market is not a widespread ability, therefore the target market is rather small.

6.5 Benefit Offered

As there is only one company (Surmet) currently making the ceramic due to the difficulty of procuring aluminum oxynitride, this process will essentially grant access to a stronger, cheaper material than bulletproof glass that is also clear and lightweight. This material, once widely
available, could create a new standard in safety and general toughness. World’s Strongest Can proposes the widening of the aluminum oxynitride market by enabling various other companies the ability to enter the market through purchasing the intermediate of production. By supplying the aluminum oxynitride powder to these companies at a low price, they will be able to produce the end product and immediately enter the market competitively against Surmet. The marketability for World’s Strongest Can’s product, is the high marketability of our customer’s product.

6.6 Competitor Analysis

There are not currently many competitors to us in this industry, but the current competitor we do have has a stronghold on the entire market we wish to enter. We aim to compete with them by having lower production costs, and in turn a lower selling point.

6.7 Existing Competitors

As previously mentioned, there is only one competitor currently in this market. This competitor is a company called Surmet, based in Massachusetts, who only has one production facility. Surmet is a material solutions company who currently produces five main products, all of which are ceramics. Surmet sells the equivalent to what our company is making, ALON, at a price of $10-$15 per square inch, and produces an unspecified “tonnage” of ALON product annually. Our company plans to greatly reduce this cost while still being able to produce a comparable amount of product.

6.8 Potential Competitors

Potential competitors include the competitors that have either the capability to enter the market, and interest to enter the market, or both. A few examples of local companies with such capabilities are: Alcoa, Temper Inc. and SunRock Ceramics.
6.9 Business Plan Conclusion

After analyzing the entire market, a proposal was made to a group of investors for the actual implementation of the industrial plant. This proposal included financial calculations and estimated projections for the future of the company, and concluded with a request for a loan based upon the profitability of the proposed company.

7 Conclusion

Analyzing all of the potential processes that could be used to produce AlON revealed the most efficient and cost effect method. The most effective synthesis route was determined to be a process that first converts aluminum to aluminum oxide and aluminum nitride. These two reactants can then be converted to the desired aluminum oxynitride. It has been determined that this process is in fact feasible, since the synthesis route chosen is already used in industry. It also can be concluded that it is possible to obtain all required aluminum from recycled beverage cans due to the amount of available cans in a given area and the purity of aluminum that can be achieved through recycling. During next semester, a detailed design of the process will be made. The goal of this project for the fall semester was to determine the process to be used to produce AlON powder. Now that this process has been determined, a detailed design of the process and the equipment necessary must be performed. This will include size and cost of equipment, energy costs, and a complete economic analysis.
Acknowledgments

There are many people responsible for contributing to the success of this project, and Team 09 would like to acknowledge them. First of all we would all like to thank our families for their unwavering love and support. We would like to thank God for always being with us and among us. We would like to especially thank Professor Jeremy Van Antwerp for consistently giving constructive critiques and feedback, supplying ideas and thoughts to further the progress of the project. And finally, we would like to thank our industrial mentor’s, Luke Martin and Bill Dykstra from Temper Inc. for supplying practical industrial expertise and critiques about our project. Without all of this support, we would not have been able to have accomplished such a successful project.
Appendix:

Table 4 - Cost of Materials Feasibility Study

<table>
<thead>
<tr>
<th>Raw material cost</th>
<th>price of aluminum cans $/kg</th>
<th>Price of cans/year</th>
<th>price of Nitrogen/kg</th>
<th>price nitrogen/year</th>
<th>price of oxygen/kg</th>
<th>price of oxygen/year</th>
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<tbody>
<tr>
<td>$</td>
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<td>1,962,722.02 $</td>
<td>0.16 $</td>
<td>44,962.22 $</td>
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<tr>
<td>total raw material cost/year</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>$</td>
<td>2,911,522.80</td>
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Table 5 - Feedstock Quantity Feasibility

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<th>cans in GR/yr</th>
<th>weight of can (g)</th>
<th>percent Al of can</th>
<th>weight of aluminum per year (g)</th>
<th>amount of powder per year (kg)</th>
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<td>422460.8947</td>
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<td>48,852.47</td>
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</tbody>
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6. (Sennan, Japan Patent No. 4612045, 1986)


12. (Kawasaki, Japan Patent No. 5,769,331, 1998)
