Team 9: World's Strongest CAN

Preparation of Transparent Aluminum

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Engr339/340 Senior Design Project
Calvin College
16 Nov 2015

Project Proposal and Feasibility Study

Calvin College
16 November, 2015
Professor Jeremy Van Antwerp

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 development of Aluminum Oxynitride is a process that is up and coming, and certainly has room for improvement. While the applications for this product are vast and evident, the price at which it is available is staggering, 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 500 tons per year of Aluminum Oxynitride (AlON) in the powder form. The purpose of creating this process is to market this powder to various companies who will be able to create the actual transparent ceramic Aluminum Oxynitride. 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 in order to acquire pure Aluminum to be reacted further, and transformed into Aluminum Oxynitride powder.

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Introduction

1.1 Course Introduction

Calvin College Engineering Program encapsulates the culmination of learning through the utilization of a senior capstone project. This project is comprised of 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 student's 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

Aluminum oxynitride ceramic is a highly utilizable material on the commercial market. With material properties such as high hardness and good transmission, aluminum oxynitride has been found to be superior in protection from 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 aluminum oxynitride is an up and coming process, currently only being produced by one company, Surmet. The monopolization of this field, and the methods of producing the aluminum oxynitride, the resulting 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. In order to achieve the cheaper production, the aluminum used in the synthesis of aluminum oxynitride will be acquired through stripping aluminum off of used beverage cans (UBC's). The initial goal for this project is the production of aluminum oxynitride powder, which can be physically manipulated into the final product, a hard and optically transparent ceramic. The physical manipulation of the powder can either be sold to other companies to produce the ceramic for commercial sale, or the ceramic production can be produced by us. Either way, the production of aluminum oxynitride will become more widespread, and the price will be driven down, resulting in larger implementation of the product, and improving the defense sectors around the globe.

1.4 Design Norms

During this design project, 3 specific design norms will be kept in mind including stewardship, caring, and trust. Stewardship will be displayed through this design since this process will utilize 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 making this product more readily available shows care for the people who would benefit from this product. Finally, this design team will strive to display trust through the design project. The product, ALON transparent aluminum, is used in many life or death situations and must be dependable and trustworthy in these crucial moments.

1.5 Project Management

In order 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, piña coladas, and getting caught in the rain. 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 concentration 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 work 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.

Team Webmaster:

Based on his keen knowledge of computers, writing code, and simulation software, Zhihong was appointed 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 1.5.1) includes all major milestones to be completed this semester, and the dates on which they should be done.

Task Name	Start	End	Duration (days)
Research separation of aluminum from cans	10/8/2015	11/12/2015	35
•Research Synthesis of Aluminum Oxide	10/21/2015	11/15/2015	25
•Research development of aluminum oxynitride via previous components	10/21/2015	11/18/2015	28
•Research synthesis of oxynitride via nitridation	10/22/2015	11/30/2015	39
•Research target markets	11/15/2015	11/30/2015	15
Make contact with professional advisor at Alcoa	10/22/2015	10/30/2015	8
Prepare PPFS	10/21/2015	12/11/2015	51
Set up the webpage	10/5/2015	10/30/2015	25
Oral Presentations 2	11/4/2015	12/9/2015	35
Part 2 Second half of the project			
Finalize Design decisions for synthesis of aluminum oxynitride	2/8/2016	4/6/2016	58
Determine feasibility of self producing ceramic	2/8/2016	4/6/2016	58
Develop Posterboard and work on final presentation	3/14/2016	5/15/2016	62
Write Final Report	3/14/2016	5/1/2016	48

Figure 1.5.1- Senior Design Schedule

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 in order 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 VanAntwerp. This is a time when Professor VanAntwerp can offer us guidance and technical advice, as well as answer any questions the team may have come across.

1.6 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 always supporting us. We would like to thank God for always supporting us. And we would like to thank Professor Jeremy VanAntwerp for always supporting us. Without all of this support, we would not be able to have done such an incredible job on this project.

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 aluminum oxynitride 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,[1] 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 components military wide. With substantially superior performance against conventional ballistics, as well as high performance against improvised explosive devises,[2] aluminum oxynitride 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.[3] With such a higher price mark up, the aluminum oxynitride has not yet been able to integrate 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, such as banks, hospitals, among many others.

Aluminum oxynitride is a new, up and coming technology, without much widespread knowledge of its capabilities. Currently only being produced by one company, Massachusetts

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[1] "2015 Defense Budget by Country". www.globalfirepower.com. Retrieved 2015/11/12

[2] "© 2011 Surmet Corporation" http://www.surmet.com/products-and-applications/Direct-Fire-and-Blast-Protection/index.php Retrieved 2015/11/12

[3] "Live Science Staff" http://www.livescience.com/420-military-aluminum-windows-stop-50-caliber-bullet.html Retrieved 2015/11/12

based Surmet corporation, the availability of this product is limited, and as previously mentioned, the costs are quite high.

2.3 Project Constraints

The production of aluminum oxynitride can be gone about it numerous different ways. There are multiple different chemistries that can be used to produce the desired product, however 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 stripping of used beverage cans.
In the team's attempt to lower production costs, and therefore purchasing costs of the transparent aluminum oxynitride ceramic, the utilization of recycling methods to take UBC's and utilize the aluminum present within them will be a huge stepping stone.

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 powdered form aluminum oxynitride, as well as the end product ceramic. The research was conducted primarily through the utilization of the research database SciFinder Scholar.

During the initial research phase of this project, numerous different alternatives for how to conduct this project were discovered. The process of stripping aluminum from the used beverage cans can be performed in a few different ways. The portion of the project regarding the chemistry needed to go from aluminum to aluminum oxynitride contained the most potential alternatives. With numerous routes to produce aluminum oxynitride, each design alternative had to be analyzed in order to determine the optimal production process.

2.4.2 Analysis of Design Alternatives

The main purpose of this project is to develop the optimal process to allow for cost effective production of aluminum. 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 aluminum oxynitride, the feasibility study helped set the limits for what that would entail.

The analysis of self-production 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. The major sections of this project discussed in this report can be seen in the block diagram below.

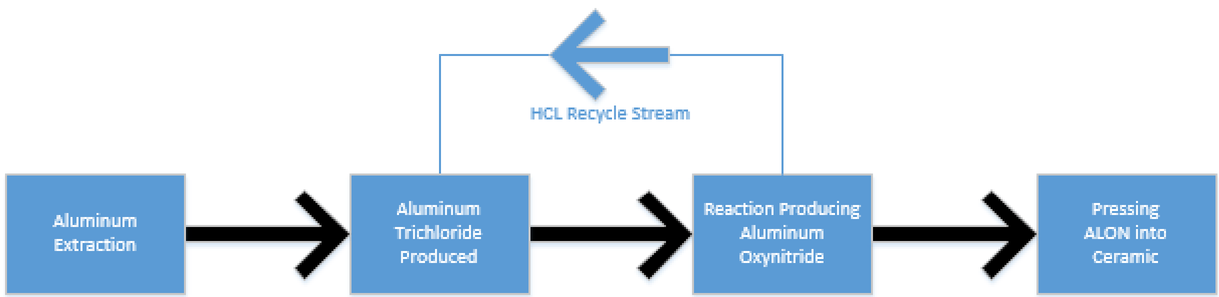

Figure 2.4.1-Block Diagram of Process

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 3.2.1 below.

	Synthesis equation	Required temperature (°C)
1	$Al_2O_{3\,(s)} + AlN_{(s)} \rightarrow AlON_{(s)}$	≥1650°C
2	$Al_2O_{3\,(s)} + C_{(s)} + N_{2\,(g)} \rightarrow AlON_{(s)} + CO_{(g)}$	≥1700°C
3	$Al_2O_{3\,(s)} + C_{(s)} + Air \rightarrow AlON_{(s)} + CO_{(g)}$	≥1700°C
4	$Al_2O_{3\,(s)} + Al_{(l)} + N_{2\,(g)} \rightarrow AlON_{(s)}$	>1500°C
5	$Al_2O_{3\,(s)} + Al_{(l)} + Air \rightarrow AlON_{(s)}$	>2045°C
6	$Al_2O_{3\,(s)} + NH_{3\,(g)} + H_{2\,(g)} \rightarrow AlON_{(s)} + H_2O$	≥1650°C
7	$Al_{(l)} + Air \rightarrow AlON_{(s)}$	~1500°C
8	$AlCl_{3\,(g)} + CO_{2\,(g)} + NH_{3\,(g)} + N_{2\,(g)} \rightarrow AlON_{(s)} + CO_{(g)} + N_{2\,(g)} + HCl_{(g)}$	900°C
9	$Al_2O_{3\,(s)} + BN_{(s)} + N_{2\,(g)} \rightarrow AlON_{(s)}$	≥1700°C

Table 3.2.1- Chemical Reactions known to produce aluminum oxynitride[4]

As can be seen in the table above, there are many different reactants that can be used in order to create aluminum oxynitride, and almost all of the reactions require different temperatures.

3.3 Structure and Properties

Structure and properties will be analyzed further along in the project.

3.3.1 Structure of Aluminum Oxynitride Powder

3.3.2 Structure of Aluminum Oxynitride Transparent Ceramic

[4] “The Influence of Sintering Additives on theMicrostructure and Properties of AlON”, Yechezkel Ashuach Dec. 2003 Retrieved: 2015/11/12

3.3.3 Properties

4 Analysis of Design Alternatives

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 Synthesis Options

After discovering the numerous pathways of producing the aluminum oxynitride, the optimal route for the production was a key decision in the project process. A table showing all of these various pathways can be seen in Table 3.2.1. The decision for the optimal chemistry route comes down to factors such as availability and cost reactants, required temperature for each particular chemistry, the waste products produced, and the phase of the reactants in each chemistry. These factors were weighted, and placed into a decision matrix to help determine which of the chemistries was optimal. This decision matrix can be seen in Table 4.2.1, with the reaction numbers referring to those listed in Table 3.2.1.

Decision making Factor	Weighting	Reaction 1	Reaction 2	Reaction 3	Reaction 4	Reaction 5	Reaction 6	Reaction 7	Reaction 8	Reaction 9
Required Temperature	9	4	3	3	5	1	4	5	9	3
Reactant Availibility/Cost	6	2	6	7	3	4	8	10	5	
Reactant Phase	7	3	3	3	3	3	3	5	10	3
Waste Products	4	7	5	5	7	7	7	7	9	7
	Total	97	104	110	112	82	133	168	217	76

Table 4.2.1- Decision matrix highlighting optimal aluminum oxynitride synthesis route

The decision making factors listed above were weighted based on the importance of each factor to the final synthesis of the product. The temperature required in the reaction was the most heavily weighted factor as it holds a direct correlation to energy costs. The higher the temperature required in the reaction, the more money will be required in energy costs. These energy costs will represent one of the larger portions of the total costs for the aluminum oxynitride production, and as the primary goal for this project is reducing the costs of the final product, this factor becomes very important. The reactant availability factor is a measure of how acquirable the reactants for each reactant are. The more readily available and lower cost the reactants are, the higher score they received on the decision matrix. In addition to the availability of the reactants, the phase of the reactants was another important factor. Throughout the nine reactions, the reactant aluminum was comprised of all three phases, solids, liquid, and gas. It was determined that gas was the optimal phase for the reactant aluminum, because it allows for chemical vapor deposition, which is a method of solid production utilizing only gaseous reactants. Chemical vapor deposition allows for highly purified products, which will ensure quality on the final product.[5] The liquid phase is the second preferable phase as the solution will be pure, well mixed, and have less difficulty with packing and crystal structure. The final decision factor is the waste products

[5] "CVD Processes and Equipment" Handbook of Chemical Vapor Deposition http://www.ewp.rpi.edu/hartford/users/papers/engr/ernesto/morens/EP/References/CVD%20Processes%20and%20Equipment.pdf Reviewed: 2015/11/13

emitted from each chemistry, taking into account both the environmental impacts of the byproducts, and the usability of those products moving forward.

After analyzing all of these criteria, all nine reactions were given scores comparable to their attributes. The scoring system used was determined by judging which criteria would be the most ideal, and then assigning scores based on how each reaction compares to its comrades. As can be seen in Table 4.2.1, reaction 8 was found to be the most optimal chemistry.

The chemistry in reaction 8 was particularly pleasing due to its significantly lower operating temperature, at 900 °C compared to the other temperatures which were much higher. In addition, as mentioned above, the gas phase reaction was particularly enticing, as the chemical vapor deposition method for acquiring the aluminum oxynitride appeared to be the most pure way of acquiring it. The waste products in this reaction include carbon monoxide, nitrogen, and hydrogen chloride. Carbon monoxide is a harmful gas, and therefore must be burned before being emitted to the atmosphere, however after that occurs it becomes harmless, along with the nitrogen. The hydrogen chloride will be able to be recycled in our system to help assist the production of the reactant aluminum chloride. The aluminum chloride is synthesized by the exothermic reaction of pure aluminum and hydrogen chloride. The pure aluminum in this case will come from the melted down aluminum cans, and the hydrogen chloride will be able to be recycled back through the system. With all of these attributes contributing to the appeal of this reaction, it was the clear and obvious choice for the route to pursue to create the aluminum oxynitride powder.

5 Project Feasibility

5.1 Quantity of Feedstock

Taking used aluminum beverage cans for the feedstock in this process is one way in which the cost of aluminum oxynitride 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 aluminum oxynitride.

The amount of cans recycled in the Grand Rapids area was used as a basis. Every year in Grand Rapids, roughly 33 million cans are recycled. At approximately .95 grams Al/gram, there is on average 11.9 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.

Aluminum oxynitride powder which will be produced in this process is 56% aluminum by weight. With 390,000 kg of aluminum recovered, 700,000 kg of aluminum oxynitride powder can be produced from cans in the Grand Rapids area. 700,000 kg equates to 700 tons, which exceeds the initial goal of producing 500 tons per year. This shows that it is in fact feasible to begin this process with aluminum cans. Obviously it is not possible to use every single can recycled in Grand Rapids, but cans could be acquired from surrounding cities. Also, if this plant was constructed in a larger city.

5.2 Market Analysis

Market analysis will be performed in further detail along with the business plan

5.3 Cost Analysis

5.4 Business Plan [Optional]

The business plan for this project will be completed in conjunction with BUS-357 at the end of the Fall 2015 semester. Once this plan has been completed, it will be inputted into this document.

5.5 Looking Ahead

5.5.1 Detailed Process Design

5.5.2 Feasibility of Producing Ceramic

6 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 trichloride in the presence of hydrochloric acid. This aluminum trichloride can then be converted into the desired aluminum oxynitride powder. Once this powder is made, it can either be sold as is or pressed into a transparent solid.

It has been determined that this process is in fact feasible, although it is not yet known if this process will significantly reduce the cost of aluminuin oxynitride. During the remainder of the semester, as well as next semester, a detailed design of the process will be analyzed, determining if the new process reduces the cost of aluminum oxynitride.

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