Radiators

Taking Advantage of Aluminum Metal

Engineering Design 100

Section 004

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Abstract:

The purpose of this design was to create a product that will increase the efficiency and sustainability of a particular system across the campus through the use of aluminum. The final solution for this design focused on heating systems. Walls behind heating radiators have the ability to absorb on average of 11% of heat, causing unwanted energy loss. The addition of a thin, inexpensive copper-aluminum alloy panel behind the radiator in every dorm will reflect heat in the intended direction. Around 10% of that heat will be returned and used for heating the space.

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Introduction

Alcoa is the world's third largest producer of aluminum with corporate headquarters in New York City. Alcoa began when Charles Hall and some investors founded The Pittsburgh Reduction Company in 1888. In 1907, the company became known as the Aluminum Company of America. Finally in 1999, it was renamed Alcoa, Inc. Alcoa has been growing ever since its discovery. Today, Alcoa is 125 years old and is located in 30 countries with over 200 locations. Alcoa has 61,000 employees worldwide and generated $23.7 billion in 2012.

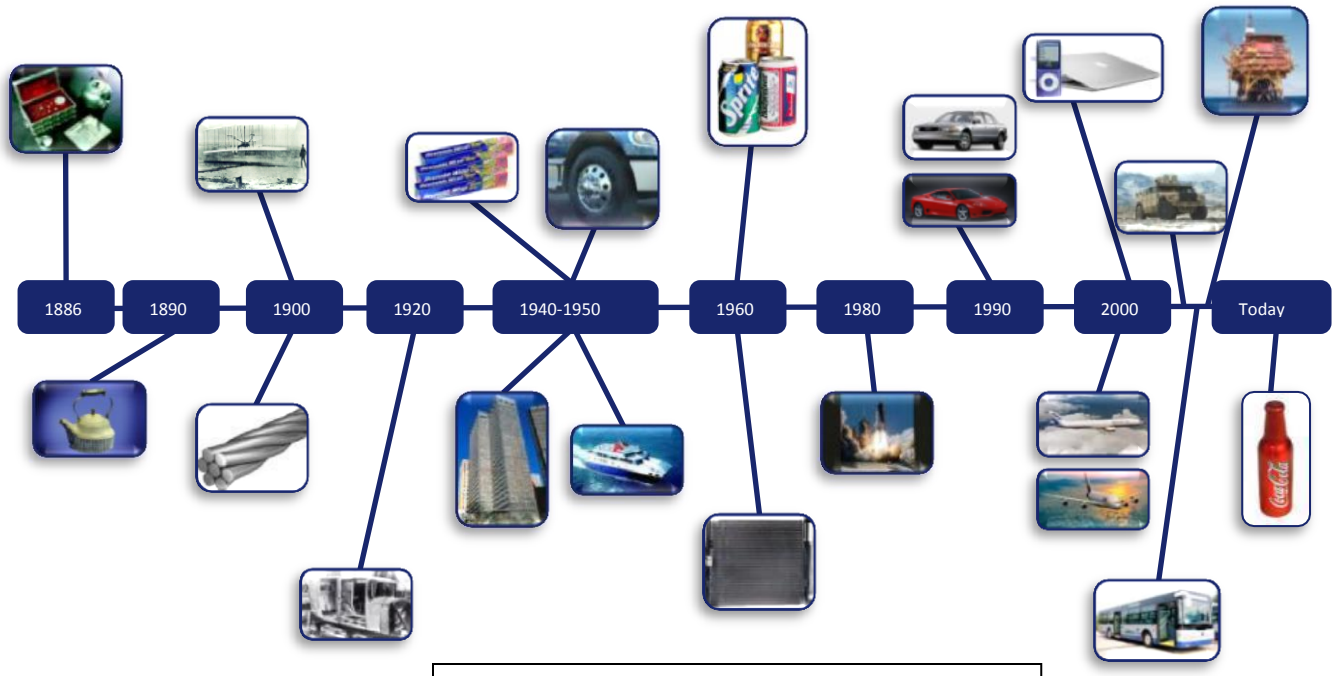


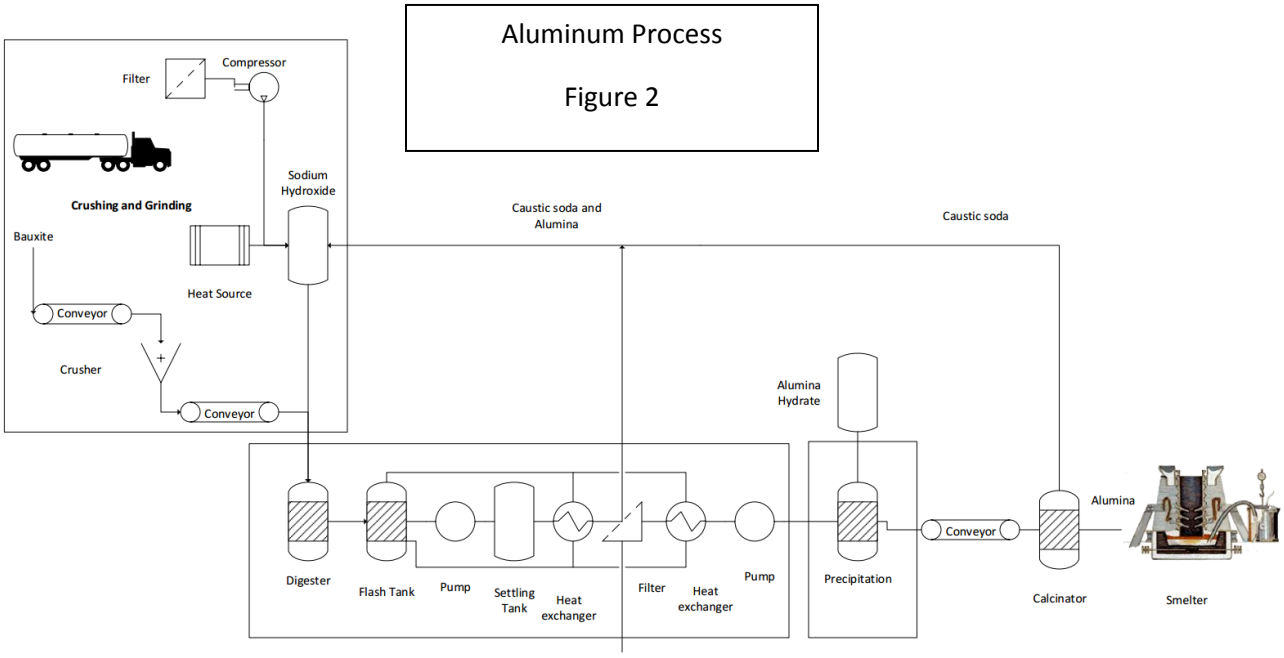
Figure 1

Alcoa's progress throughout the years.

After the discovery of aluminum in 1825 in Denmark, pure aluminum was so rare that it was considered as a precious metal. Pure aluminum is not found in nature, it always exists in a form of compounds such as potassium aluminum sulfate and aluminum oxide. Even though aluminum is one of the most abundant metals in earth's crust (8.2%), it was very difficult to extract it from those compounds. Couple years before the founding of Alcoa, Charles Martin

Hall discovered and patented an affordable way to create aluminum through electrolysis which allowed him to create Alcoa (1). He managed to bring the cost down to about 18 cents a pound making aluminum no longer considered as a precious metal (1).

Today, aluminum is the second-most used metal after steel. Today, aluminum is made out of bauxite by the same chemical process that Charles Hall originally discovered, electrolysis. Figure 2 demonstrates how alumina is first extracted out of bauxite and then processed by electrolysis. Electrolysis is a chemical decomposition produced by passing an electric current through a solution containing alumna, also known as aluminum oxide.



Aluminum found its way into many different applications such as transportation, construction, packing, electrical components, and much more. Several important properties of aluminum allowed the metal to become the second-most usable metal today. First, aluminum is very light (density of only 2.79g/cm^3) being about three times less dense then steel.

Aluminum is capable of excellent conductance of both heat and electricity [1] [2]. Several alloys of aluminum can exceed steels strength, aluminum is also an excellent reflector: which is capable of reflecting up to 95% of the light that hits the metal.

Many believe that aluminum is the metal of the future. Thus, this fall of 2013 Alcoa presented EDSNG 100 courses with a new challenge which states “Identify opportunities across the campus to take advantages of aluminum’s intrinsic properties for the purpose of increasing the efficiency or sustainability of products and product systems.” This is an opportunity to effectively increase the sustainability and efficiency of energy use by engineering students who have been waiting for such opportunity. This opportunity requires instance research and creativity, my team believes to be the team that provides Alcoa with new insights, ideas, and encouragement.

Project Management: Gantt Chart

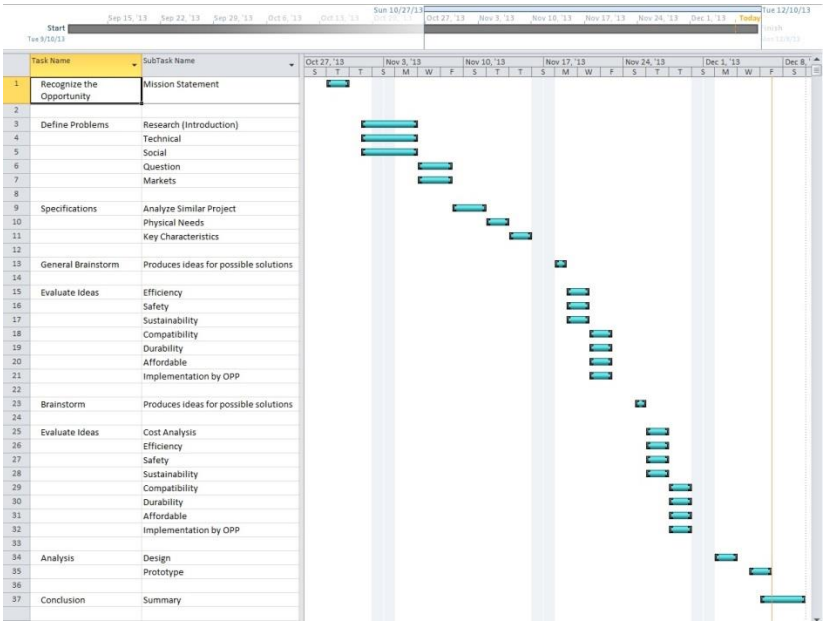


Figure 3

Mission Statement / Defining the problem / Specification

After careful analysis of the objective of this project we decided to have a general mission statement which states: to create a process or a product that will increase efficiency and sustainability of a particular system across the campus through the use of aluminum. Several steps must be taken in order to define our problem. First, technical background research must be done; all of the team members must understand the processes behind creation of aluminum and all of its components. We must also understand the history and the current citation about the usage of aluminum. There are several social aspects that are needed to be done in order to fully understand the need for this project, things such as money, parts, and stakeholders. Internet and library research are vital to this design project. Identifying markets such as Alcoa and Penn State Campus must be well understood for a successful product. Questions, interview, and surveys must be done in order to identify all of the specifications of this design process. Specifications are listed in Figure 4. After all of that is completed, more thorough research is required. This time, we must understand and develop all the principles and usefulness of aluminum itself.

Specifications

Figure 4

1. **Safety**
2. **Efficiency**
3. **Sustainability/Durability**
4. **Marketable**
5. **Affordable**
6. **Implementation by OPP**

Concept Development

There are many different qualities that metals have; some of them are more useful than others. In order to identify aluminum strengths, this team had to point out important properties of metals and identify properties that aluminum is especially good at. The properties that were compared are those as followed: weight, electrical and thermal conductance, strength, tensile, reflectiveness, reactiveness, heat capacity, and emissivity. After evaluating each intrinsic property, qualities such as weight, thermal conductance, heat capacity, reflectiveness, and strength turned out to be the strengths of aluminum. This evaluation can be summarized in Figure 8 below. For closer comparison of properties between aluminum and other metals, tables with accurate values can be found in Appendices section at the end of the report.

Properties (metal)	Aluminum/Alloy	Most commonly used/The best
Weight	Al(lightest basic metal) (26.98amu, 2.7g/cm3)	Al Li(6.9amu)
Electrical Conductance	Al ($.377 \times 10^6$cm/Ω)	Cu ($.596 \times 10^6$cm/Ω)
Tensile Strength	Kobe's alloy (780MPa) [5]	Steel (ASTM A514) (690 MPa) Carbon Nanotube (11000-63000)
Elastic modulus (Young's modulus)	Al (10,000,000 psi) [6]	Mg (6,530,000 psi) [6]
Reflectiveness/Shines	Al (97%) [7]	Gold (>97%) [7]
Reactiveness	Aluminum [4]	Potassium [4]
Thermal Conductance	1050A (229W/mK)	Copper
Heat Capacity	Al (24.2 Jmol/K)	Water (38.09 Jmol/K) Air (29.19 Jmol/K)
Emissivity	Al oxidized (.02)	Al Oxidized (.11)

Figure 8

Brainstorming / Evaluating Ideas / Weighted Matrix

As soon as more thorough research had been done on the strengths and weaknesses of aluminum, the team needed to brainstorm by implementing all the strengths of aluminum and its alloys. As shown in Figure 5 bellow which depicts some of the ideas this team came up with. Brainstorming was divided into two parts including general applications following with more specific possible ideas. Next the team had to evaluate all of the ideas that were generated in brainstorming phase. This is shown in Figure 6. After evaluation was finished the team had to decide on a single idea that will receive the rest of the attention throughout this project. As shown by the Figure 6, radiator is the most logical choice to go with. Weighted matrix is necessary in order to rank the specifications that are to be focused on the most. Figure 7 shows the weighted matrix raking all of the specifications with maximum of 10 points with categories such as relevance, importance, and implementation. By this evaluation it was determined that there are more than one important specification. OPP implementation and efficiency are the two specification that the team must pay attention the most.

Properties	General	Specific
Lightweight	Auto Industry Packing	Cutlery
Conductivity (electrical/thermal)	Wiring/Heating	Heaters , Radiators
Reflectiveness	Insulation	Bus, Buildings, Clothes
Strength	Structural supports	Cutlery
Reactiveness	Corrosion	Faucet, Ceiling for Beaver Stadium

Brainstorming

Figure 5

Ideas

Evaluation of Ideas
Figure 6

Specifications	Cutlery	***Radiators***	Bus Insulation	Clothes	Faucet	Ceiling for Beaver Stadium
Safety	+	+	+	+	+	+
Efficiency	+	+	+	+	0	0
Sustainability/Durability	+	+	+	+	+	+
Marketable	0	+	+	+	+	0
Affordable	+	+	-	0	0	-

Radiators

Weighted Matrix
Figure 7

Specifications	Relevance (3)	Importance (4)	Implementation (3)	Total (10)
Safety	2	3	2	7
Efficiency	3	4	3	10
Sustainability Durability	3	3	2	9
Marketable	3	3	3	9
Affordable	2	4	3	9
OPP	3	4	3	10

Identifying Specific Mission Statement / Proposal

Mission Statement:

To improve the efficiency and sustainability of heat transfer throughout the campus by the use of aluminum. Replacing or adding to the current radiators with more sustainable and efficient parts.

Introduction to Heating Systems

University Park Campus has a very a developed heating energy system. The campus is heated by district heating system. District heating is a system for distributing heat generated in a centralized location for residential and commercial heating requirements such as space heating and water heating. The heat is generally obtained from a cogeneration plant burning fossil fuels. There are two actively working cogeneration plants in the campus that provide both heat and some other alternative energy for different uses serving more than 200 buildings on University Park. One of those plants is located in the West Campus and the other is in East Campus. The combination of cogeneration and district heating systems is very energy efficient. While a basic thermal plant that is just working for the heat production generates 20-35% energy efficiency, this percentage in the cogeneration plants is significantly higher, with an amount of 80%. Cogeneration plants are also environmentally friendly as they produce half the pollution of a typical utility power station. Cogeneration plants at PSU are consisted of boilers, turbines, pumps, fans and electric generators. Low-pressure turbines exhaust steam that is delivered to the buildings in the campus. High-pressure turbines deliver heat to the building off campus.

The thermal efficiency in a basic cogeneration system is calculated by the Rankine cycle, which is:

$$\eta_{th} \equiv \frac{W_{out}}{Q_{in}} \equiv \frac{\text{Electrical Power Output} + \text{Heat Output} + \text{Cooling Output}}{\text{Total Heat Input}}$$

η_{th} = Thermal efficiency

W_{out} = Total work output by all

Q_{in} =Total heat input into the system

The specifications for the energy production in cogeneration plants at University Park are indicated below:

-WEST CAMPUS:

Steam Capacity: 350000 pounds per hour

Electric Capacity: 6 mW

Plant Efficiency: 50%-70%

-EAST CAMPUS:

Steam Capacity: 35000 pounds per hour

Electric Capacity: 7 mW

Plant efficiency: 80%

The heat produced in cogeneration plants is transported to the building around the campus as a steam through thermal pipes. There are 2 types of systems for building heating such as water and forced air heating. Water heating is the conventional heating system for many years that is more efficient for heating buildings than any other system. However, in the modern world forced air systems seem more useful as they have better air conditioning effects, energy savings up to 15-20% and even conditioning. At Penn State University Park Campus, both types of steam heating is used around the campus. For example in dormitories such as West, Simmons, McElwain, and Atherton the heating is provided by steam radiators. However, everywhere else heating is supplied by hot water.

The purpose of our innovative heating radiators for the heating system is to convert all the heating distribution system in the University Park to the forced air system to have a reach more efficiency in long extent. As the steam radiators are not as powerful in heat conducting as radiators supplied by hot water, we would like to change the material that is used in radiators with a more conductive one. In general, especially in dormitories, the materials used in radiators are iron, copper, or steel. We are going to change their structures with aluminum cases, so the goal of this project is get a more efficient heat conductance system.

Introduction to Radiators

According to the online dictionary radiator is a thing that radiates or emits light, heat, or sound. There are several different types of radiators, they include: hot water, steam, fan assisted heat exchanger, under floor, portable, and electric baseboard. They all share the same goal which is to heat the surroundings or to emit heat as efficient as possible.

Radiators that use hot water consist of hollow metal container filled with hot water. As it gives out heat, the hot water cools and sinks to the bottom and exits the radiator through a different pipe where it can be reheated again and enter the radiator for another cycle. Steam works a little different from water radiators. Steam is far easier to distribute than hot water, however, high temperature at which steam systems operate make them less efficient and more expensive. Fan assisted heat exchanger (radiator) is fed by hot water from the heating system.

A switch can turn an electric fan which blows air over the heat exchanger to circulate it in a room. But this radiator can be noisy. Under floor radiator uses small tubing or heating cables that are installed under the floor. This system can be inefficient and expansive. Electric baseboard and portable radiators can be more efficient than previous radiators. Electric elements, which can direct heat to specific areas, that are indented to be heated, can be useful for many purposes. Some visuals are listed below to demonstrate several types of radiators.

Defining the problem / Specifications

In order to define the problem and understand the meaning of more specific mission statement, this team needed to repeat the process listed on page 6. Defining the problem involves several parts such as technical and social background research. Both parts contain several things that must be done. They include understanding radiators and heating systems as a whole, understanding all the parts and money that must be involved in order to make this project possible. Through questioning and researching several markets such as Alcoa and Penn State campus (OPP) this team was able to define the problem completely.

Certain specifications must be created for the guideline and the boundaries of this project. Those specifications can be found in Figure 4 on page 6 of this report. Original specifications were not changed because the goal of this design did not change.

Brainstorming

After researching heating systems and radiators, some ideas were generated. An addition of an aluminum alloy thin panel behind the radiator will allow for heat to be directed toward the space in a room instead of a wall. Another idea involves the installation of an air vacuum to get rid of unnecessary heat loss through the air. This air vacuum will be covering only the radiator and therefore will not harm the surroundings. Third idea involves the installation of a under floor aluminum heating pad. The last idea is to replace the radiator material as a whole with a new aluminum alloy with better properties. This is summarized in Figure 10 listed below.

Evaluating Ideas / Cost Analysis

In the current project after evaluating each idea and incorporating them within in the radiator systems we concluded that aluminum foil reflector is the most beneficial system because of the advantages it provides for the radiator and over the other ideas as seen in the given Figure 10. Aluminum foil reflectors will concentrate the heat into the places that are needed without extra cost only by directing the heat into the places we find fit.

Ideas	Al foils reflector	Air Vacuum	Radiant Heating	Another Alloy
Safety	+	+	0	+
Efficiency	+	+	0	+
Sustainability	+	-	+	0
Durability	+	+	+	+
Marketable	+	-	+	+
Affordable	+	-	-	-

Figure 10

After brainstorming, ideas were analyzed; the team came up with the idea of using aluminum foil reflectors in the radiators. Then the research showed what can be the next alternative alloy instead of aluminum. Research shows that the most suitable three aluminum alloys are silicon, copper, and magnesium [3]. According to Innovations article of Patricia T.Foley, copper is the most durable metal [3] of these three because copper is used in products to last as a lifetime or even longer. Also, magnesium alloy corrosion resistance is pretty good [4]. In science, construction companies use this material to increase the lifetime of the building. Although its surface could erode easily, it has no effect in the mechanical structure. Sometimes silicon's good corrosion resistance [3] property is used in heaters. However, its durability is weaker than copper and magnesium alloys. According to www.metalprices.com, costs of

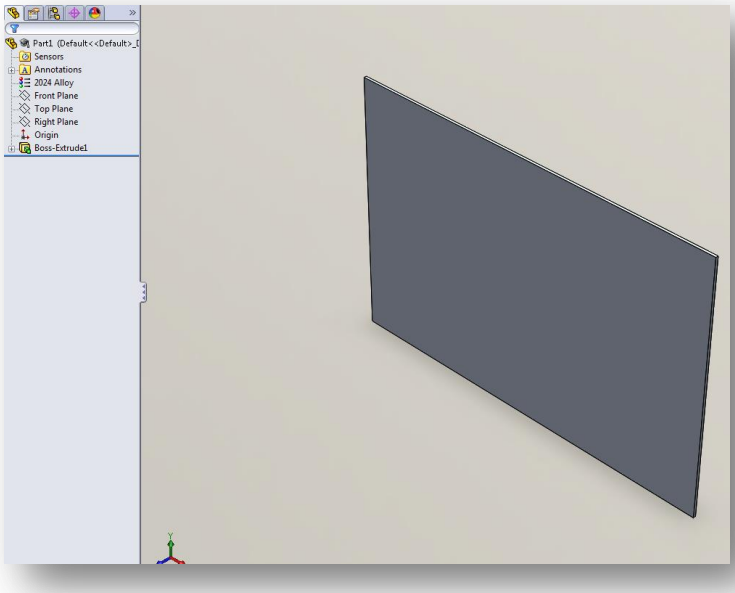
magnesium, copper, and silicon per pound are respectively 1.25$, 3.16$, and 0.97$. This evaluation is summarized in Figure 11.

Al Alloys	**Silicon**	**Copper**	**Magnesium**
Safety	2	3	1
Heat Capacity	2	1	3
Durability	2	3	1
Affordable	2	1	3
Reflectiveness	2	3	1

Figure 11

Analysis/Conclusion

After the design process was completed several conclusions were made. The best solution to the design problem turned out to be an aluminum alloy foil being placed behind all of the radiators located in the dorms. Aluminum alloyed with copper is the best alloy to be used for this reflector. After analyzing the cost of both systems (current and improved), an average of 10% of heat energy will not be lost and will be used for heating.



Appendices/References

Appendix 1

Electrical Conductivity	Material
0.377 10^6/cm Ω	Aluminum
0.452 10^6/cm Ω	Gold
0.596 10^6/cm Ω	Copper
0.63 10^6/cm Ω	Silver

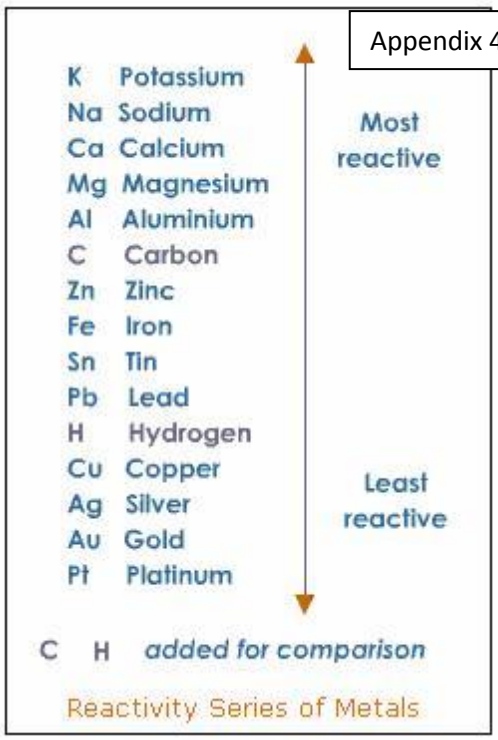
Appendix 2

Material	Thermal conductivity (W/m K)*
Diamond	1000
Silver	406.0
Copper	385.0
Gold	314
Aluminum	205.0
Al_2O_3	30

Appendix 3

Copper	385	$Jkg^{-1}K^{-1}$
Magnesium	1030	$Jkg^{-1}K^{-1}$
Silicon	711	$Jkg^{-1}K^{-1}$

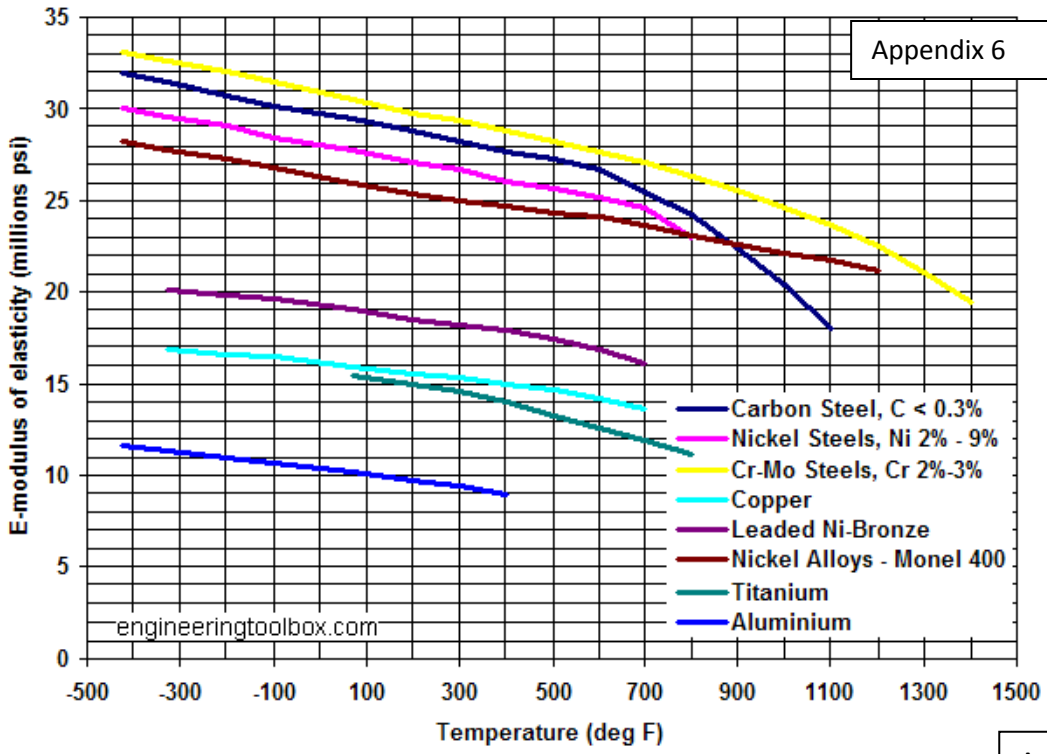
Appendix 4



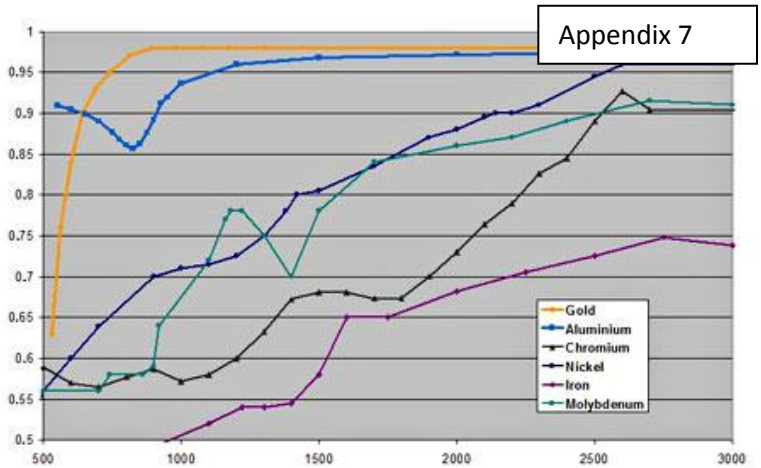
Appendix 5

Strong	Stronger	Strongest
Titanal	Weldalite	Kobe's alloy
Tensile strength: 700MPa*	Tensile strength: 710-720MPa*	Tensile strength: 780MPa*

Appendix 6

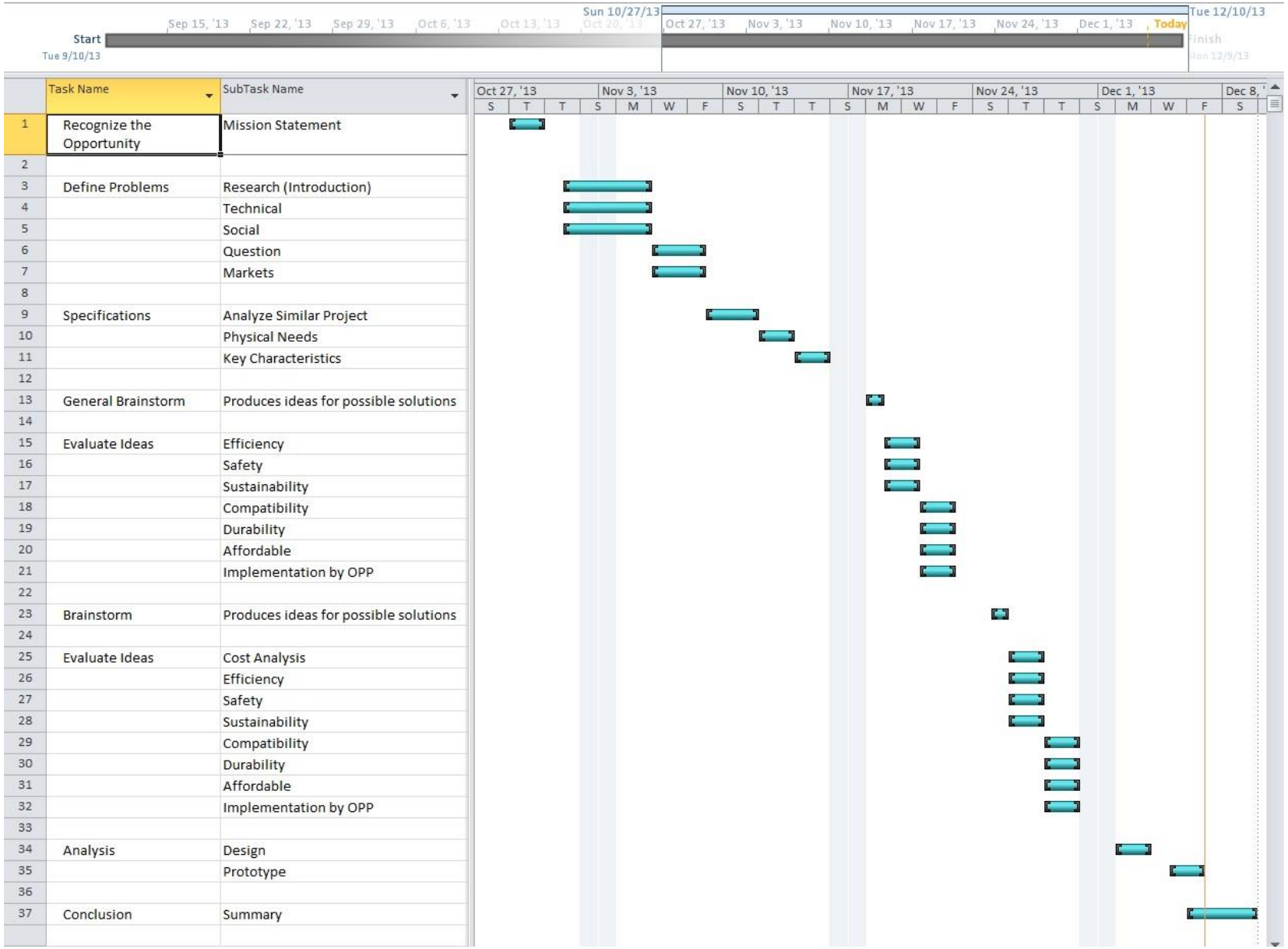


Appendix 7



Appendix 8

Material	Specific Heat Capacity [J/kg°C]
Water	4200
Alcohol	2500
Ice	2100
Aluminium	900
Concrete	800
Glass	700
Steel	500
Copper	400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Sep 22, '13
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Sun 10/27/13
Oct 27, '13
Nov 3, '13
Nov 10, '13
Nov 17, '13
Nov 24, '13
Dec 1, '13
Today
Tue 12/10/13
Finish
Task Name
SubTask Name
1 Recognize the Opportunity Mission Statement
3 Define Problems Research (Introduction)
4 Technical
5 Social
6 Question
7 Markets
9 Specifications Analyze Similar Project
10 Physical Needs
11 Key Characteristics
13 General Brainstorm Produces ideas for possible solutions
15 Evaluate Ideas Efficiency
16 Safety
17 Sustainability
18 Compatibility
19 Durability
20 Affordable
21 Implementation by OPP
23 Brainstorm Produces ideas for possible solutions
25 Evaluate Ideas Cost Analysis
26 Efficiency
27 Safety
28 Sustainability
29 Compatibility
30 Durability
31 Affordable
32 Implementation by OPP
34 Analysis Design
35 Prototype
37 Conclusion Summary

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