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Learning Outcome Assessment 3

Design Modification of Rapid Solidification Processing (RSP)

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

Team 5

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Abstract:

Using Rapid Solidification Process (RSP) improves the mechanical properties of metal due to the micro structural modification and provides an increase in the capability of the structures. The RSP uses one drum for the molten to take the form of a ribbon, yet the molten will have two separate sides with different microstructures, the air side and the drum side. This project is set overcome this problem by adding another drum that will allow both sides of the molten to have fine microstructures and both have drum sides, which will exclude the air side.

Acknowledgments:

We would like to express our highest appreciation for the support, guidance, assistance, encouragement, and supervision that was generously shown from Dr. Fraj AlShmmri during this project. It was an honor to be able to cooperate with him and accomplish this much in this project.

We would also like to thank Dr. PanagiotisSphicas for the help, effort and time he gave us regarding the required forms and documents for the project.

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Chapter 1

1.1 Introduction

The development of material is what is targeted to achieve in this project, Al-Si alloys precisely. Al-Si is needed in the automobile industries. These industries require specific material in its production. Al-Si alloys has good properties that will satisfy these industries.Many researches have recently started focusing on the Al-Si alloys. Excellent thermal conductivity and lower density make Al-Si alloys in the manufacture of engine components an appropriate alternative for cast iron. The increase in the maximum operating temperature and engine pressure requires the improvement of the thermo-mechanical fatigue of Al-Si alloys.

Necessities toenlighten fuel economy and reduce emissions requires adjustments in the materials and the design of engine blocks. The major characteristics for engine blocks are high resistance of wear, and low friction coefficients.

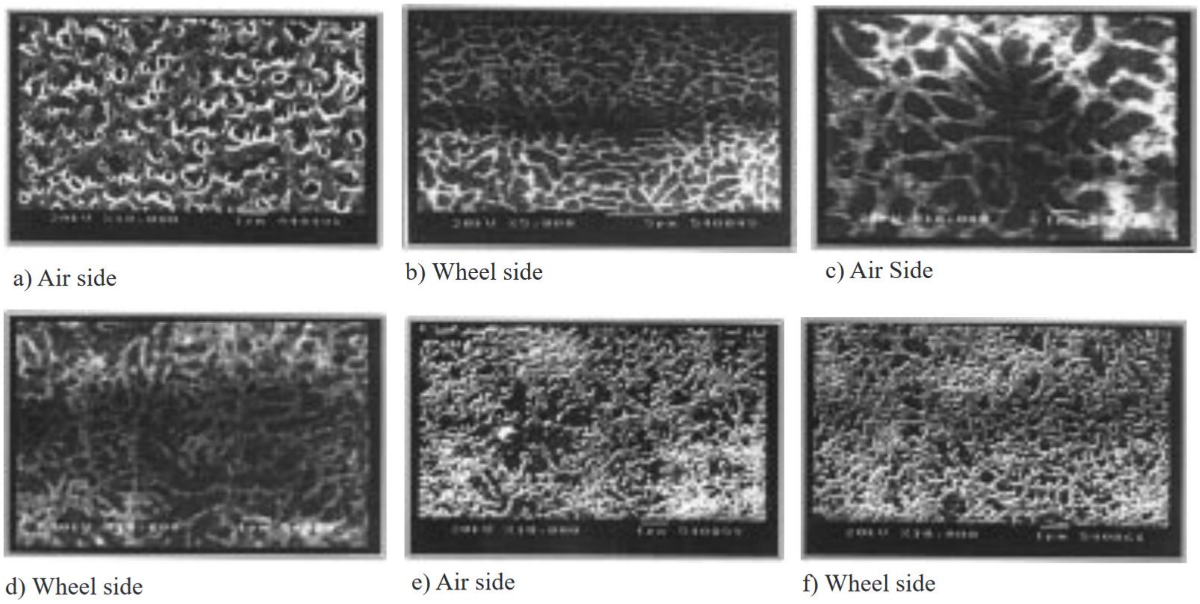
In this project, adding another drum to the rapid solidification process (RSP) is what is set to achieve. This way both sides of the molten will go through the drums and have fine microstructures. When the Al-Si alloys are melted and start to drip, before falling into the drums, the alloys are conventional, and will fall in the shape of a needle. To avoid the shape of that, quenching is required. Quenching occurs in RSP. This way, the alloys will no longer be in the shape of needles and will take the shape of ribbons. Chopping the ribbons and turning them into flakes, to be able to produce the required shape and further processors, is the step following the RSP.

1.2 Project Definition:

Melt spinning is a rapid solidification process that is used to produce refined, advanced, and new composite structures.The Rapid Solidification Process (RSP) usually uses one drum to produce the Al-Si material. Having one drum would produce inconsistent ribbons, where some of the ribbons could be damaged, as well as the molten itself, having one side (drum side) that is finer the other side (air side) because of not having contact with the drum. This project will require two rotating copper drums, and the melting system with a furnace.The system is consisted based on manufacturing design, where itmelts theAl-Simaterials in the form of ribbons, and heat transfer,that will occur between the melting system and the molten, where the furnace will provide a high amount of heat to melt the Al-Si materials to form the alloys. The reason it requires two drums, is to provide consistency in finishing, where the molten will have both sides go through the drums.

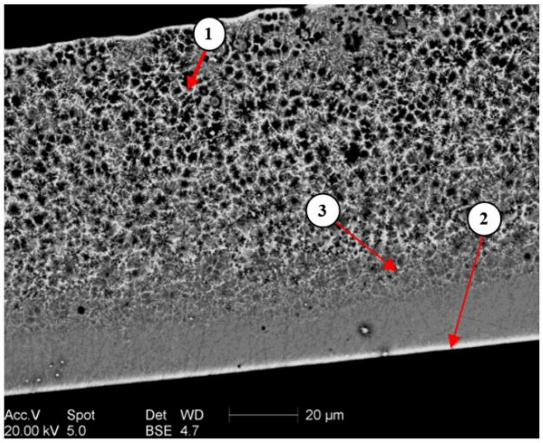
1.3 Problem Statement:

The microstructures of the ribbons produced by RSP were found to consist of sections in previously reported experiments[1, 25, 26, 27]. The drum side (wheel side) as shown in (**Error! Reference source not found.**,**Error! Reference source not found.**)and the air side (free side). Because of the effect of cooling, the drum side shows fine microstructures, while the air side shows microstructures that are coarser than the drum side. The fine and coarse microstructures were reported to collect separate sides during the HIPing process, as shown in**Error! Reference source not found.** [26].



a) Air side
b) Wheel side
c) Air Side
d) Wheel side
e) Air side
f) Wheel side

Figure 1 - Scanning Electron Microscope (SEM) micrographs of melt-spun (a, b) Al-8wt% Si (c, d) Al-12wt% Si (e, f) Al-16wt% Si alloys [1].



(1) Air side zone 2 coarse Si particles (2) Straight line (3) Wheelside zone 1 fine Si particles

Figure 2- Field Emission Gun Scanning Electron Micrograph (FEGSEM) backscattered micrograph of a Sample ribbon unetched (Al 21Si 3.9Cu 1.2Mg 2.4Fe 1.4Ni 0.4Zr) [26].

The best solution to this problem would be to eliminate the air side, where this can be done by introducing two drums.

1.4 Objectives:

•Designing a furnace to melt the Al-Si.

•Designing a melt-spinning prototype using two drums.

•Melting the Al-Si alloys to allow the RSP to take place

•Chopping the ribbons to flakes for various utilizations.

1.5Specifications:

Table 1

Item	**Type of Metal**
Inlet Nozzle	Cast Iron
Furnace inside the inlet nozzle	Heating Coil
Inner Furnace	Cast Iron
Outlet Nozzle	Cast Iron
Two Drums	Copper
Melt Spinning Cooling System	Copper
Ribbon Chopper	Copper

1.6Applications:

•This project will be useful to the department for educational purposes.

•Al-Si alloys would variously be produced, which will benefit automobile industries for the fabrication of engine blocks.

• Automobile industries could use the Al-Si alloys for decreasing fuel consumptions and emissions.

Chapter 2: Literature Review

In this chapter, Aluminum alloys and its element will be discussed. So will the Rapid Solidification Process, its effects on mechanical properties, its advantages, and the production methods of it will also be mentioned and clarified.

2.1 Aluminum Alloys:

In engineering structures, a wide range of properties are used with aluminum alloys. As a result of the components of the Al alloy, as well as the result of heat treatments and manufacturing processes vary widely with the strength and durability of Aluminum alloys.

Their fatigue strength is an important structural limitation of aluminum alloys. In contrast to steels, aluminum alloys do not have a well-defined fatigue limit, meaning fatigue failure will eventually occur even under the smallest cyclic loads. This means that engineers need to assimilate these loads and design a fixed life instead of an infinite life.

Their sensitivity to heat is another important property of aluminum alloys. Without first glowing red, aluminum will melt. Therefore, forming operations in which a blow torch is used requires some expertise; since no visual signs show how close the aluminum is to melt.

Like all structural alloys, aluminum alloys are also subjected to internal stress after heating, such as welding and casting. In this regard, the problem with aluminum alloys is their low melting point, which makes them more susceptible to distortions from the stress relief thermally induced[1].

2.1.1 Aluminum-Silicon (Al-Si) Alloys:

Al-Si casting alloys have been increasingly used in the automotive industry over the past decade as an appropriate alternative for cast iron in engine component manufacturing.The main advantage of Al-Si alloys, in addition to their high strength-to-weight ratio, is their excellent thermal conductivity, which allows the extraction of combustion heat faster than cast iron.In order to increase efficiency, the engine must increase the maximum operating temperature and pressure. The increase in operating temperature, which leads to the weakening of Al-Si hypoeutectic alloys, requires the strengthening of Al-Si alloys at high temperatures[3].

Al-Si alloys should urgently be used to reduce fuel consumption and gas emissions. To be able to use the Al-Si alloys in automobiles industries, the alloys must be improved by the optimization of the production process or the chemical composition. This well cause delaying the fatigue cracks and increase the lifetime of the materials [3].

Al-Si alloys are used extensively in the casting industry of aluminum alloys. Due to its low cost and increased cast fluid capacity, silicon is the most important additive to aluminum to improve its casting properties. Since cast aluminum in the automotive industry is widely used, this use of silicon is therefore the largest industrial use of metallurgical grade silicon, which is silicon that is highly pure (98% or higher)[2-4].

2.2 Alloying elements and their effect:

The addition of alloying elements to aluminum is the main method used to produce a selection of different materials that can be used in a wide assortment of structural applications.

If the seven designated aluminum alloy series used for wrought alloys are considered, which are based on the international alloy designation system, identification of the main alloying elements used for producing each of the alloy series will immediately occur. Furthermore, examining the effects of each of these elements on aluminum.

Commonly used elements and their effect have also been added.

Table 2

Series	Primary Alloying Elements
1xxx	Aluminum (Al) – 99% or more
2xxx	Copper (Cu)
3xxx	Manganese (Mn)
4xxx	Silicon (Si)
5xxx	Magnesium (Mg)
6xxx	Mg and Si
7xxx	Zinc (Zn)

2.2.1: Effects of Alloying Elements on Aluminum:

Copper (Cu) 2xxx: Typically, Al-Cu alloys contain between 2%-10% copper, with smaller additions of other elements. The copper delivers substantial strength and hardening increases. Copper insertion into aluminum can also reduce ductility and resistance to corrosion. Al-Cu alloys are more susceptible to solidification cracking; therefore, some of these alloys may be the most challenging to weld aluminum alloys. These alloys include some of the heat treatable aluminum alloys with the highest strength. Aerospace, military vehicles, and rocket fins are the most common applications for 2xxx series alloys[7].

Silicon (Si) 4xxx: Adding silicon to aluminum reduces the temperature of melting and increases fluidity. A non-heatable alloy is produced by silicon alone aluminum; however, it produces a precipitation hardening heat treatable alloy in combination with magnesium. Therefore, in the 4xxx series there are heat and non-heat treatable alloys. Aluminum silicon additions are commonly used to make castings. Filler wires for fusion welding and aluminum brazing are the most common applications for the 4xxx series alloys [6-8].

Magnesium (Mg) 5xxx: Adding magnesium to aluminum increases strength and enhances the ability to harden. These alloys are the non-heatable aluminum alloys of the highest strength. They are therefore widely used for structural applications. The alloys of 5xxx are produced primarily as sheets and plates and only occasionally as extrusions. The reason behind this is the rapid hardening of these alloys. They're hard and costly to extrude. The common applications for the 5xxx alloys are trucks and train carriers, construction vehicles, ship and boat construction, chemical tankers, pressure vessels and cryogenic tanks [6, 8].

Iron (Fe): Iron is the most common impurity found in aluminum. It is intentionally added to some pure 1xxx series alloys to provide an increase in strength [5].

Many aluminum alloys are used in today's industries. The Aluminum Association currently registers over 400 wrought alloys and over 200 casting alloys. One of the most important considerations of welding aluminum is, of course, the identification of the type of aluminum base alloy to be welded. If the type of base material of the component to be welded is not available through the reliable source, selecting appropriate welding procedures may be difficult. There are some general guidelines on the most likely type of aluminum used in various applications, such as the above. It is necessary to be aware, however, that incorrect assumptions concerning the chemistry of an aluminum alloy can have very serious effects on weld performance. Positive identification of the type of aluminum to be made and the development and testing of welding procedures to verify welding performance is strongly recommended.

2.3 Al-Si Phase Diagram:

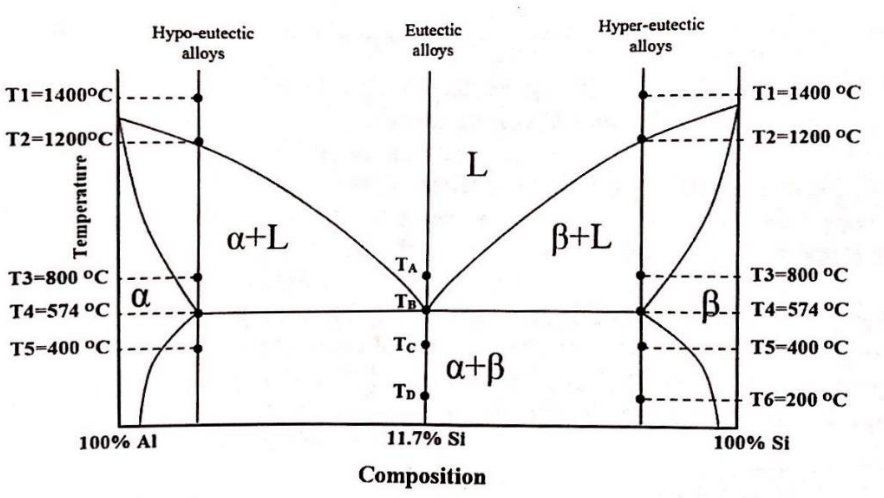


Figure 3 - Schematic of Al-Si Phase Diagram

At$T_1 = 1400^{\circ}\mathrm{C}$ in the Hypo-Eutectic:A mixture of Al and Si to place it on the left of the eutectic point by the alloy's overall composition. The alloy is initially at a temperature sufficiently high to ensure that the mixture is completely liquid. At the correct composition, the diagram is marked with an arrow and indicates the current temperature, which in this case is the starting temperature. The following circle gives a stylized representation of the microstructure of the alloy, which shows no interest since the alloy is liquid. It is called hypo-eutectic when the composition of an alloy places it to the left of the eutectic point.

At$T_2 = 1200^{\circ}\mathrm{C}$ in the Hypo-Eutectic: When the liquid line is reached, the mixture is slowly cooled, there is no change in state until it reaches temperature 1200℃. Here αbegins to solidify at any favorable nucleation sites, as the labeling suggests. It solidifies and dendrites, growing into it grains. The first solid to form is called the primary solid, where $\alpha$is formed in this case.

At$\mathbf{T_3 = 800°C}$ in the Hypo-Eutectic: The existing nucleation sites will grow as the alloy continues to cool and further nucleation sites will continue to form within the mixture's liquid parts. These nucleating and growing regions of solid alloy form grains and form the boundaries of grains when they meet. The primary α dendrites are growing, which accounts for the shapes in cross sectional samples of the α forms. As the remaining liquid cools its solid α composition also becomes richer in Si, as shown in the diagram of the phase. If cooling is not slow enough (i.e. non-equilibrium), then Si atoms can't diffuse into the centers of αgrains. If this is the case, coringwill happen.

At$\mathbf{T_4 = 574°C}$ in the Hypo-Eutectic: It removes Al and Si atoms from the remaining liquid as αsolidifies. For the most part, $\alpha$is Al (with a small amount of Si) and the remaining liquid in Si becomes relatively richer. This continues until enough AI has been removed to eutectically compose the remaining liquid–sliding down the liquid line. At 574°C, at the point where the temperature crosses the eutectic line, this composition will be achieved. At this point αstops forming as a discrete solid and the remaining liquid begins to solidify into the $\alpha$and βstripy (lamellar) eutectic composition. Hence solid forms of eutectics.

At$\mathbf{T_5 = 400°C}$ in the Hypo-Eutectic: The existing eutectic nucleation sites will grow, adding α to the α and βstrips in the eutectic regions to the βstrips. New sites are going to continue to form. Note that, unlike the α solidification, to achieve full solidification, it is not necessary to continue to lower the temperature. The eutectic liquid solidifies at a specific temperature in the same manner as a pure solid.

At$\mathbf{T_A = 800°C}$ in the Eutectic: Consider a mixture of elements Al and Si in their eutectic proportions at a high enough temperature to make the mixture fully liquid.

Each diagram is marked with an arrow at the eutectic composition and indicating the current temperature, the initial temperatures in this case. The circle below the diagram shows a stylized representation of the alloy's microstructure, which is showing no interest as the alloy is liquid.

At$T_B = 574°C$ in the Eutectic: The mixture is slow cooled, undergoing no change in state until it reaches temperature 574°C, where it starts to solidify at any favorable nucleation sites. Note that the alloy forms into "strips" which are alternate of $\alpha$and β. These layers are often only of the order of 1 micron across and the reason that the eutectic forms in this way can be understood by considering the diffusion times required to form the solid. The "stripy" microstructure is known as lamellar microstructure.

At$T_C = 400°C$ in the Eutectic: As the alloy continues to cool the existing nucleation sites will grow, adding $\alpha$to $\alpha$and $\beta$to β. These nucleating and growing regions of solid alloy will form grains. Grain boundaries occur where growing grains, which will be of differing orientations and form different nucleation site, meet. Further nucleation sites will continue to form within the liquid parts of the mixture. Remember though, this happens over a very short time scale and with no further decrease in temperature, not over a temperature range.

At$T_D = 200°C$ in the Eutectic: The entire mixture rapidly solidifies into a eutectic solid.

Looking at the phase diagram, the compositions of α and βchange with temperature.

By considering tie lines and the phase diagram,β has a decreasing proportion of Si in α decreases.

That means that even though the alloy is now solid, the composition of the stripes of α and βmust continue to change as it cools (to room temperature for example). Atoms of Al and Si will diffuse across these "stripes" to produce the equilibrium composition changes by diffusion, which is a slow process. It is important that alloys are allowed to cool at equilibrium of they are to be exactly eutectic composition.

At$\mathbf{T_1 = 1400°C}$ in the Hyper-Eutectic: A mixture of Al and Si so that the overall composition of the alloy places it to the right of the eutectic point. Initially, the alloy is at a high enough temperature to ensure that the mixture is fully liquid.

The diagram is marked with an arrow at the correct composition and indicates the current temperature, which is the start temperature in this case. The circle below gives a stylized representation of the alloy's microstructure, which is showing no interest as the alloy is liquid.When the composition of an alloy places it to the right of the eutectic point, it's called hypo-eutectic.

At$\mathbf{T_2 = 1200°C}$ in the Hyper-Eutectic: The mixture is also slow cooled, it is undergoing no change in state, until it reaches temperature 1200°C when the liquid line is reached. Here, as the labeling suggests, β starts to solidify at any favorable nucleation sites. It solidifies and dendrites, which grow to become grains to it. The first solid to form is called the primary solid, where in this case β is formed.

At$\mathbf{T_3 = 800°C}$ in the Hyper-Eutectic: As the alloy continues to cool the existing nucleation sites will grow and further nucleation sites will continue to form within the liquid parts of the mixture. These nucleating and growing regions of solid alloy form grains and when these meet grain boundaries are formed. The primary β dendrites grow, which accounts for the shapes the β forms in cross sectional samples. As the remaining liquid cools its composition of the solid βalso becomes richer in Si, as shown by the phase diagram. If cooling is not sufficiently slow (i.e. non-equilibrium) then Si atoms will not be able to diffuse into the centers of the grains of β. If this is the case, coring will occur.

At$T_4 = 574°C$ in the Hyper-Eutectic: As β solidifies it remove AI and Si atoms from the remaining liquid. β is mostly Si (with a small of AI) and so the remaining liquid becomes relatively richer in AI. This continues until enough Si has been removed so the remaining liquid – sliding down the liquid line – is of eutectic composition. This composition will be achieved at temperature 574°C, at the point where the temperature crosses the eutectic line. At this point β stops forming as a discrete solid and the remaining liquid starts to solidify into the stripy (lamellar) eutectic composition of alpha and β. Therefore, solid eutectic forms.

At$T_5 = 400°C$ in the Hyper-Eutectic: The existing eutectic nucleation sites will grow, adding α to the strips of α and β to the strips of β in the eutectic regions. New sites will continue to form. Note that, unlike the β solidification, it is not necessary to decrease the temperature to achieve full solidification. The eutectic liquid solidifies in the same way as a pure solid, at a specific temperature.

At$T_6 = 200°C$ in the Hyper-Eutectic: The entire alloy has now solidified into a mixture comprising grains of β and grain of eutectic mixture ($\alpha \& \beta$).

The diffusion processes through the solid, which occur as the alloy cools, are more complex than those of the eutectic case. As with a eutectic alloy, the amount of Al in the βphase changes with temperature. Also, Al will have to diffuse through the β. This diffusion must also occur in the grains of pure β, as the composition of β also changes. This can be seen by examining the diagram.

2.4 Rapid Solidification Process:

The rapid solidification process is one of more than 30 other techniques presented and have been discussed in a manner which will aid the user in selecting a method appropriate to his needs. Many processes have been successfully applied to a wide variety of metal and alloy systems, with every indication that expanded use will continue to be seen in the future. Rapid Solidification Technology (RST) in the most general view,involves processes that take metals and alloys from the liquid, vapor, or plasma state to the solid state in a few milliseconds. This produces materials that are solidified at rates in the vicinity of 106 degrees per second. The primary feature of "Rapidly Solidified" RS materials is that properties are significantly different, and often better, than a conventionally processed material of the same composition. These features are significant because they enable the development of new alloy compositions and microstructures [10].

RST's art and science is barely 55 years old, having started with Pol Duwez's work in the late 50s and early 60s at the California Institute of Technology, his technique is shown in (Figure 5). RST has a significant impact on technological developments despite the recent emergence. The criterion for rapid solidification is is somewhat arbitrary, but normally it means that in a very short time, usually milliseconds, the temperature of a molten material is reduced to a certain value well below the freezing point. This can give rates of change of temperature of $10^2, 10^6$, and even as high as $10^{10} C/s$ [10-13, 14, 15].

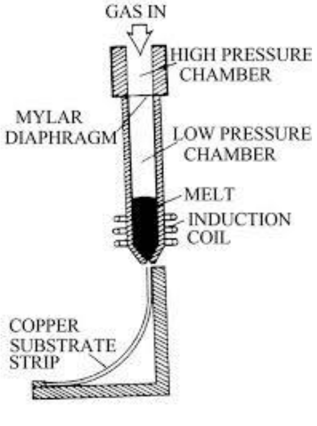


Figure 4 - Gun Technique of Duwez for Rapid Solidification of Melt [13]

It allows the production of amorphous (glassy) metallic ribbons. The lack of atomic long-range order leads to superior soft magnetic properties. The main effect of such rapid cooling is to suppress the atom diffusion movement in the quenched material. In many cases, in such a short time, the atoms go from high mobility in the molten state to relative stability in the solid state that they cannotreach the equilibrium (lowest energy) crystal sides they would normally occupy in a more conventional, slowly cooled material.

Some amorphous compositions can be transformed into nanocrystalline materials through a special annealing treatment. Amorphous and nanocrystalline soft magnetic alloys are the foundation for many innovative applications such as magnetic pathways, inductive components or electronic article surveillance (EAS) labels[10-13, 14, 16].

2.4.1 Effects of Rapid Solidification on Mechanical Properties:

Due to microstructural refinement, rapid solidification has improved the mechanical properties of metals. The yield stress and hardness of bulk metallic glasses (BMGs) can be twice as those of steels. They also display more elastic strain and fracture toughness of than ceramics and less brittle than conventional oxide glasses. It shows that the mechanical properties for the BMGs are significantly different from that for the crystalline alloys [1, 10-13, 14, 17, 18].

The RSP provides improved structures and consequently improved properties in two main ways [15, 19, 20, 23]:

1- Production of refined structures are more homogenousmaterials(e.g. by producing fine dendrites and eutectics or by reducing and eliminating the segregation of intercellular and interdendritic alloys).

2- Production of new alloy compositions, microstructures, and phases (e.g. Extended solid solubility, new phase reaction sequences and microstructure of metallic glass).

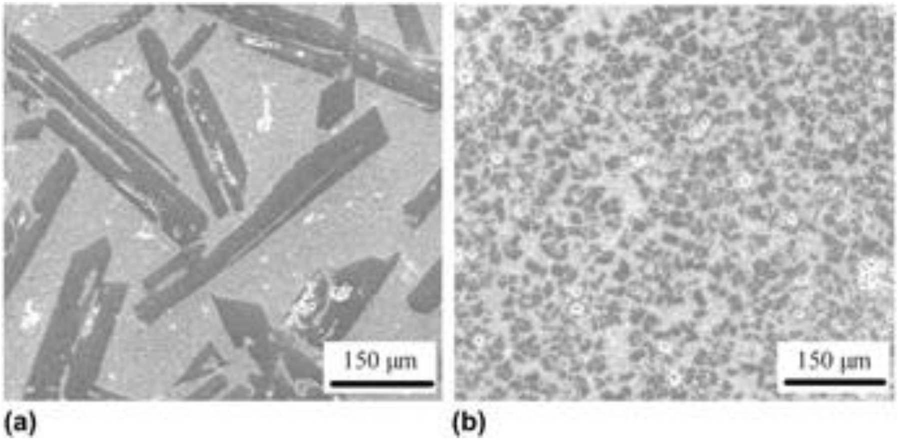


Figure 5 - (a) primary Si in Al-Si alloy by conventionally cast. (b) uniform Si in Al-Si alloy by rapid solidification [21].

Figure 5 - (a) shows the primary Si in Al-Si Alloy by conventionally cooling routes. The primary Si has a cuboidal form which can be seen in the micrograph. However, the mixture is non-lamellar in shape and appears to consist of separate flakes in section (although studies have shown that the flakes are actually three-dimensional interconnected). These coarse Si flakes promote fragility within these alloys, making them less expensive to cast. To be of any great use to these alloys, we must somehow improve their properties and deal with the brittle Si flakes. The RSP is the best option to avoid these flakes. It makes the Si particles uniform, homogeneous and reduced size of the dendrite as shown in Figure 5- (b) [14, 21].

2.4.2Advantages of rapid solidification process:

The major effects of rapid solidification are [10-13,14, 16, 22]:

1. Grain size generally decreases as the solidification rate increases.

2. Chemical homogeneity generally increases as the solidification rate increases.

3. Extension of solid solubility generally increases as the solidification.

4. Metastable crystal structures, many previously unreported, are often created.

5. Crystal structures of certain classes of alloys can be completely suppressed, and a new class of materials- metallic glasses -can be created.

6. Retention of non-equilibrium crystal structure.

2.4.3 Limitation of rapid solidification process:

The following show some limitations of the rapid solidification process [10-13, 17]:

1. Need to safely handle for rapid solidification products.

2. Sample dimensions achievable during processing restrict the application of BMGs as structural materials and also prevent detailed studies mechanical properties under different loading conditions.

3. Brittleness at ambient temperature: monolithic BMGs, without crystalline structure, dislocation contribution to ductile deformation is impossible, usually they exhibit very limited globe plasticity at room temperature.

4. It has a very limited plasticity before fracture at room temperature.

2.4.4Production Method of rapid solidification process:

There are various methods of rapid solidification processes. Each method has a different technique and a different application.This project will specifically use the melt spinning method.

2.4.4.1 Melt Spinning:

Melt spinning uses a liquid metal jet, which is extruded by an orifice. However, solidification is achieved in melt spinning when the molten jet impinges on a rotating solid substratum surface. Early spinning experiments have been performed with a rotating water-cooled metal disk acting as a substratum. Filaments are usually made several mm wide and as thin as 25 pm (Figure 7).

There are several variations in melt spinning that involve rotating wheels, belts, and other substrates that yield filaments, flakes, or powders.

Melt spinning is also used on a laboratory scale because the equipment is easy to build and operate, compact, and doesn’t require a large capital outlay. The filaments which are produced are continuous and generally experience high quench rates. Uniform filament production requires good control of the liquid metal stream; thus, like melt extrusion, great emphasis has been placed on the liquid metal jet's stability. In free flight spinning, the size of the orifice controls the diameter of the fiber produced. The main advantage of this technique is the simplicity of the principle concerned, although parameters are required for liquid jet stability. To this end, strict control of operating velocities (several meters per second) is required for relatively high extrusion.

Melt spinning can be used to produce wires of between 100 and 500 microns in diameter, as well as thin ribbons of up to several centimeters in width[10-13, 17, 19, 23].

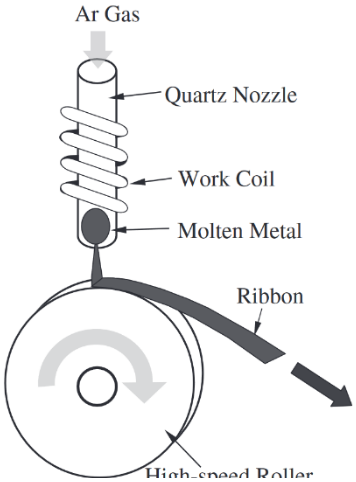


Figure 6- Schematic of the melt spinning process [17].

Chapter 3: System Design

In this chapter, the design of the project will be displayed and discussed. The chapter will present details about the chosen materials, the theories, and the theoretical calculations used to approach the project.

3.1 Design Constraints and Methodology:

3.1.1 Geometrical Constraints:

Difficulties were faced while designing and planning for the project.The unavailability of some of the parts needed to build the prototypecaused a lot of delays.The copper drums with an opening for placing the cooled water was a huge conflict for a couple of local manufacturing shops. Eventually, a local shop was found to fulfill the requirements,yet the quality of the copper drum was not as expected, which could affect the performance of the smoothness in rotation. Another issue was how fast we could make the copper drum rotate. The RSP required a lot of speed to allow the molten to immediately quench and become solidified. Due to the high cost of reaching this speed, experiments were made to allow the drums' rotating speed to reach its requirement depending on the size of the prototype.Minimizing the weight of the system was a huge issue to consider as well.The system's weight should be minimized as a much as possible to allow transporting the prototype easily.

3.1.2 Sustainability:

A problem in terms of sustainability due to chance of gettingcorrosion could occur. Because mostof the equipment of the prototype are metallic materials. To avoid this problem, we used coating to prevent the metal components from corrosion.

3.2.3 Environmental:

Considering the environment is necessary. The purpose behind using Al-Si alloys is to decrease the consumption of fuel and gas emissions. This will cause a decrease in pollution. Using these alloys in the automotive industries certainly help the environment.

3.2.4 Social:

The modification of this process will benefit theAutomotive, Aerospace, and Manufacturing industries. It will allow these industries to use this process to create engine blocks, pistons, and many other parts required for these industries.

3.2.5 Economic:

This project will help decrease the waste of material by reusing the wasted material. It will also further decrease thermal expansion, and allow manufacturers in Automobile industries to develop material.

3.2.6 Safety:

Lubricating the Gears is very important, adding grease to the gears will give a fine result, without adding grease, damage will occur to the gears du to friction. Adding water to the drums will allow the copper drums to cool and allow the process to succeed, without adding water, the molten could stick to the drums and shafts, this will lead to failure in the process.

3.2.7 Ethical:

The project has no similar work done previously. We have modified the project based on previous researches about melt spinning, which without it, the project wouldn’t have been made nor thought of.

3.3 Systems and Selection of Components and Assemble:

3.3.1 Body:

The Description of Aluminum 5052 is an Aluminum Magnesium alloy which can be hardened by cold work: it is not heat treatable to higher strength. It is about mid-way through the series of Aluminum Magnesium alloys for alloying content and strength. It has excellent fatigue properties, with an endurance limit of 115 MPa in the H32 temper and 125 MPa in the H34 temper. Machinability 5052 is readily machinable by conventional methods. It should be machined at high speed with copious lubrication to avoid thermal distortion of the workpiece. Sharp tools are essential. High speed steel or tungsten carbide may be used. Cuts should be deep and continuous, with high cutting speeds. Woodworking machinery may be suitable for short runs.

3.3.2 Gears:

AISI 4140 Chrome - Moly High Tensile Steel, generally supplied hardened and tempered to Condition “T” in sections up to 100mm, with a tensile strength of 850 – 1000 MPa and aiming for this strength range in larger sections. It offers a very good balance of strength, toughness and wear-resistance.

3.3.3 Shaft:

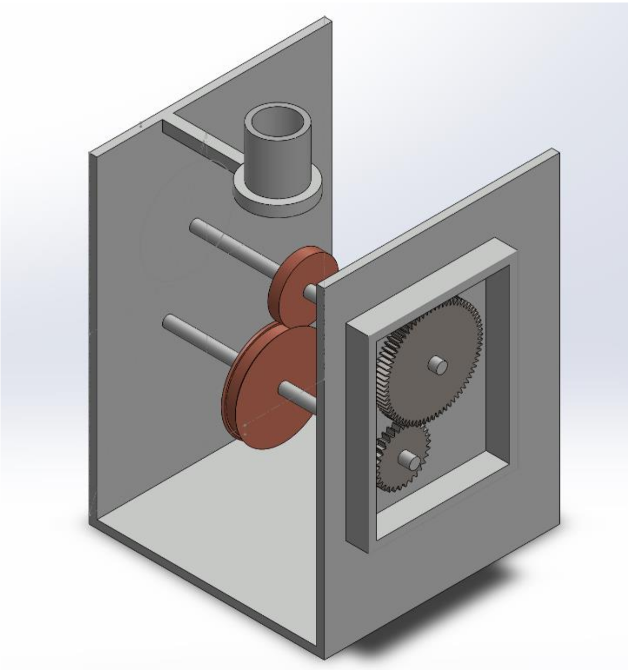
Carbon steel is available as bright drawn key steel in flat and square sections. With medium tensile strength key steel is used widely in general engineering for components such as plain, gape head, taper and parallel keys. Key steel is produced to the required tolerances as specified in British Standard BS46 and BS4235.Carbon spring steel specifications EN42, CS70, CS80, CS95 and CS100 are available as hardened and tempered spring steel strip, annealed spring steel strip, spring steel plate and spring steel sheet. EN43 spring steel is available in bar and plate. The grades commonly conform to BS970, BS1449, BS EN10083-1, BS EN10083-2, BS EN 10277 and BS EN 10278 standards.X120Mn12 1.3401 is a manganese steel with 1% carbon steel and an 11% to 14% manganese content supplied in plate. Offering excellent work hardening properties high manganese steel can be supplied in full plates or cut to your requirements.

3.3.4 Drums:

Tiger Bronze is a versatile, all-purpose bronze bushing slim}.f that can be sassily machined down to a wide array of machined parts, component, bushing. Bronze sleeve and guide. Pressure tight properties make this the ideal bronze for marine application or pump and value parts. Tiger Bronze is very cost efficient 1with a wide selection of sizes {over? SUU standard sizes} combined with moderate strength. Easily machined and adapts to prevailing shaft condition makes this the workhorse among bronze bushing alloys. Tiger Bronze is the preferred bronze alloy replacement for OEM machine parts due to its versatility Reliability.

3.3.5 Assemble:

The project was successfully manufactured in Riyadh. With a team of eight hard working members, and with CNC machines that helped with the specific detailed finishes, the project was manufactured as designed and accomplished its purpose with a great result.



3.4 Engineering Standards

Table 3 - Engineering Standards

Component	Standards
Body	Aluminium 5052
Gears	AISI 4140
Shafts	B S46
Drums	A STM B505
Electrical Motor	YC712-4

Figure 7-Pictures of The Body

Figure 9- Gears

Figure 8- Copper Drums

Figure 11- Cast Iron Nozzle

Figure 10-Shaft

Figure 12-Electrical Motor

3.5 Engineering calculations

Torque being transmitted if a certain amount of axial force is being applied. Also, we need to determine the dynamometric force which would be essential enough to produce about 5-10% significant losses in torque and speed transmission which would allow us to apply an external force via motor.

Theoretically, we can use the following formulas,

1. **Torque= Force*perpendicular distance (**from the center axis to the point of action of force**)**
2. **Power=(2*pi*N*T)/60**

Where **N** is the number of rotations per minute and **T** is torque

The unit of torque is **Nm.**

Electric Motor - Torque vs. Power and Speed

0.75 *power (kW)*

1680 *speed (rpm)*

Torque (Nm) = 4.26

The torque delivered from an electrical motor producing *0.75 kW (750 W)* at speed *1680 rpm* can be calculated as

$$T = (750\ W)\ 9.549 / (1680\ rpm)$$

$$= \underline{4.26}\ (Nm)$$

Electrical Motor Efficiency when Shaft Output is measured in Horsepower

If power output is measured in *horsepower (hp)*, efficiency can be expressed as

$$\eta_m = P_{out}\ 746 / P_{in}$$

Where

P_{out} = *shaft power out (horsepower, hp)*

P_{in} = *electric power in to the motor (Watt, W)*

In our case our efficacy is obtained by the supplier which is close to 91%

The shaft power produced by an electric direct current motor with *36 V, 91%* efficiency and *5 amps* - can be calculated in *watts* as

$$P_{shaft\_kW} = 0.91\ (36\ V)\ (5\ amps) / 1000$$

$$= \underline{0.1638}\ \ kW$$

$$= \underline{163.8}\ W$$

Mechanical Losses

Mechanical losses includes friction in the motor bearings and the fan for air cooling.

Shear Stress and Angular Deflection in a Solid Cylinder

A moment of *1000 Nm* is acting on a solid cylinder shaft with diameter *10 mm (0.10 m)* and length *100 mm*. The shaft is made in steel with modulus of rigidity *79 GPa* ($79\ 10^9$ *Pa)*.

Maximum shear stress can be calculated as

$$\tau_{max} = T\ r / J$$

$$= T\ (D / 2) / (\pi\ D^4 / 32)$$

$$= (1000\ Nm)\ ((0.10\ m) / 2) / (\pi\ (0.10\ m)^4 / 32)$$

$$= \underline{266643231}\ Pa$$

$$= \underline{26.6}\ MPa$$

The angular deflection of the shaft can be calculated as

$$\theta = L\ T / (J\ G)$$

$$= L\ T / ((\pi\ D^4 / 32)\ G)$$

$$= (0.10m)\ (1000\ Nm) / ((\pi\ (0.10\ m)^4 / 32)\ (79\ 10^9\ Pa))$$

$$= \underline{0.021}\ (radians)$$

$$= \underline{1.2}\,^{o}$$

Chapter 4: System Testing and Analysis

In the chapter, the results of the project will be discussed and the approach to experiment the prototype well also be mentioned.

4.1 Experimental Setup and Testing:

The usageof safety boots, gloves that withstand heat, and safety glasses so that the molten metallic wouldn't cause harm when testing. The prototype was set at an open area in the garage where there is electricity toplug the motor that supplies power to the shaft. Then heated the molten metallic to pour it down on the bigger drum with 15 radius that rotates at high speed with 1680 rpm and when pouring it down it goes through the other drum (8 radius) and then by quenching by pre-cooling the drum before the testing. The molten metallic goes through two drums and it goes out as a solid material. It didn't go well for 3 times because more heatingto the material was required, so it can become completely melt and go through the nozzle above the big drum. The power supplier was burnt because it couldn't take the heat.

4.2 Results, Analysis and Discussion:

4.2.1 Results and Analysis:

The Rapid Solidification process was successfully achieved. It went through the drum and solidified immediately and smoothly. The quenching occurred, the molten switched from a liquid phase to a solid face within less than a second. The molten took the shape of ribbons, and some took the shapes of flakes as well, which is the objective of the project. (Figure 13- a) The Lead wire before Melting b) Flakes produced from the RSP)

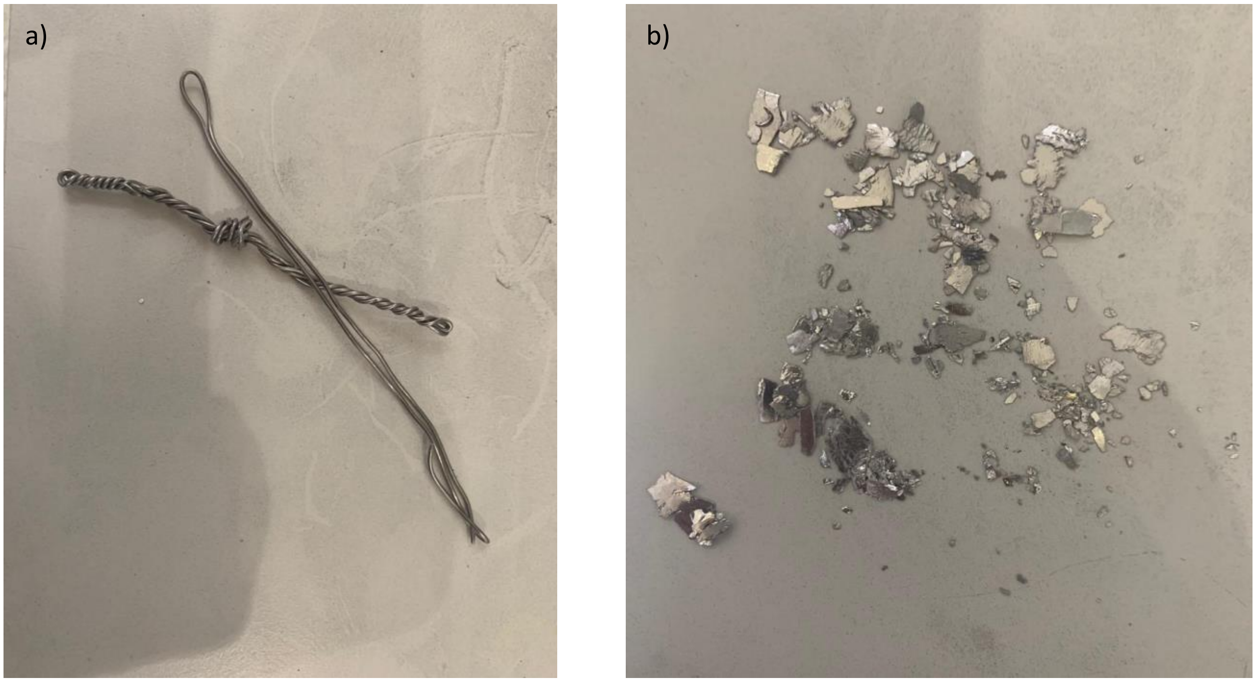


Figure 13- a) The Lead wire before Melting b) Flakes produced from the RSP

4.2.2 Discussion:

The solidification resulted in increasing the strength of the material, increasing ductility, and reshaping the material with a thickness of 1mm. further test must occur to view the microstructures of the material to provide more results to discuss.

The material was very light before quenching, it had the same thickness before and after the process. The increase in strength and toughness of the material was obvious, it can be seen with the naked eye, and can be felt as well. The quenching was successful with this result. The ductility of the material increase, before the material was quenched, bending the material would cause to break with the slightest force. After quenching the material, the force needed to break the material was twice as much. This proves that the addition of another drum into the melt spinning process has developed the material as targeted.

Chapter 5: Project Management

In the chapter, how the project was planned and how it was achieved with the contribution of each member.

5.1 Project Plan:

The project comprises of various tasks that are assigned to each group member in an equal manner, to ensure fairness between the members. Each member was given a specific task that needed to be completed within a certain amount of time. The times and dates listed in the Gantt

	Start Date	Days to Complete	Student Responsible
Task 1			
Defining The Project	28/1/19	3	Everyone
Identifying and detemining Objectives	28/1/19	2	Everyone
Group Meeting to Divide Tasks	2/2/19	1	Everyone
Working on Divided Tasks	2/2/19	2	Everyone
Task 2			
Group Meeting to Collect Information	2/4/19	1	Everyone
Writing First and Second Chapter	2/4/19	2	Mohammed Hassanein
Reviewing Progress with the Advisor	2/6/19	1	Mohammed Hassanein
Editing the Written Chapters if Required	2/6/19	1	Mohammed Hassanein
Submitting First and Second Chapter	7/2/19	1	Mohammed Hassanein
Task 3			
Designing the Project	8/2/19	4	Mohammed Al Muraisel
Preparing The Presentation	14/2/19	2	Everyone
Practicing for the Midterm	16/2/19	1	Everyone
Ordering Requirements and Parts	17/2/19	14	Adeeb AlAnazi
Task 4			
Working on Divided Tasks	18/2/19	5	Everyone
Group Meeting to Collect Information	23/2/19	1	Everyone
Writing Third and Fourth Chapter	24/2/19	6	Mohammed Hassanein
Reviewing Progress with the Advisor	3/2/19	1	Mohammed Hassanein
Editing the Written Chapters if Required	3/2/19	1	Mohammed Hassanein
Collecting the Ordered Material	3/3/19	2	Adeeb AlAnzi
Task 5			
Preparing The Presentation based on updates	3/3/19	2	Mohammed Al Muraisel
Practicing for the Presentation	3/5/19	3	Everyone
Preparing the Prototype	3/8/19	8	Everyone
Testing the Prototype	16/3/19	1	Everyone
Distinguishing Any Problems in the Prototype	16/3/19	1	Everyone
Fixing the Problems and Re-Testing The Prototype	16/3/19	3	Everyone
Task 6			
Group Meeting to Collect Information	19/3/19	1	Everyone
Writing Fifth and Sixth Chapter	19/3/19	7	Mohammed Hassanein
Reviewing Progress with the Advisor	26/3/19	1	Mohammed Hassanein
Editing the Written Chapters if Required	26/3/19	1	Mohammed Hassanein
Preparing The Presentation based on updates	27/3/19	4	Mohammed Al Muraisel
Practicing for the Presentation	31/3/19	2	Everyone
Printing and Preparing the Required Form of Submission	4/2/19	1	Adeeb AlAnazi
Task 7			
Finalizing The Material		2	Mohammed Hassanein
Editing The Data if Required	4/5/19	1	Mohammed Hassanein
Final Preperation for the Presentation	4/6/19	3	Everyone
Reviewing Progress with the Advisor	4/9/19	1	Mohammed Hassanein
Editing The Data if Required	4/9/19	1	Mohammed Hassanein
Submiting the Final Data	14/4/19	1	Mohammed Hassanein

Chart were followed to ensure consistency and quality of the work done by the group members.

5.2 Challenges and Decision Making:

Every task has its challenges. We faced a great deal of challenges and setbacks while our project was in its developing stages. From designing, up to assembling and testing, the issues we faced were a great setback to the progress of the project, but in spite of these obstacles, with proper guidance from the advisor and regular group meeting these setbacks were resolved.

5.2.1 Manufacturing the Prototype:

The prototype required CNC machines to be able to finish specific details. Finding a workshop with CNC machines with the price range the group has set, was difficult, and was not accomplished. The prototype was manufactured in Riyadh. There was a delay in manufacturing the prototype due to the unavailability of some parts. Parts were taken from Khobar and Riyadh, and the transportation took a lot of time.

5.2.2 Inserting Water into the Shafts:

This process requires shaft seals and a cooling pump, which pumps cold water continuously into the shafts. The smallest size of the shaft seals available was 1 inch, the diameter of the shaft was 25mm, finding a shaft seal with this size was not possible according to the time given.

5.2.3 Rotating Speed:

The project required a minimum of 800 rpm for the drums. That required a bigger motor with higher rotating speed. The motor that was provided had 1680 rpm, with the gear box dropping the speed by dividing the speed by seven.

Equation 1-Rotating Speed

$$\frac{1680}{7} = 240\,rpm$$

The gear box was the only one found, with a reduction rate of 7. This caused a huge decrease in the rotating speed of the drums.

5.3Contribution of Team Members:

Each member's contribution and their willingness to work was discussed in our first meeting as a team, and the tasks were divided and agreed upon by each member. Table 4-Contribution Tableshows how much work each group member contributed, as a rough percentage.

Table 4-Contribution Table

Task	Assigned Member	Contribution
Chapter 1: Introduction	All Members	100%
Chapter 2: Literature Review	All Members	100%
Chapter 3: System Design	Mohammed Al Naeem & Mohammed Hassanein	50% Each
Chapter 4: System Testing & Analysis	Adeeb Al Anazi	100%
Chapter 5: Project Management	Mohammed Al Naeem	100%
Chapter 6: Project Analysis	Mohammed Hassanein	100%
Chapter 7: Conclusion &	Mohammed Al Muraisel	100%

Future Recommendation		
Parts Purchased	Mohammed Hassanein Adeeb Al Anazi Mohammed Al Muraisel Mohammed Al Naeem	40% 20% 20% 20%
Manufacturing	Mohammed Hassanein Adeeb Al Anazi Mohammed Al Muraisel Mohammed Al Naeem	40% 20% 20% 20%
Testing	All Members	100%

5.4 Project Bill of Materials & Budget:

Table 5- Project Bill Table

Material	**Cost**
Body	3200SR
Shafts	600SR
Gears	450SR
Nozzle	100SR
Motor	1200SR
Molten material	100SR
Safety gadget	150SR

Chapter 6: Project Analysis

In this chapter, the Project analysis will be mentioned, including its effect on the economy, the environment, and many other factors.

Project Analysis

6.1 Life-Long Learning

We had believed in our minds while starting to work on our project and that was to accomplish all the targets we set at the beginning of the semester. Wewere, of course, inclined to just use software and hardware to complete it by consuming our time in a very competent way. In regards, to achieve all these thin

In addition, in order to achieve all of these things, we had to arrange and impose a pre-arranged schedule that really provided us with an improvement in every aspect that we worked o n and we would like to share some of that experience.

6.1.1: Software Skills:

We first referred to certain websites online when designing our prototype and then tested the constraints on Solid-Works Simulation. We designed and simulated the necessary components for our project to ensure a suitable process in line with our material needs that are sufficient to withstand our system in order to be able to operate efficiently. It all went very well with the group’s contribution and support since each member was able to solve an obstacle more rapidly depending on the way they thought. Correspondingly, we utilized Microsoft Excel to exhibit the charts and graphs displaying our experimentation data.

6.1.2: Hardware Skills:

To conduct a performance test of our system, we utilized a weight Scale to measure the force applied and a Tachometer to measure the rotational velocity of the shaft. Having sufficient background knowledge about forces and rotational speed. The Dynamometer we installed gave us the values of torque with the help of the industrial gears shaft. The actuators installed were tasked with engaging and disengaging the nozzle and the other was installed linearly to the shaft to apply an axial force. Both gears were operational with the use of the motor we purchased for the project.

6.1.3: Time Management:

We had about three months of total time to complete the project, we really needed to manage our time efficiently so that we could face unforeseen difficulties and obstacles in advance. Fortunately, all group members were in close contact and when making decisions, everyone was on the same page, which really helped to cut time and make effective use of it.

6.1.4: Project Management:

We needed a very complicated plan to follow our project step by step, to complete the entire schedule. Tasks were assigned based on the most convenient time schedule available to each group member; this was accomplished through weekly meetings with all group members. Thankfully, he kept us alert at all times to our very humble group leader and this mutual communication.

6.2 Impact of Engineering Solutions

6.2.1: Society:

We started the RSP Technology Modification Project, which developed some revolutionary AL-SI alloys that meet the specific needs of this market. Materials have been specially developed for pistons, suspension components, fasteners and hydraulic parts, for example, which can withstand extreme demands.

Because every second and every gram counts in the racing industry, it follows logically thatMany racing teams have selected RSP Technology as their partner for special materials development.

We add the other drum so that the specific composition of the alloy and its fine microstructure, the RSP material will be stronger at higher temperatures, has a lower specific gravity, enabling the design of a lighter piston resulting in higher motor efficiency. Also, the piston can be designed to have less play when fitted, which improves the motor's performance. Furthermore, we consider that developing microstructure because RSP material is used as a replacement for titanium in the orthopedic industry, which is heavier and more difficult to work on. These titanium components are frequently used in other medical devices for external prostheses

. <u>6.2.2: Economy:</u>

Economically, each part used in the assembly of our prototype was found in Riyadh, Subsequently, most of the parts were affordable excluding the gears and shafts which was machined by CNC. They were more expensive due to them being made of the CNC which is cost by the hour. This shows that this project need lots of searching and team work because it’s not easy to manufactured. Moreover, there is no complexity when it comes to operating this process, it is very easily operated and gives immediate results.

Chapter 7: Conclusion

In this chapter, the conclusion of the project will be stated, with future recommendations of how to achieve a more successful project.

7.1 Conclusion:

Everything considered, the goals above were accomplished.The misfortunes were at two points, the first misfortune was the difficulty in finding a manufacturing shop because the prototype requires CNCmachines that will provide fine finishes and specific details in the design. It wasn't easy to find a shop that had CNC machines. The second problem is the lack of time given to do research and design the prototype, but thankfully the project was successfully completed.The target of developing material was achieved. Generally, the hypothesis and goals were effectively cultivated which, at the outset, appeared a removed accomplishment bound to be jumped with disappointments and disasters. Be that as it may, by a legitimate submitted and capable cooperation between our gathering. We had the capacity to accomplish what we had defined as an objective in the beginning of the semester. The project was successful, effective, and have developed Al-Si material that will certainly be applicable in Automotive industries.

7.2 Future Recommendations:

The responsibilities given were completed and achieved; though there was shortage in equipment that were difficult to provide. Heating coils with high heating temperatures (+800℃) must be acquired to be able to allow Al to reach the melting temperature. The nozzle should have at least a 4mm outlet hole to allow the molten to fall smoothly on the copper drums. The gear base must be repositioned due to changes that provided better results. Finally, continues lubrication is needed and quite necessary.

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