Fabrication of Pinion Gear for Power Window of a Car through Powder Metallurgy Technique

by

Nur Syahadah binti Jamaludin

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

(AP DR PATTHI BIN HUSSAIN)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NUR SYAHADAH BINTI JAMALUDIN

ABSTRACT

Powder Metallurgy (P/M) is a long standing business that grew at a rapid rate from the 1980s. Much of its growth derived from powder-based parts replacing castings, forgings, and machined parts. The industry demonstrated that it could meet the needs of manufacturers but at a lower cost. More than 73% of all P/M parts are sold to the automotive industry. P/M is useful in making parts that have irregular curves, or recesses that are hard to machine. It is suitable for high volume production with very little wastage of material. Secondary machining is virtually eliminated. Typical parts that can be made with this process include cams, ratchets, sprockets, sintered bronze and iron bearings (impregnated with oil) and carbide tool tips. P/M could potentially become an industry with saturated markets and grow mainly by acquisition or increasing market share. Though P/M technology has been widely used in automotive industry in many countries such as the United States, this technique is still new and not yet developed in Malaysia. Thus, this project is carried out to fabricate pinion gear for power window of car through P/M technique. The aim of this project is to optimize the P/M technologies so that it can be implemented in Malaysian automotive industry in future. The scope of works covers literature review, copy drawing of existing pinion gear, fabricate die and mould of pinion gear, fabricate gears using P/M, conduct laboratory test and communicate the findings.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Powder metallurgy uses sintering process for making various parts out of metal powder. The metal powder is compacted by placing in a closed metal cavity (the die) under pressure. This compacted material is placed in an oven and sintered in a controlled atmosphere at high temperatures and the metal powders coalesce and form a solid. A second pressing operation, repressing, can be done prior to sintering to improve the compaction and the material properties. [1]

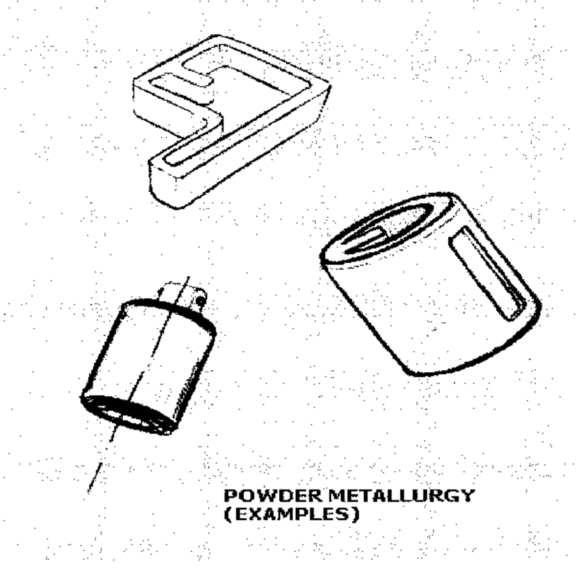


Figure 1.1: Products of P/M [1]

The properties of this solid are similar to cast or wrought materials of similar composition. Porosity can be adjusted by the amount of compaction. Usually single pressed products have high tensile strength but low elongation. [1]

These properties can be improved by repressing as in the following table. [1]

Material	Tensile MPa (psi)	Tensile as Percent of Wrought Iron Tensile	Elongation in 50 mm (2 in)	Elongation as Percent of Wrought Iron Elongation
Wrought Iron, Hot Rolled	331 (48,000)	100 %	30 %	100 %
Powder Metal, 84 % density	214 (31,000)	65 %	2 %	6%
Powder Metal, repressed, 95 % density	283 (41,000)	85 %	25 %	83 %

Table 1.1: Properties of Metal Solids

The advantages of the powder metallurgy technique are:

- Machining operations are almost eliminated
- Close dimensional can be maintained
- A high rate of production may be achieved by cutting down production time, and
- It is possible to ensure uniformity of composition and structure by controlled conditions of working.

The disadvantages and limitations are:

- The size of the product is limited as it depends upon the capacity of the press and compression ration of the powders,
- Complicated shapes are difficult to attain due to the low flow ability of metal powders
- This technique is not economical for small-scale production.

PROBLEM STATEMENT

1.2.1 Problem Definition

Powder Metallurgy (P/M) is a long standing business that grew at a rapid rate from the 1980s. The industry demonstrated that it could meet the needs of manufacturers but at a lower cost. More than 73% of all P/M parts are sold to the automotive industry. Though P/M technology has been widely used in automotive industry in many countries such as the United States, this technique is still new and not yet developed in Malaysia. Thus, this project is carried out to design and fabricate pinion gears for power windows of car through P/M technique as resemblance of significance of this technique to be developed and established in Malaysia automotive industry.

1.2.2 Significant of the project

The aim of this project is to optimize the P/M technologies as resemblance of its high potential so that it can be implemented in Malaysian automotive industry in future.

1.3 OBJECTIVE

The objectives of this project are:

1.3.1 To fabricate the pinion gear through powder metallurgy technique.

1.3.2 To study the microstructure P/M product based on the fabricated pinion gear.

1.3.3 To apply knowledge, expanding thoughts, solving problems independently and presenting findings through minimum guidance and supervision.

1.4 SCOPE OF STUDY

For this project, generally the scopes of works are:

1.4.1 Literature review

Further details on powder metallurgy, automotive industry, pinion gears and other related topics are to be obtained from this activity.

1.4.2 Fabrication of die and mould

Fabrication of the pinion gear will be based on reverse- engineering technique as the pinion gear will be fabricated using powder metallurgy technique based on the existing model of power window system, specifically of Toyota car.

1.4.3 Fabrication of pinion gear

As the die and mould ready, the mixture of metal powders will be then prepared. Then the powder will be pressed at certain range of tonnage. Later, the pressed sample will be sintered following the respective cycle profile.

1.4.4 Conduct laboratory test

The laboratory test will be conducted once the component has been produced. The test is be focusing on the properties of the component which results from the compacting and sintering process. The result will then be analyzed and compared between the before and after sintering condition.

1.4.5 Communicate the findings

The findings will be reported to the supervisor via progress report and the final report will be compiled and submitted at the end of the period.

CHAPTER 2

LITERATURE REVIEW & THEORY

2.1 Automotive Gears

Modern metallurgy has greatly increased the useful life of automotive gears. Automotive gears transmit torque and rotation through an angle from a power source to the driven member. Extreme pressure gear oil is a lubricant for automotive gears and bearings. [2] Normally, automotive gears are machined from wrought bar stock and subsequently heat treated to develop the required surface hardness and tooth bending fatigue durability. [3]

Automotive gear ratio is the number of turns of the drive wheels in relation to the number of turns of the engine. If the engine is considered the input and the drive wheel is considered to be the output then the input gear or the pinion is said to mate with the output gear or the ring gear to drive or rotate it. [3]

Gears play an important role in trucks, car, buses, motor bikes and even geared cycles. These gears control speed and include gears like ring and pinion, spiral gear, hypoid gear, hydraulic gears, reduction gearbox. [3]

Depending on the size of the vehicles, the size of the gears also varies. There are low gears covering a shorter distance and are useful when speed is low. There are high gears also with larger number of teeth. These high gears cover a longer distance with one revolution of pedal. [3]

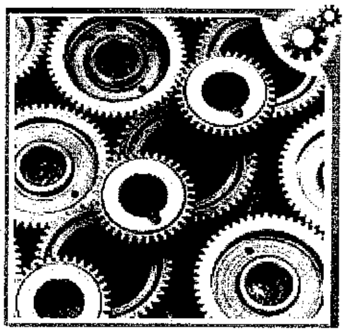


Figure 2.1: Automotive gears [3]

2.2 Pinion Gears

It is a small cogwheel. The teeth fit into a larger gear wheel. Rotational motion is converted into linear motion when the pinion turns and moves the rack. Pinion gears are engineered to be the best gears. [4]

Pinion gear system involves the use of a small round gear called pinion and a large flat gear called rack, more the number of teeth in the pinion gear, more is the speed of rotation. Pinion with smaller number of teeth produces more torque. Pinion is attached to the motor shaft with glue. Rotation of pinion is done by rotation of pinion about a fixed center that helps the rack to move in the straight line. If the rack is moved and the pinion rotates, then the center of the pinion moves taking along the pinion with it. [4]

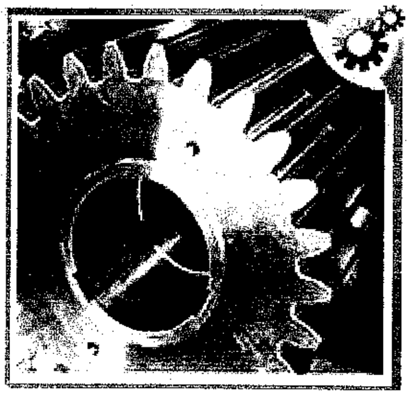


Figure 2.2: Pinion Gears [4]

2.3 The Lifting Mechanism

This superb device is the heart of a power-window system.

The window lift on most cars uses a really neat linkage to lift the window glass while keeping it level. A small electric motor is attached to a worm gear and several other spur gears to create a large gear reduction, giving it enough torque to lift the window. [5]

An important feature of power windows is that they cannot be forced open -- the worm gear in the drive mechanism takes care of this. Many worm gears have a self-locking feature because of the angle of contact between the worm and the gear. The worm can spin the gear, but the gear cannot spin the worm - friction between the teeth causes the gears to bind. [5]

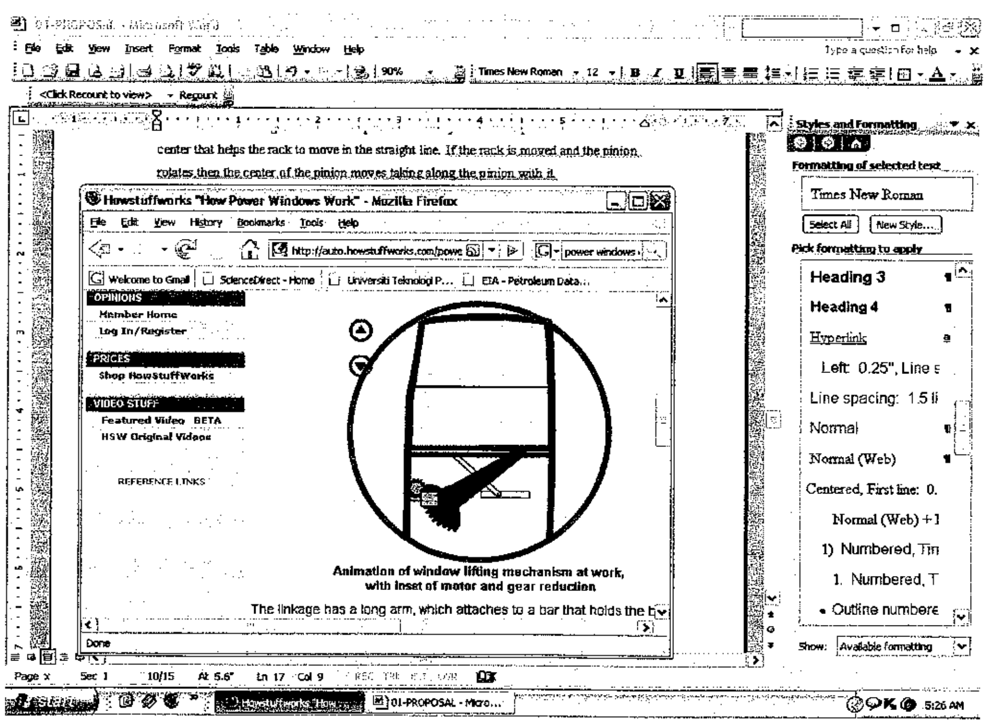


Figure 2.3 [5]: The window mechanism moves up.

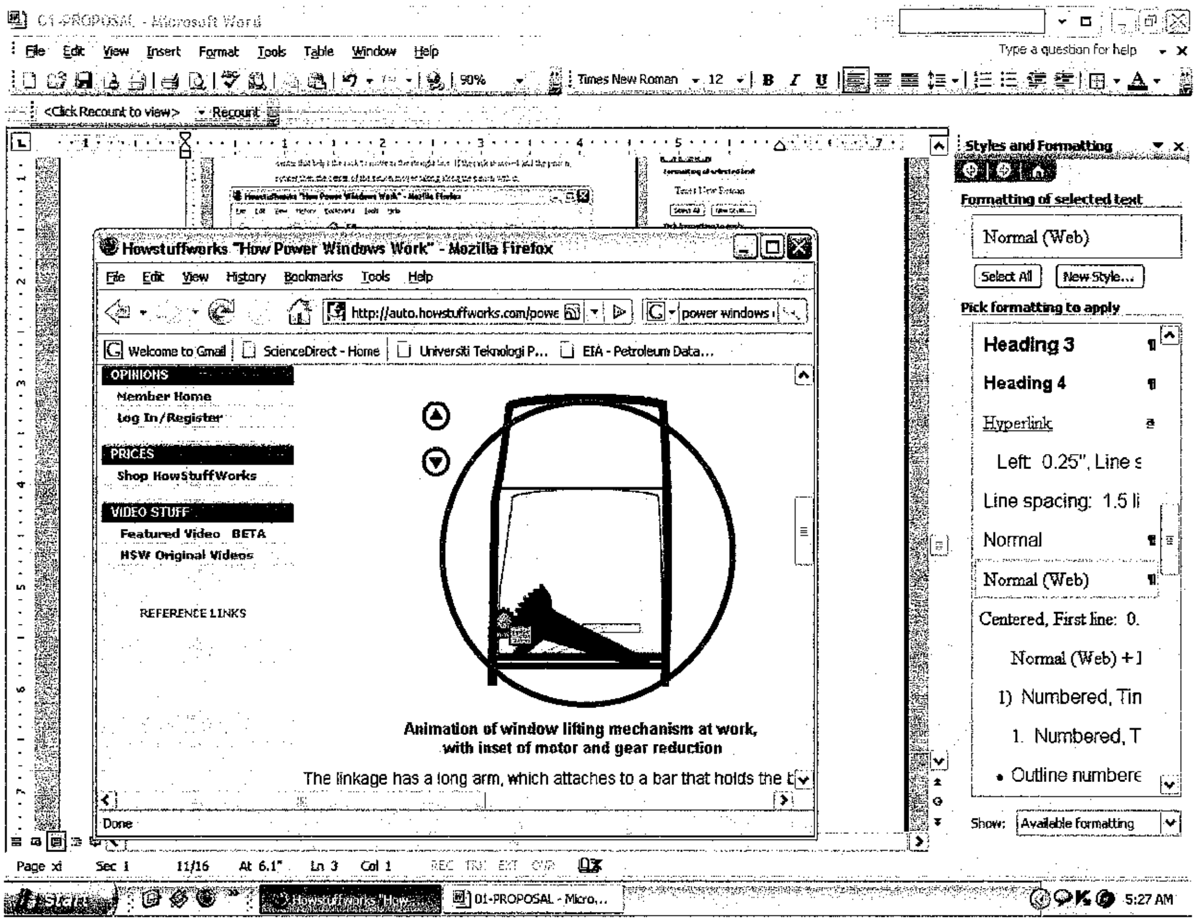


Figure 2.4 [5]: The window mechanism moves down.

The linkage has a long arm, which attaches to a bar that holds the bottom of the window. The end of the arm can slide in a groove in the bar as the window rises. On the other end of the bar is a large plate that has gear teeth cut into it, and the motor turns a gear that engages these teeth. [5]

The same linkage is often used on cars with manual windows, but instead of a motor turning the gear, the crank handle turns it. [5]

2.4 POWDER METALLURGY MARKET

The worldwide market for P/M components is expected to approach USD 30 billion by 2012, growing from USD 23 billion in 2007 at an average annual growth rate (AAGR) near 5%. Over the period, the traditional P/M markets of North America and Europe will lose market share to China, India and other expanding Asian countries. [7]

Specifically, the North American P/M parts business, which was worth about $5 billion in 2007, will grow to $5.5 billion in 2012. The current $9.5 billion European P/M market is expected to reach $11.6 billion in 2012. In contrast, the Asian market for P/M components is estimated at $7.62 billion in 2007 and is expected to increase to $12.6 billion in 2012. [7]

This is according to a new market study entitled "The Powder Metallurgy Industry Worldwide 2007-2012" released by Materials Technology Publications. Featuring over 450 pages and over 100 tables of statistical data, this third edition of the report also examines the raw materials (metal powders) supply sector in detail. The high quality of today's metal powders makes possible a wide range of new P/M materials for specialized demands such as bearings, bushings, gears and pistons for industries ranging from automotive and aerospace to medical and electronics. The technology offers significantly improved performance and greater design flexibility compared with traditional metalworking techniques such as casting, extrusion or forging. [7]

In most industrial countries, 70-85% of finished P/M components are for the automotive industry. The North American P/M industry continues to suffer because the US automotive industry has been loosing market share to Japanese companies, who tend to use less P/M parts per vehicle. In addition, other Asian automobile makers, particularly those in China and India, are set to be major competitive forces within the next five years.

As the major powder metallurgy markets in North America, Western Europe and Japan are relatively mature, the established P/M industry in these areas is looking to expand into other geographic regions, especially China, India and Eastern Europe. [7]

Information concerning the activities of hundreds of companies (including financial results and market position) is also provided in the report, as are the R&D activities of research centers and other organizations worldwide. [7]

Yoshiyuki Kato presented his own paper on the P/M market in Asia. He broke up the continent and presented results on each country individually. [7]

There are 30 P/M companies in Japan and in 2006; the market size was $130m. Business trends lie heavily within the automotive market. The Japanese P/M market's future plans involve further penetration of automotive engine parts, medical resources and other high performance parts production. "The Japanese market is growing at an encouraging pace", said Mr Kato. "In 2002 it was worth Yen 8.5million, and in 2006 this figure increased to Yen 14.2million." That represents annual growth rates of around 17 per cent. The telecom and industrial parts markets are also prospering in Japan. The dominant material used is stainless steel – which is responsible for over half of production. [7]

Those in the know predict that smaller European P/M component makers will have a big challenge satisfying the tough registration requirements of the new REACH legislation In Korea, the P/M market has a smaller presence, with only nine P/M companies. Telecommunications and the automotive sector dominate the market share and the industry depends heavily on electronic parts, especially mobile phone parts. There are between 80-100 injection machines in Korea, and 28-30 furnaces. "The business unit is small", he said. [7]

Taiwan has 15 companies in the P/M market and most focus on parts for tools. The majority of the materials used are low alloy steels. "The Taiwan P/M market is very competitive," said Kato. "The interest in the industry is very high and although the major P/M companies have achieved excellent growth, the smaller companies have struggled". The Taiwan P/M market has a good relationship with the Chinese market. [7]

Statistics for the Chinese P/M market aren't readily available. There are anywhere between 15 and 30 P/M companies in China. Most of these specialize in the telecommunications industry, fire arms and watch parts. The trend is for low end parts production and domestic use. "At the moment there are several companies in China which plan to start up in the P/M business. The industry is increasing, although at present the business unit is small". [7]

Malaysia, Australia, Thailand and India make up the rest of the P/M market, although there are only five companies within this space. They are heavily focused on the automotive industry and on sanitary parts. "Their strong point is their low cost", Kato said. There is high motivation for business in Asia and the interest in P/M technology for auto parts production is expected to grow in the future. [7]

All P/M respondents are interested in progressing R&D. But statistics show that very few are actually spending money in this area. Titanium and functionally gradient materials top the list of research areas, as does lower cost powder, new alloy development and better molded part quality. [7]

2.5 POWDER METALLURGY TECHNOLOGY

Generally, the powder metallurgy technology consists of several processed in producing the final product as per in Figure 2.5.

2.5.1 Producing Powder

Two main methods of producing powder are mechanically such as mechanical pulverization and atomization and chemically such as chemical reduction process and electrolyte process. Thus production process will influence the shape of the particle itself. The shape will influence packing, flow and powder compaction. Particle shape varies with the particle size and manufacturing technique. Small powders or irregular shaped particle do not pack and flow easily. The small particles have a high surface area, and the irregular particles have many surface asperities. Sharp corners are a source of friction between particles that exhibit flow and packing. Both attributes are important to powder shaping since the powder needs to fill out a die cavity rapidly and uniformly. The packing density decreases because of poor flow past neighboring particles.

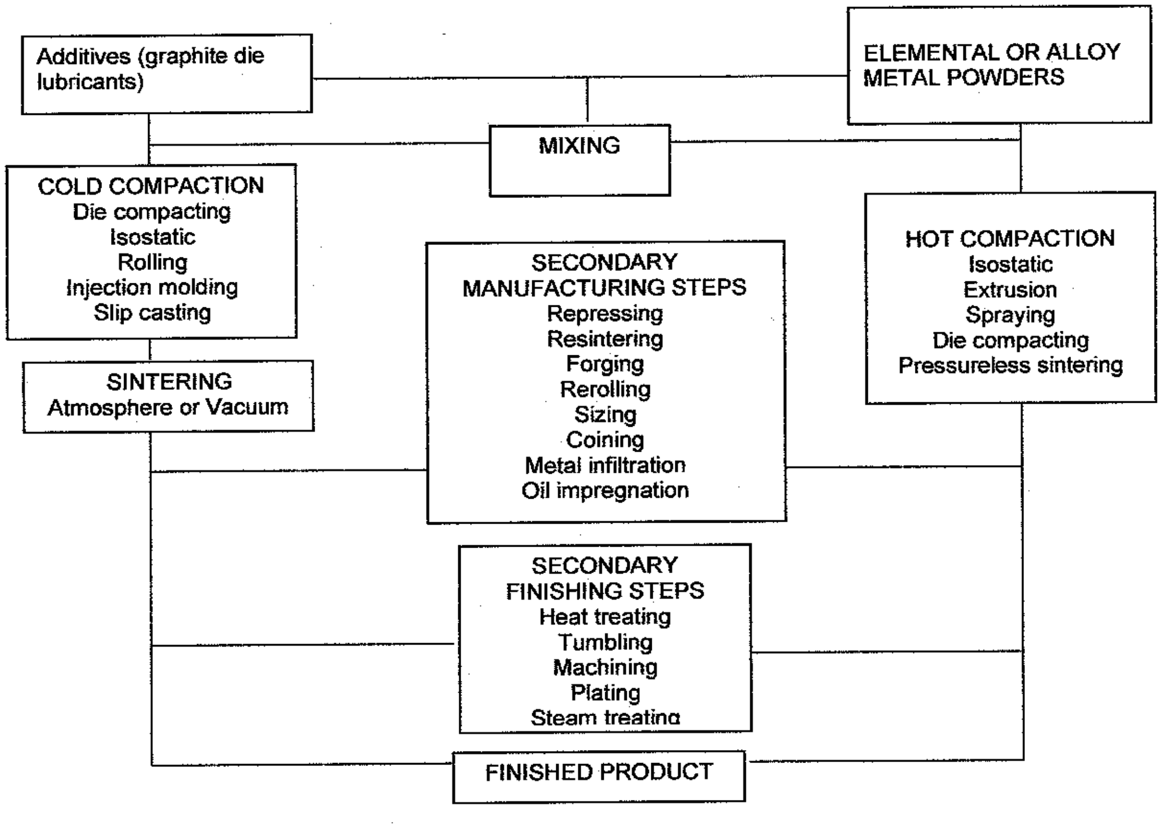


Figure 2.5: The steps of powder metallurgy process in general

2.5.2 Mixing the powder

Mixing the powders as preparation to compacting is very important aspect of the main process especially when producing alloys through powder metallurgy process. Accurate proportioning of the powders is extremely important since the ratios of quantities will govern the nature of the final products as regards both mechanical and physical properties.

2.5.3 Compacting the powder

Compacting or pressing the powders into their semi-finished form prepatory to sintering is also important. This process is carried out at room temperature by pressing the powder into shapes in dies, uisng presses that either hydraulically or mechanically actuated. High pressures are required and the degree of pressures required will depend on the required density of the final product and the ease with which the particles will weld together. The purposes of compaction are to obtain the required shape, density and particle to particle contact. Usually, the compacting process used is die compaction. Die compaction involves the pressurization of the powder in a rigid tool set. A conceptualization of a die compaction is illustrated in Figure 2.6.

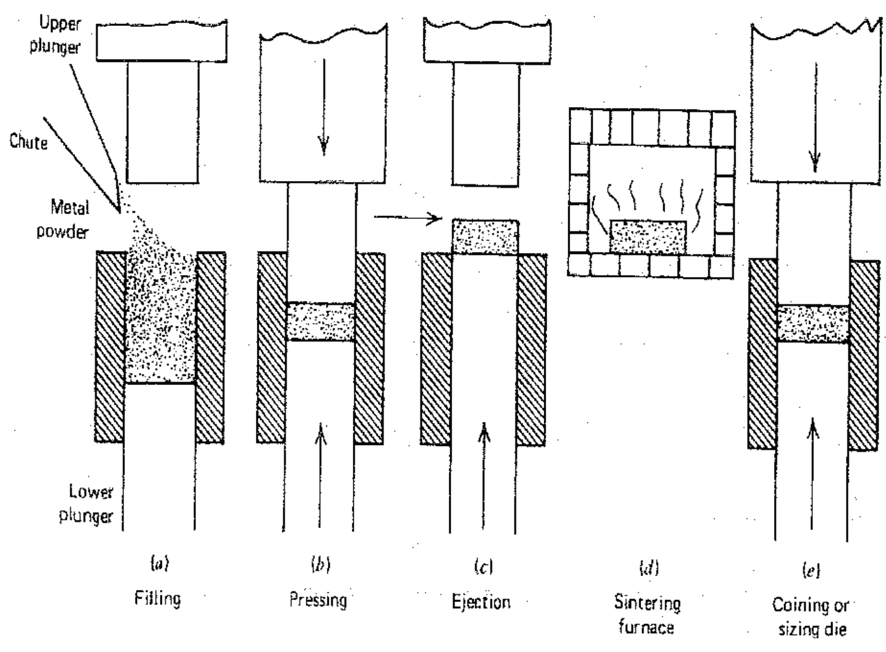


FIGURE 17.10. The depth of die cavity and length of plunger stroke is determined according to the density required. (*a*) A measured amount of metal powder is placed in the die cavity through the chute. (*b*) Pressure is applied. (*c*) The briquette is ejected from the die cavity. (*d*) The parts are sintered at a specified temperature for a given length of time. The parts are now ready for use. (*e*) If more precision is needed, they can be sized in a coining die.

Figure 2.6: Die compaction cycle

The selection of the punch die materials for the process depends on the abrasives of the powder metal and the number of parts to be made. The most common die materials are air or oil hardening tool steels. Punches are generally made of similar materials.

Usually, the compaction process is aid with some binder. Binder is a temporary vehicle for packing a powder into desired shape and holds the particles at that shape until the beginning of sintering. The binder is removes by the heat during sintering process. The appropriate binder need to be carefully chose since some ingredient of the binder can tailor the properties of the end result.

2.5.4 Sintering

Sintering is the process of heating compacted component at relevant temperature, preferably below the melting points in a furnace with controlled atmospheric conditions. Usually, the range of temperature for sintering is between 60% and 90 % of the melting point and the maximum sintering temperature for this material is 1300°C . Most of the metals react with gas of their surroundings atmosphere. Sintering is conducted in suitable atmosphere. Sintering is conducted in suitable atmosphere to provide protection against oxidation and re-oxidation of sintered parts of sintered parts. Below are the classifications of sintering atmospheres:

- Oxidizing: air, carbon dioxide, water vapor
- Reducing: hydrogen, carbon monoxide, methane, cracked ammonia
- Carburizing: carbon monoxide, methane and other hydrocarbons
- Inert: vacuum, helium, argon, nitrogen
- Nitriding: nitrogen, and ammonia

Sintering helps in boding the individual powder particles, either by melting of minor constituents, diffusion or by metallurgical reactions between the constituents to achieve some particular type of structure. Atmospheric control is necessary to avoid oxidation and other unneeded reactions. The properties of the component will depend on the good bonding between the particles.

2.6 PROPERTIES OF METAL POWDER

2.6.1 Properties of Iron

The chemical symbol for iron, Fe, comes from the Latin word for iron - *ferrum*. Iron is the second most abundant metal in the Earth's crust (aluminium is the most abundant metal). The core of the Earth is solid iron, and iron is found in meteorites, but in the Earth's crust iron is found mainly as minerals of iron oxide - hematite, magnetite, goethite and limonite. The mineral which is mostly used as ore for making iron is hematite. Its chemical formula is Fe_2O_3. Iron metal is a silvery, lustrous metal which has important magnetic properties [16].

Figure 2.7: Hematite

Iron is about 8 times heavier than water (its relative density is 7.87). When iron is exposed to the air it starts to turn back into iron oxide and the red powder that forms on the surface of iron called rust. To make iron stronger and less likely to rust it can be combined with carbon and other elements to make steel. The mineral magnetite is very magnetic. Iron and some alloys of iron are also magnetic.

The Properties of Iron	
Chemical Symbol:	Fe
Mineral:	iron oxides: eg hematite and magnetite
Relative density:	7.87
Malleability:	High
Ductility:	High
Melting point:	1535°C
Atomic Mass:	55.85

Table 2.1: The properties of Iron

2.6.2 Properties of Copper

The word copper comes from the Latin word "cuprum", which means "ore of Cyprus". This is why the chemical symbol for copper is Cu. Reddish with a bright metallic lustre, copper is the only naturally occurring metal other than gold that has a distinctive color. Like gold, copper is an excellent conductor of heat and electricity. It is also very malleable and ductile. The most important compounds are the oxide and the sulphate, (blue vitriol). Copper is easily mixed with other metals to form alloys such as bronze and brass. Bronze is an alloy of tin and copper, and brass is an alloy of zinc and copper. Copper is also resistant to corrosion (it does not rust very easily). [16].

The Properties of Copper	
Chemical Symbol:	Cu
Mineral:	most commonly found as chalcopyrite
Relative density:	8.96
Hardness:	2.5-3 on Mohs scale
Malleability:	High
Ductility:	High
Melting point:	1083°C
Atomic Mass:	64

Table 2.2: The properties of Copper

2.6.3 Properties of Carbon

Carbon is a Group 14 element and is distributed very widely in nature. It is found in abundance in the sun, stars, comets, and atmospheres of most planets.

Carbon is found free in nature in three allotropic forms: amorphous, graphite, and diamond (further details). Graphite is one of the softest known materials while diamond is one of the hardest. Carbon, as microscopic diamonds, is found in some meteorites.

Basic information about and classifications of carbon.

- Name: **Carbon**
- Symbol: **C**
- Atomic number: **6**
- Atomic weight: **12.0107 (8) [see notes g r]**
- Standard state: **solid at 298 K**
- CAS Registry ID: **7440-44-0**
- Group in periodic table: **14**
- Group name: **(none)**
- Period in periodic table: **2**
- Block in periodic table: **p-block**
- Colour: **graphite is black, diamond is colourless**
- Classification: **Non-metallic**

Table 2.3: The properties of Carbon

2.6.4 Properties of Stearic Acid

Stearic acid is a chemical compound consisting of an 18 carbon chain whose terminal carbon is connected to an oxygen atom with a double bond and a hydroxyl group (OH) by a single bond. It belongs to class of materials known as fatty acids, produced primarily from natural fats and oils. Stearic acid is an important component in soap and other cosmetic and industrial preparations.

Historically, stearic acid has been made by a process known as hydrolysis, which involves heating the fat in an alkaline solution. This process is also known as saponification. The alkali that is traditionally used is sodium hydroxide, also known as caustic soda or lye. Hence the term "lye soap." Other methods used to produce fatty acids include solvent crystallization, hydrogenation, and distillation.

Pure stearic acid is a white, waxy solid crystalline material that melts at 156°F (69°C). It is odorless and tasteless. However, because of its natural origin, pure stearic is hard to obtain. Instead, stearic acid usually includes minor amounts of other fatty acids with different carbon chain lengths, such as lauric and palmitic acids. These trace impurities can cause the acid to vary in molecular weight, solubility, melting point, color, odor, and other physical and chemical properties. In addition to the carbon chain distribution, the degree of neutralization, or the amount of free acid present, also determines the acid's properties. These are a number of physical and chemical specifications used to ensure that the stearic acid is of a consistent quality. Specifications include the acid's saponification value, iodine value, peroxide value, free fatty acids, unsaponifiables, moisture, and trace impurities. [17]

2.7 RULES OF MIXTURES FOR ELASTIC PROPERTIES

'Rules of Mixtures' are mathematical expressions which give some property of the composites in terms of the properties, quantity and arrangement of its constituents.

They may be based on a number of simplifying assumptions, and their use in design should tempered with extreme caution.

2.7.1 Density

For a general composite, total volume V containing masses of constituents Ma, Mb, Mc,.. the composite density is

$$\rho = \frac{Ma + Mb + Mc}{V} = \frac{Ma}{V} + \frac{Mb}{V} + \frac{Mc}{V} + \ldots$$

But va/V = Va is the volume fraction of the constituents a, hence:

$$\rho = Va\,\rho a + Vb\,\rho b + \ldots$$

CHAPTER 3

METHODOLOGY & PROJECT WORK

3.1 PROJECT FLOW

The flow of the project is shown in the Figure 3.1. The first stage is to gather information about the material used, equipments needed and also the method and procedure of laboratory work. The information has been gathered from books, journals and other relevant material.

Second stage is the fabrication of die and mould. The later stage is the preparation of metal powder, fabrication of pinion gears, microstructure test and analysis. Existing pinion gears each from Proton Waja and Toyota power window system had been compared at early stage. As a result, the Toyota pinion gear had been chosen to be design model for the coming outcome. Using the Renishaw-Cyclone Series 3D Digitizer (Figure 3.2), the existing pinion gear had been reverse- engineered to obtain the 2D-die drawing. The digitized data then been used as main reference to fabricate the die and mould that used in this project. Later, the raw material for the die (Figure 3.4) which is the tool steel being sent to be further processed by Electrical- Discharge Machining (EDM) as shown in Figure 3.5. Where as the mild steel which is the raw material of the mould (Figure 3.6) was being further cut by few basic processes in manufacturing technology such as facing, drilling and boring. Then, EDM was again used to gain the desired shape on the mould. Both of the end products of die and the mould later were grinded and polished using the Grinder & Polisher machine (Figure 3.7).

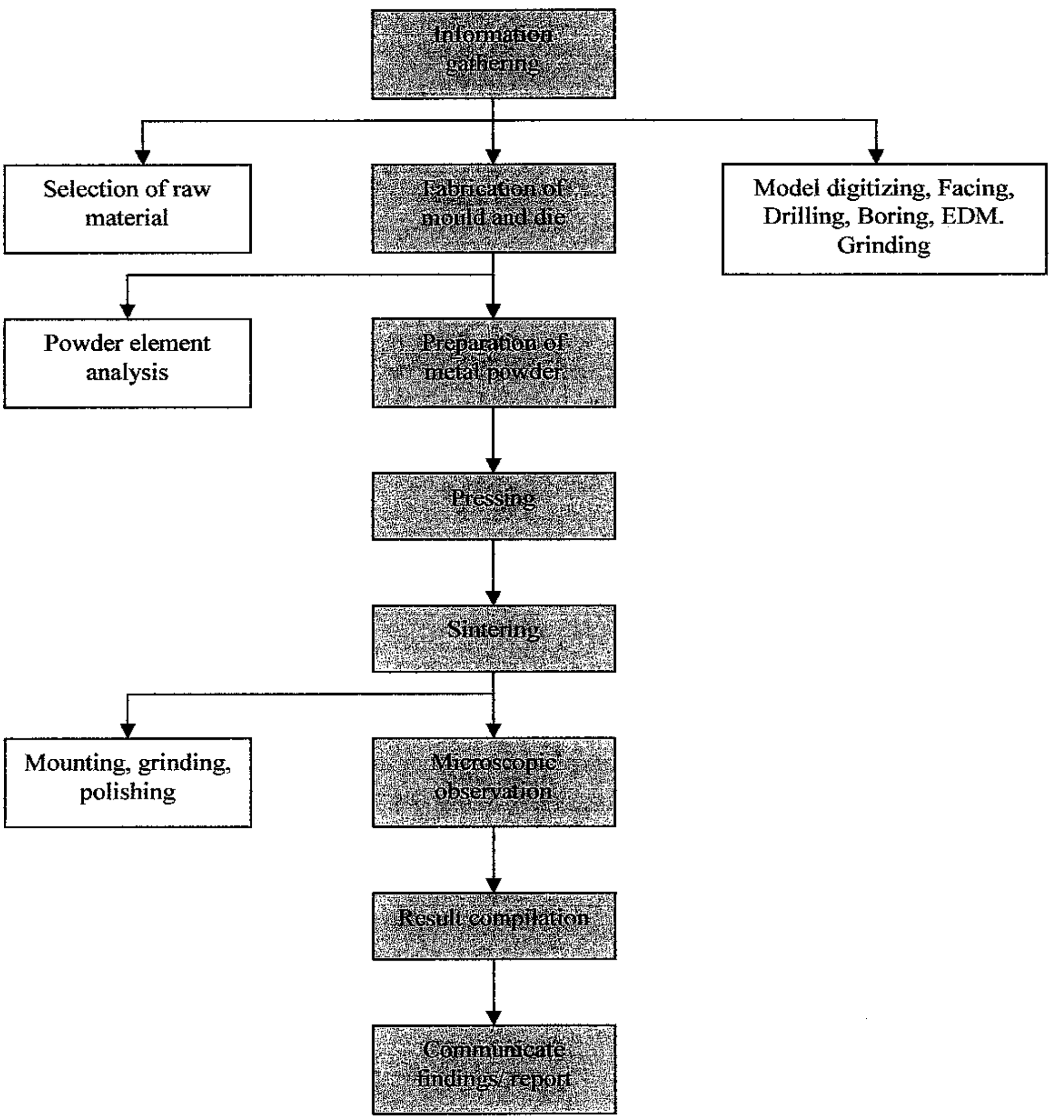


Figure 3.1: Project Flow Chart

Figure 3.2: Renishaw- Cyclone Series 3D- Digitizer

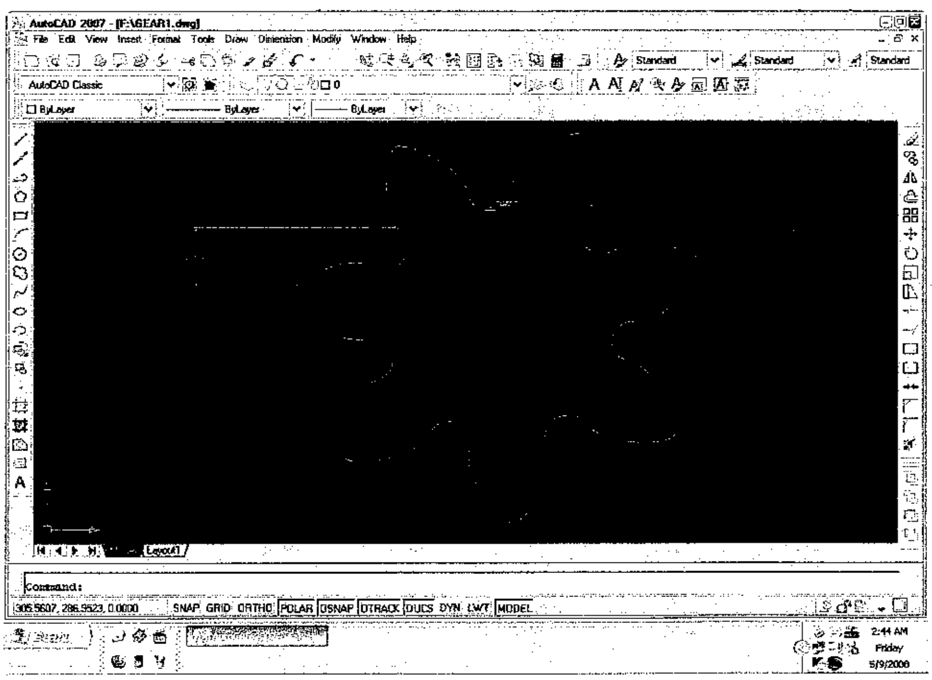


Figure 3.3: Digitized image of Toyota pinion gear

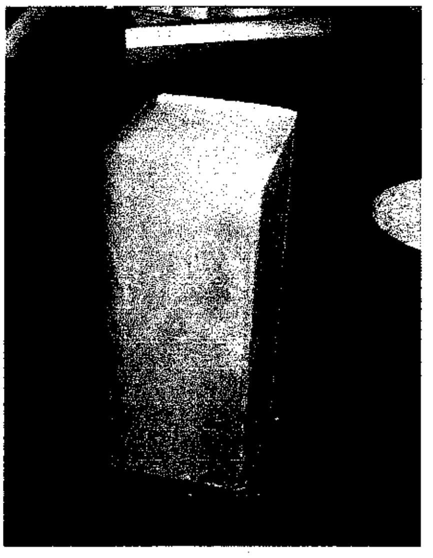


Figure 3.4: Tool steel as raw material of die

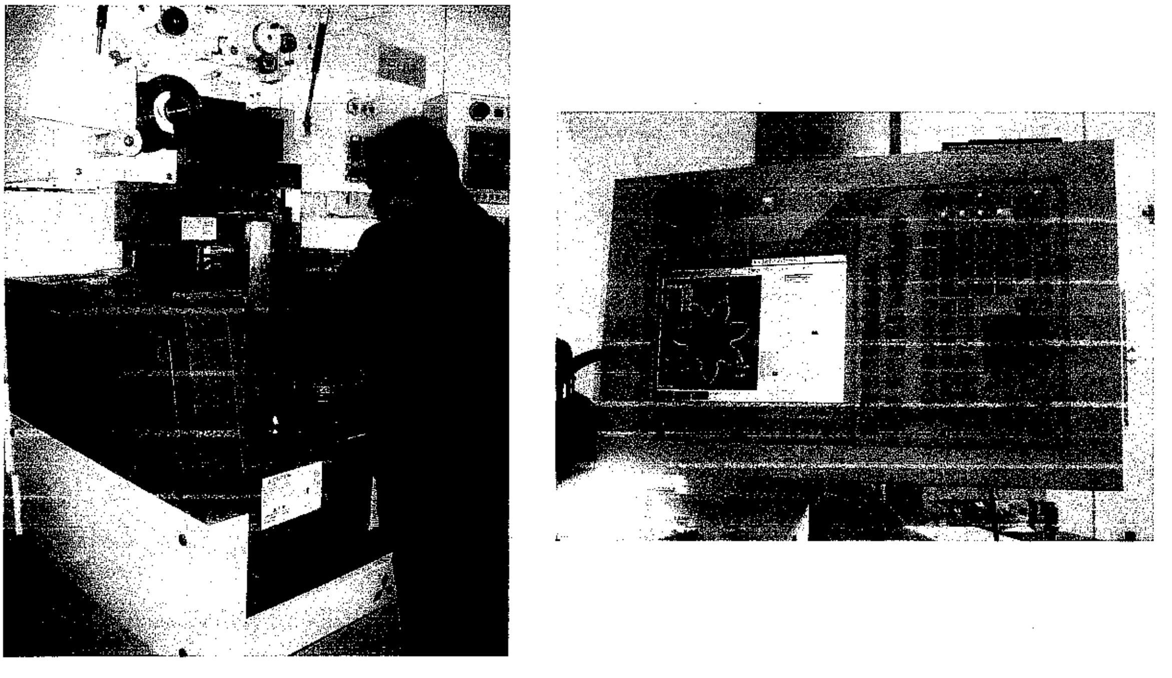


Figure 3.5: Electrical- Discharge Machining (EDM)

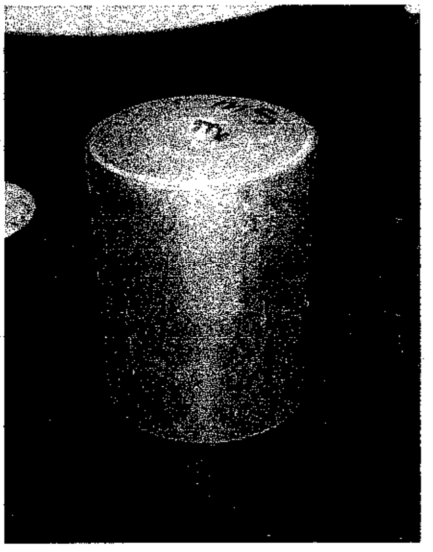


Figure 3.6: Mild steel as raw material of mould

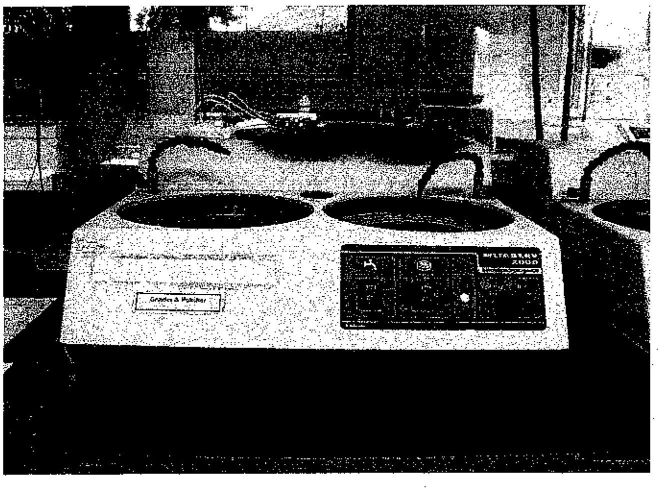
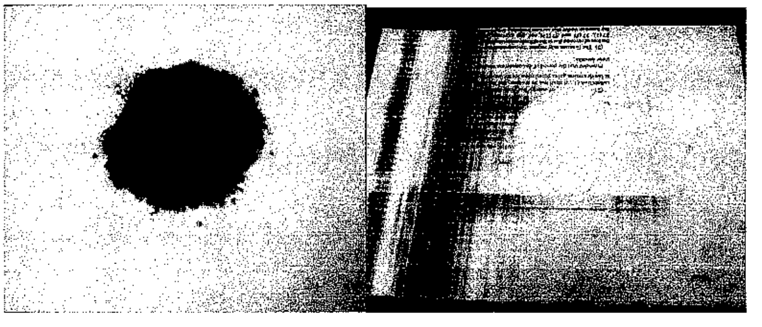


Figure 3.7: Grinder and Polisher

Soon as the die and mould were ready, the metal powder was then mixed and grinded. The iron, copper and carbon powder (Figure 3.8) were mixed together and the best ratio out of three samples of mixtures was 94:5:1 respectively for 1 hour using the ball mill machine (Figure 3.9). 2% of Stearic Acid was added into the powders as binder. The mixed powders were firstly pressed at range of tonnage 6500kg to 8500kg. Later, the best tonnage was chosen to press the powders into standard green specimens using the fabricated die and mould. This was done by using the Autopallet Press Machine (Figure 3.10).

Iron powder
Copper powder



Carbon powder
Stearic Acid

Figure 3.8: Iron, copper, carbon powder and stearic acid.

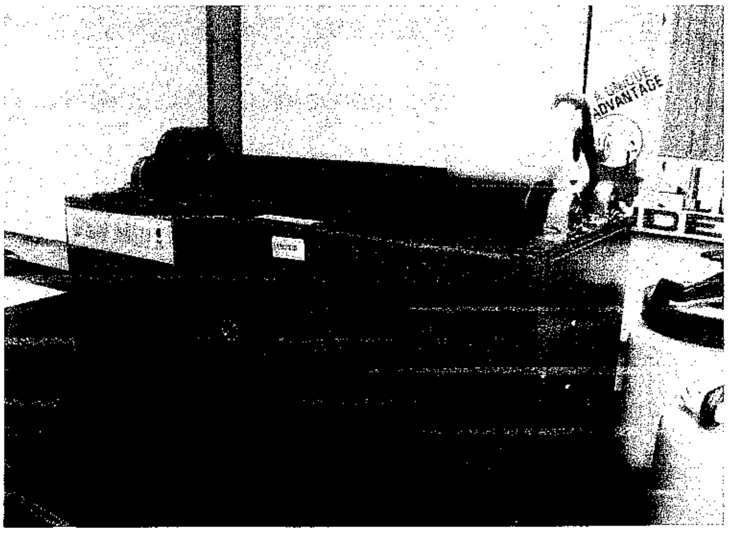


Figure 3.9: Ball mill machine

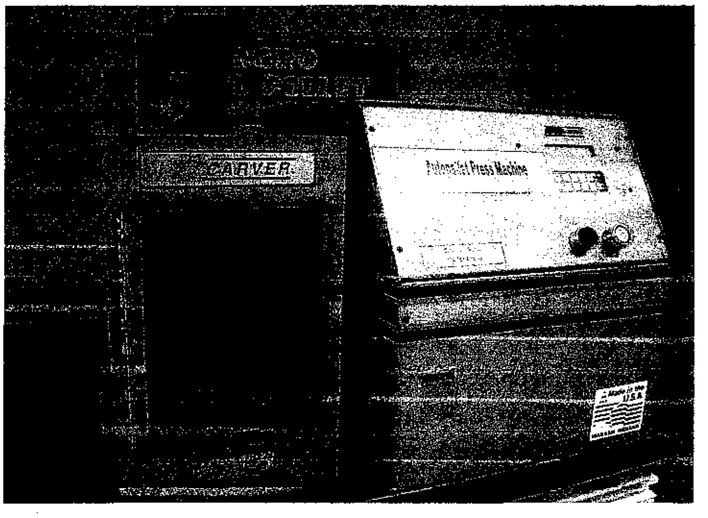


Figure 3.10: Autopallet Press Machine

The green specimens were sintered in the furnace (Figure 3.11) at 100% N2 atmosphere and the cycle profile of the sintering process is as shown in Figure 3.12.

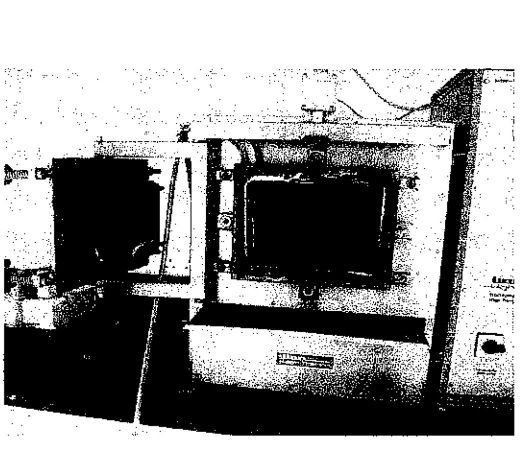


Figure 3.11: Furnace for sintering process

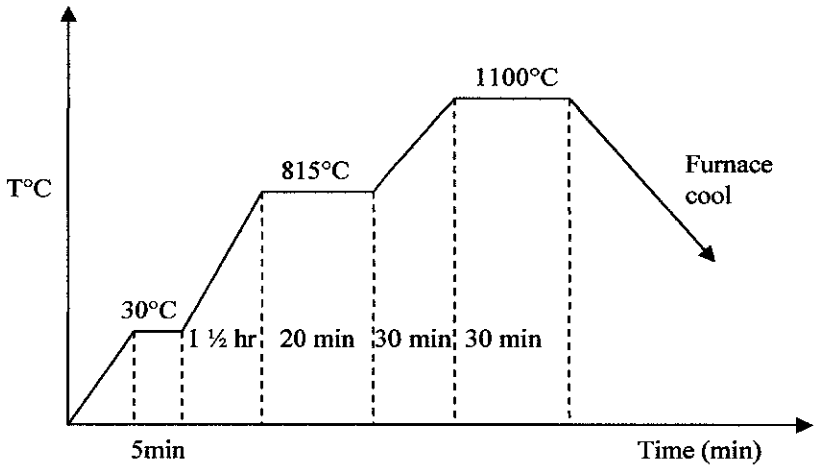


Figure 3.12: Cycle profile of the sintering process

Then, the sintered specimen were analyzed for dimensional and weight change. The microstructures of the sintered samples were then analyzed using the Optical Microscope and Scanning Electron Microscope (SEM) as shown in Figure 3.13.

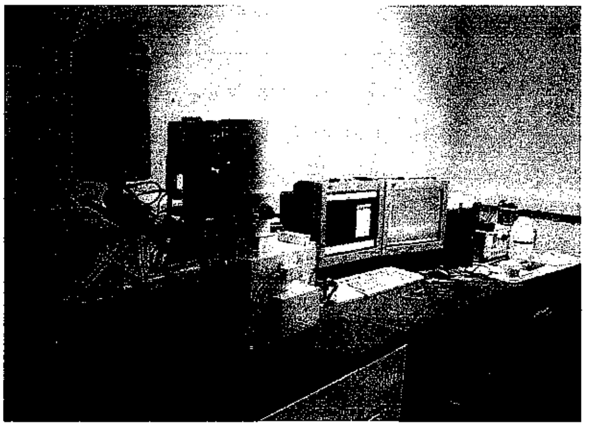


Figure 3.13: Scanning Electron Microscope (SEM)

The final stage is to compile the results and produce a report. The report has been submitted to the supervisor to be evaluated.

3.2 PROCEDURE IDENTIFICATION

There are several experiments and tasks conducted in both manufacturing and material laboratory the objectives of the project.

3.2.1 Experiment 1: Preparation of die drawing

Objective:

1. To copy drawing of Toyota pinion gear as reference for die and mould fabrication.

Equipment used:

Renishaw- Cyclone 3D Laser Digitizer.

Material used:

Toyora pinion gear

Procedure:

1. The specimen is placed on the table.
2. Using touch probe, the surface profile of the specimen is captured.
3. Two sets of output files in DXF (Drawing Interchange Format) is generated.

3.2.2 Experiment 2: Fabrication of die

Objective:

1. To fabricate the die into desired gear shape.

Equipment used:

Electron- Scanning Microscope

Material used:

Tool steel.

Procedure:

1. The drawing is saved into the equipment program..
2. The raw material is fixtured within the tank containing dielectric fluid.
3. The movement is controlled by numerically controlled systems.
4. The frequency of discharge of the energy per discharge, the voltage and the current are varied to control the removal rate.

3.2.3 Experiment 3: Fabrication of mould

Objective:

1.To fabricate the mould into desired gear shape.

Equipment used:

Lathe machine, drill bit, boring tool, EDM.

Material used:

Mild steel.

Procedure:

1. The raw material is clamped to the lathe machine
2. The cutting speed is set and the cutting fluid is ON.
3. The machine is ON for face-milling operation.
4. Then the machine is OFF to change the tool for drilling operation.
5. The machine is ON and work piece is centre-drilled on both sides before it was drilled through.
6. The machine is OFF again to change the tool for boring operation.
7. The machine is ON and hollow part of the work piece is formed within desired diameter and depth.
8. Once this finished, the machine is OFF and the workplace need to be cleaned.
9. The gear shape on the mould is then produced by using EDM.

3.2.4 Experiment 4: Preparation of Metal Powder.

Objective:

1. To prepare metal powder prior to pressing process.

Equipment used:

Spatula, beakers,100g Balancer, Ball Mill Machine, container, ball mills.

Material used:

95g iron powder, 5g copper powder, 1g carbon powder, 2g Stearic Acid.

Procedure:

1. Each of the powder is weighed accordingly to the respective amount using the balancer.
2. All of the powders are poured into the container and several amounts of ball mills are put together with the mixture.
3. The container is put in between the rollers of Ball Mill Machine.
4. The speed is set to 40 rpm and the mixture will be mixed together for 1 hour.

3.2.5 Experiment 5: Fabrication Of Pinion Gear- Pressing Process

Objective:

1. To fabricate the green samples of pinion gears.

Equipment used:

100g Balancer, Autopallet Pressing Machine, Vanier Calliper.

Material used:

Metal powder.

Procedure:

1. The mixture of metal powder is weighed according to the desired amount.
2. The metal powder is pressed using the standard stainless punch and die to obtain metal pallet at tonnage of 6000kg, 6500kg, 7000kg, 7500kg, and 8000kg.
3. The green samples sizes are gauged using the Vanier calliper.

Sample	Load (kg)	Mass (g)	Diameter (mm)	Thickness (mm)
1	6000	5		
2	6500	5		
3	7000	5		
4	7500	5		
5	8000	5		

4. Then, the tonnage whereby the best obtainable sample is produced is chosen to proceed with pressing process using the die and mould of the pinion gear.
5. The metal powder is pressed at 7000kg, 7100kg, 7200kg, 7300kg and 7500kg.

Sample	Load (kg)	Mass (g)	Diameter (mm)	Thickness (mm)
1	7000	7		
2	7100	7		
3	7200	7		
4	7300	7		
5	7500	7		

3.2.6 Experiment 6: Fabrication Of Pinion Gear- Sintering Process

Objective:

1. To help bonding the individual powder particles by introducing heat into the sample.

Equipment used:

"Carbolite" furnace, balancer, and Vanier Calliper.

Material used:

Pressed powder, and Nitrogen gas.

Procedure:

1. The pressed samples are placed inside the "Carbolite" furnace.
2. The furnace temperature is set to the desired temperature and Nitrogen gas is supplied into the furnace.
3. The samples are sintered according to cyclic profile as shown earlier in Figure 3.13.
4. The furnace is left to cool for a night before the samples are taken out.
5. The sintered samples then are weighed and the dimensions is measured.
6. The data is recorded as per table below.

Sample	Max. Temperature (°C)	Mass (g)	Diameter (mm)	Thickness (mm)
1	1100		N/A	
2	1100		N/A	
3	1100		N/A	
4	1100		N/A	
5	1100		N/A	

3.2.7 Experiment 7: Preparation for Analysis of Pinion Gear

Objective:

1. To prepare the mounted sintered sample.

Equipment used:

Grinder and Polisher, Auto Mounting Press Machine.

Material used:

One sintered sample, Phenolic Thermosetting Powder.

Procedure:

1. The pressed samples are placed inside the Auto Mounting Press Machine for Mounting operation.
2. A spoon of Phenolic Thermosetting Powder is poured inside the machine.
3. The machine is set for mounting process for 5 minutes.
4. The mounted sample is then grinded and polished using the Grinder and Polisher Machine until the surface is smooth and shining.

3.2.8 Experiment 8: Optical Microscopic and SEM Observation of Sintered Pinion Gear

Objective:

1. To observe the product microstructure and the particles bonding of sintered samples

Equipment used:

Optical Microscope, SEM.

Material used:

Mounted sintered sample and broken sintered sample.

Procedure:

a. Optical Microscope

1. The mounted sample is placed under the optical microscope.
2. The surface of the sintered sample is observed at 200x..

3. The picture of the sample is recorded.

b. SEM

1. The mounted sample and broken sintered samples are placed on the specimen holder.
2. SEM and all related switched are ON.
3. Samples are put inside the SEM.
4. Samples are scanned at appropriate magnification.
5. The observations are recorded.

CHAPTER 4

RESULTS & DISCUSSION

4.1 Experiment 1: Preparation of die drawing

Result of digitized data obtained from the Renishaw- Cyclone Series 3D Digitizer which then converted into AutoCAD is as follow:

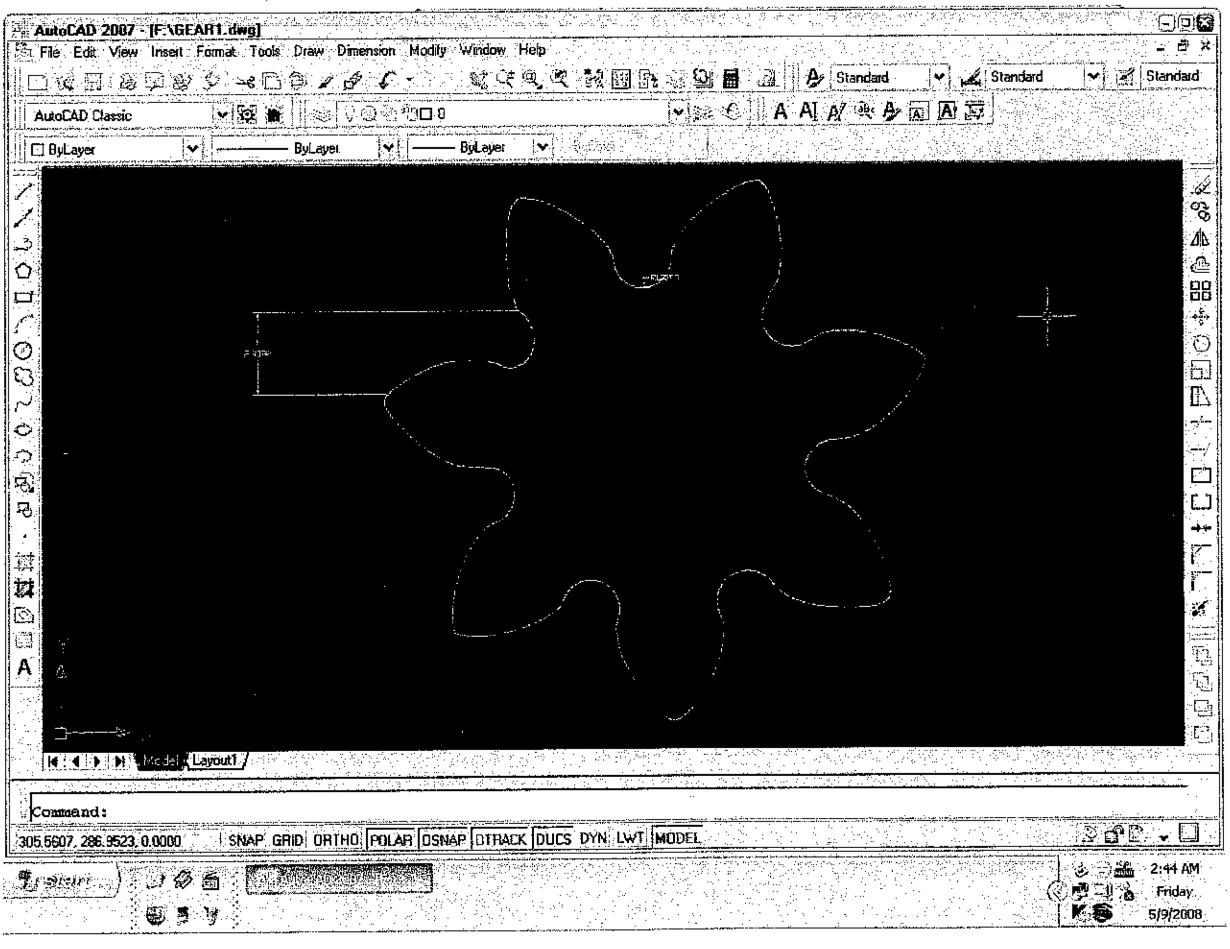


Figure 4.1: Digitized image of Toyota pinion gear

4.2 Experiment 2: Fabrication of die

The resulting die:

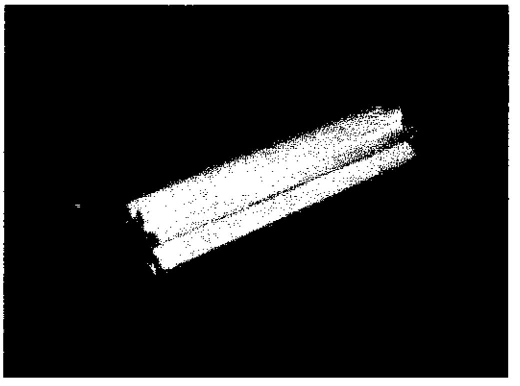


Figure 4.2: The fabricated die

4.3 Experiment 3: Fabrication of mould

The resulting mould:

Figure 4.3: The fabricated mould

4.4 Experiment 4: Preparation of Metal Powder

Basically three different compositions of mixtures have been made throughout the project. The first metal powder was mixture of 96 g iron powder, 3 g of copper powder and 1 g of carbon powder together with 0.75 % of Stearic Acid. As for this mixture, at the tonnage of 5000 kg until 10000 kg, the powder still not well-bonded and causing the gear structure to break.

The second trial was mixture of 96 g iron powder, 3 g of copper powder and 1 g of carbon powder and now with 1.5% of Stearic Acid to act as binder. Yet, at the maximum trial tonnage of 8500kg, the produced gear structure is still not meet satisfaction as it is brittle and failed in a drop- test.

Finally, the third mixture is blended with combination of 94 g of iron powder, 5 g of copper powder and 1 g of carbon powder with 2% of Stearic Acid (maximum allowable amount of stearic acid to act as binder).

4.4.1 Experiment 5: Fabrication Of Pinion Gear- Pressing Process

The pressed samples using the standard punch and mould were measured and the sizes are as follow;

Sample	Load (kg)	Mass (g)	Diameter (mm)	Thickness (mm)
1	6000	5	**13**	**5.9**
2	6500	5	**13**	**6.2**
3	7000	5	**13**	**6**
4	7500	5	**13**	**6.2**
5	8000	5	**13**	**6.1**

Table 4.1: Readings of pressed pallet samples.

Once the mould and die were ready, the experiment was followed by pressing using those two tools.

Figure 4.4: Failure of Die and Mould

However, during early stage of pressing process in this project, the experiment was failed to press powder mixture using the die and mould. In fact the mixture was also not suitable and altered until the third times while the die and mould are newly re-fabricated. Several mitigation plans had been taken such as:

1. Reduced remaining height of die before pressing.
2. Ensure stopper is also made of same material as the die which is the tool steel.
3. Put in lubricant or wax inside the mould and die before pressing.

In the later trial, the die and mould were successfully performing their functions without severe damages as earlier. The resulting pressed powders are as follow:

Sample	Load (kg)	Mass (g)	Diameter (mm)	Thickness (mm)
1	7000	7	**N/A**	**6.8**
2	7100	7	**N/A**	**6.7**
3	7200	7	**N/A**	**7.0**
4	7300	7	**N/A**	**6.9**
5	7500	7	**N/A**	**6.8**

Table 4.2: Reading of pressed pinion gear samples

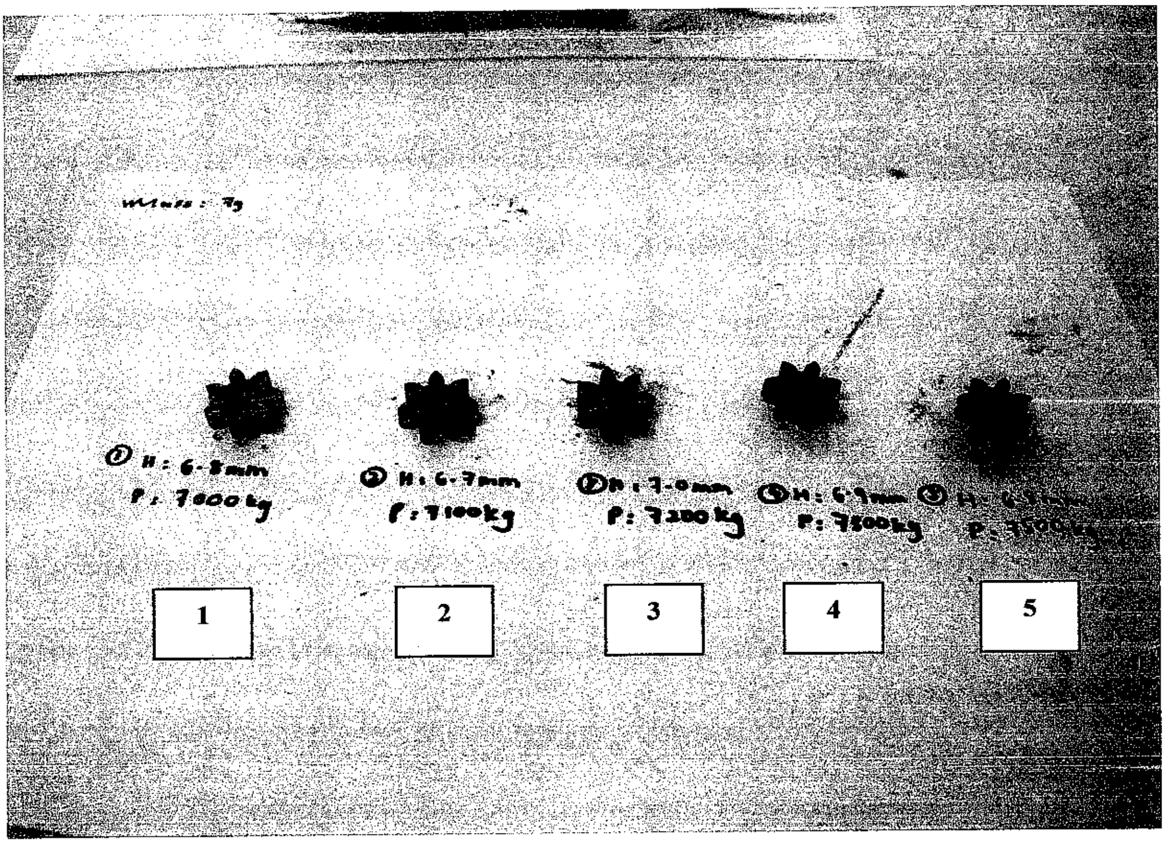


Figure 4.5: Resulting pressed samples at different tonnage.

Based on the pictures:

1. The tonnage was 7000kg and the structure was a bit brittle compared to the rests.

2. The tonnage was 7100kg and the structure was also a bit brittle but better than 1.

3. The tonnage was 7200kg and the structure was better bonded compared to 1 and 2.

4. The tonnage was 7300kg and the structure was best bonded compared to all samples.

5. The tonnage was 7500kg and the structure was broken into two pieces due to shear stress.

When a single crystal is subjected to an external; force, it first undergoes elastic deformation- that is returns to its original shape when the force is removed. An analogy to this type of behaviour is a helical spring that stretches when loaded and returns to its original shape when the load is removed. However, if the force o the crystal structure is increased sufficiently, the crystal undergoes plastic deformation or permanent deformation- that is, it does not return to its original shape when the force is removed.

There are two basic mechanisms by which plastic deformation takes place in crystal structures. One of the slipping of one plane of atoms over an adjacent plane called slip plane, is under a shear stress. Shear stress is defined as the ratio of the applied shearing force to the cross-sectional area being sheared. Just as it takes a certain amount of force to slide playing cards against each other, a crystal requires a certain amount of shear stress (critical shear stress) to undergo permanent deformation. Thus, there must be a shear stress of sufficient magnitude within a crystal for plastic deformation to occur; otherwise the deformation is plastic only.

The shear stress required to cause slip in single crystals is directly proportional to the ratio ***b/a,*** where *a* is the spacing of the atomic planes and *b* is inversely proportional to the atomic density in the atomic plane. As *b/a* decreases, the shear stress required to cause slip decreases. Therefore, it can be stated that slip in a single crystal takes place along planes among *maximum atomic density* or, in other words, that slip takes place in closely packed planes and in closely packed directions.

Because *b/a* ratio varies for different directions within the crystal, a single crystal has different properties when tested in different directions; this behaviour is called anisotropic. A simple example of anisotropy is the behaviour of woven cloth, which stretches differently when we pull it in the planar direction than along its thickness direction.

The second and less common mechanism of plastic deformation in crystals is twinning, in which a portion of the crystals forms a mirror image of itself across the plane of twinning. Twins form abruptly and are the cause of the creaking sound that occurs when a tin or zinc rod is bent at room temperature. Twinning usually occurs in hcp metals.

The actual strength of metals is approximately one to two orders of magnitude lower than the strength levels obtained from the theoretical calculations; this discrepancy has been explained in terms of defects and imperfections in the crystal structure. Unlike the idealized models, actual metal crystals contain a large numbers of defects and imperfections, which are categorized as follows:

- *Point defects,* such as vacancy (missing atom), an interstitial atom (extra atom in the lattice), or an impurity (foreign atom that has replaced the atom of the pure metal).
- *Linear*, or *one-dimensional, defects,* called dislocations.
- *Planar*, or *two-dimensional* , *imperfections* such as grain boundaries and phase boundaries.
- *Volume*, or *bulk, imperfections*, such as voids, inclusions (non-metallic elements suchj as oxides, sulfides, and silicates, other phases, or cracks.

4.2.6 Experiment 6: Fabrication of Pinion Gear- Sintering Process

As being sintered at the desired various temperatures, the result of the sintered samples are as follow;

Sample	Max. Temperature (°C)	Mass (g)	Diameter (mm)	Thickness (mm)
1	1100	**6.6136**	N/A	**7.0**
2	1100	**6.7972**	N/A	**6.8**
3	1100	**7.1085**	N/A	**7.4**
4	1100	**6. 7592**	N/A	**7.2**
5	1100	**6.9243**	N/A	**7.8**

Table 4.3: Reading of sintered pinion gear samples

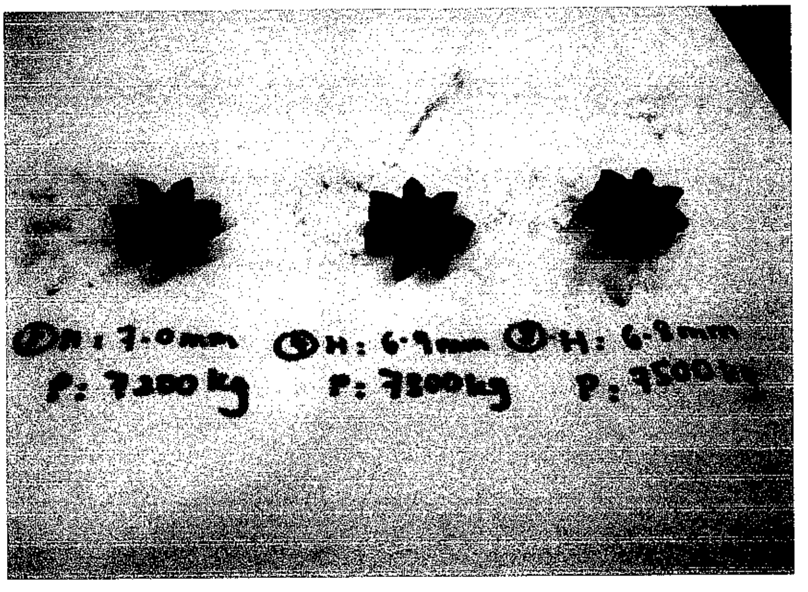


Figure 4 6: Resulting sintered samples

From rough observation and based on the data gathered, it shown that oxidation due to absence of 5% H2 gas, has happened which resulting the sintered samples to change in colours and expand in weight. Assumption made is there might some leakage within the furnace.

4.2.7 Experiment 7: Preparation for Analysis of Pinion Gear

Resulting mounted samples is as follow;

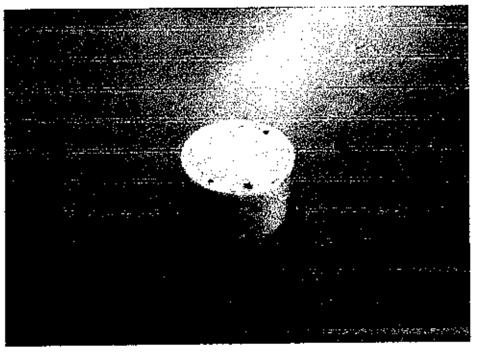


Figure 4.7: Mounted sintered samples

4.2.8 Experiment 8: Optical Microscopic and SEM Observation of Sintered Pinion Gear

a. Optical Microcsope

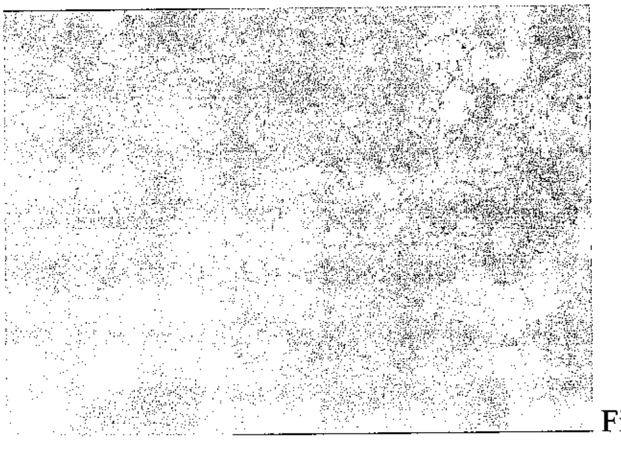


Figure 4.8: 200x

The profile shown that the structures of metal powders are merely broken in bonding.

b. SEM

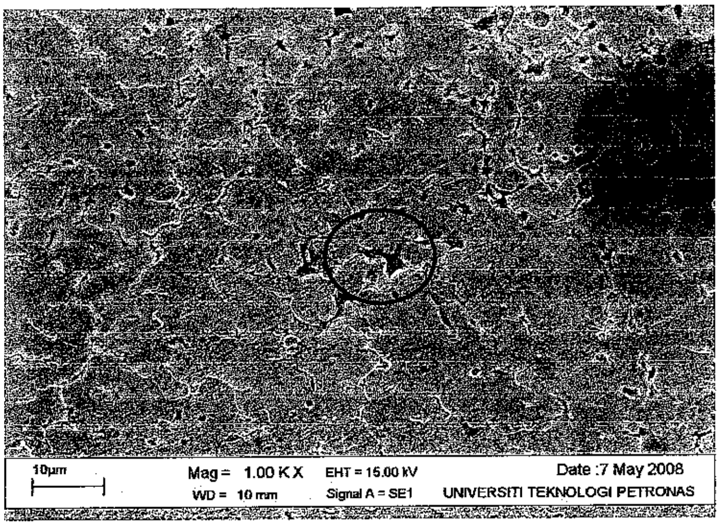


Figure 4.9: 1000x

Void space due to binder. Less binder is recommended to have good metal bonding.

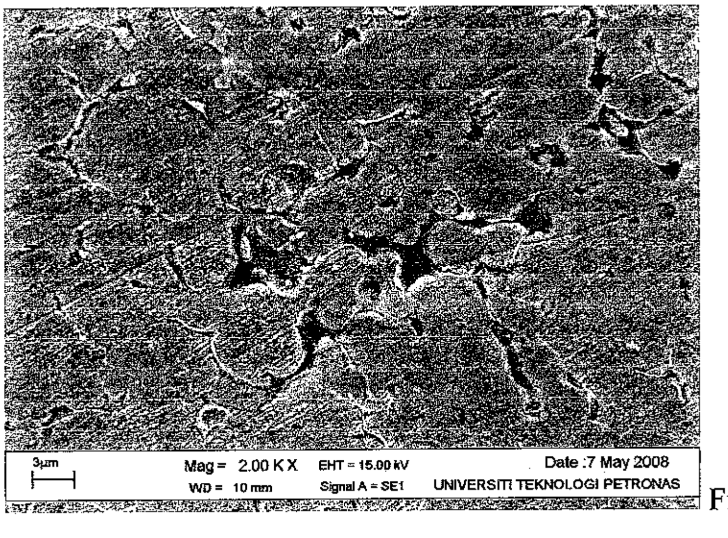


Figure 4.10 2000x

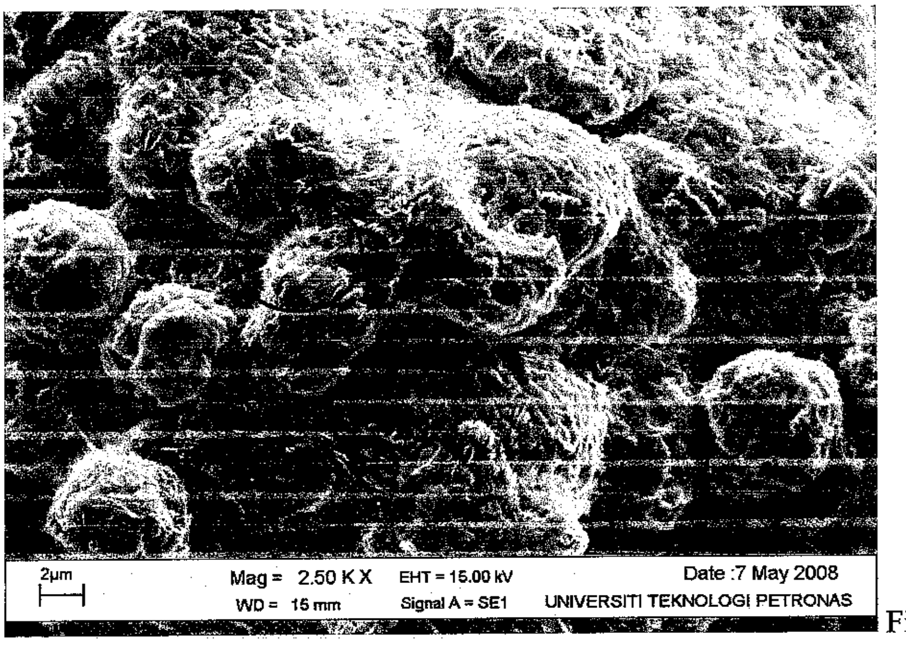


Figure 4.11: 2500x

Rust formation in circle.

CHAPTER 5

CONCLUSION & RECOMMENDATION

The project is to produce the pinion gear component using the powder metallurgy technology. The project achieves its objectives as author manages to develop the component through P/M technique. Furthermore several analysis also been made. There are three main factors has been considered in this project, pressing load, mixture compositions and sintering temperature. Other than that, oxidation of the metal powder has made the results slightly different from expected one. Absence of hydrogen will actually initiate corrosion and oxidation during the sintering process. Thus, further research should be fully equipped with hydrogen gas for sintering. In a nutshell, this project can be further developed to carry the main aspiration of producing automotive components using P/M technique in Malaysia.

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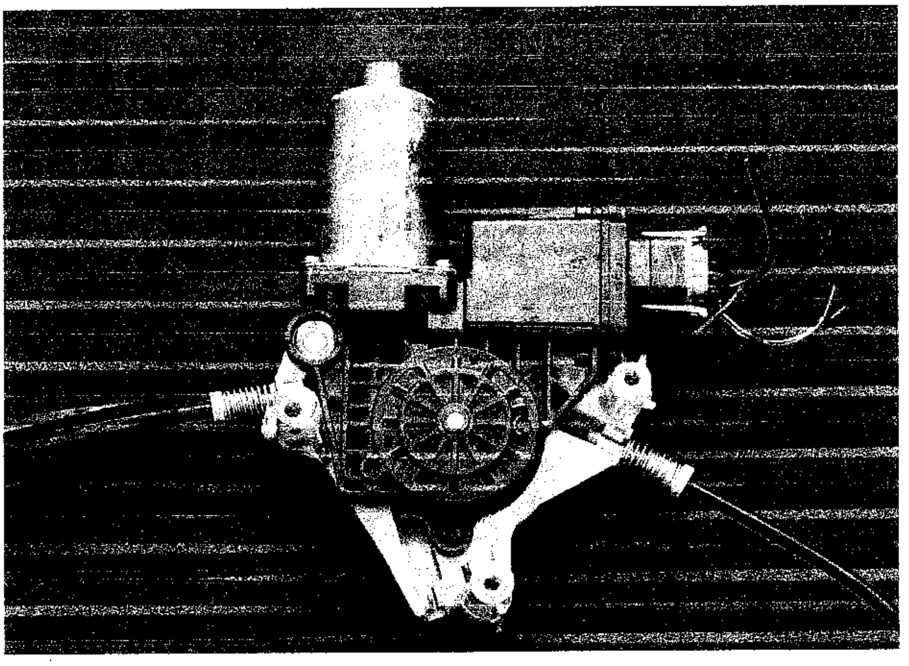
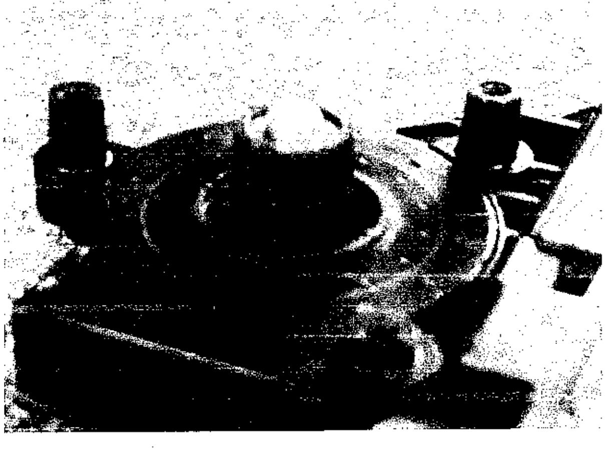
APPENDICES

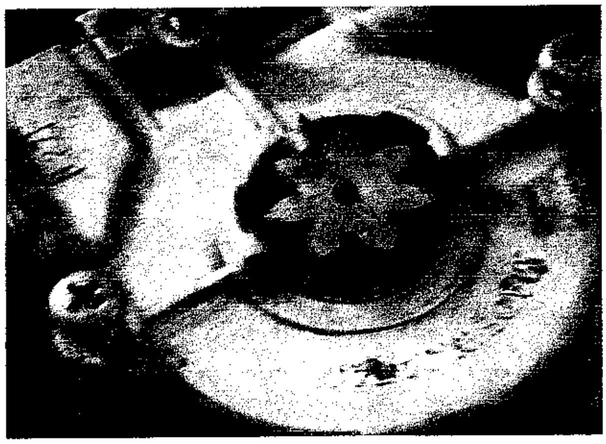
APPENDIX A: Collections of pictures



Initial power window system of Proton Waja.

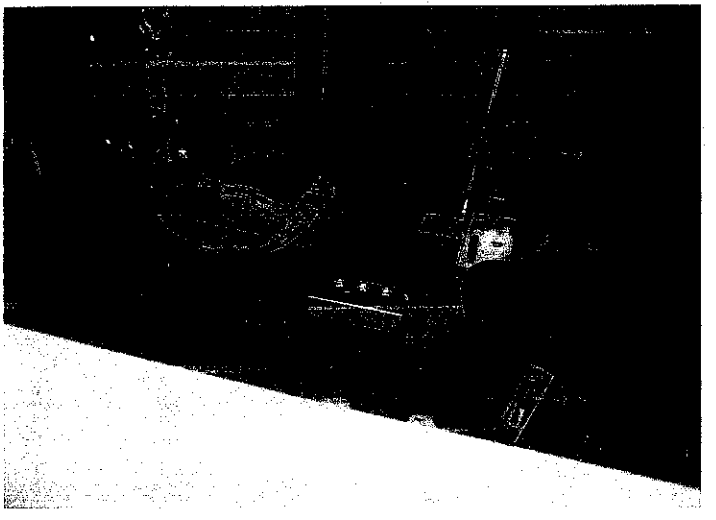


Pinion gear from Proton Waja.

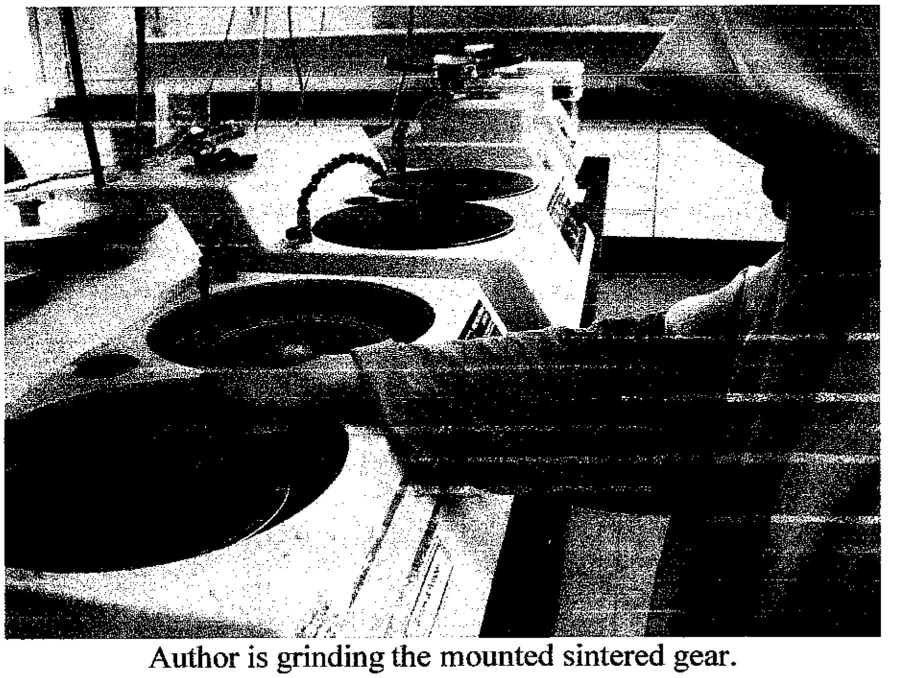


Pinion gear from Toyota model.

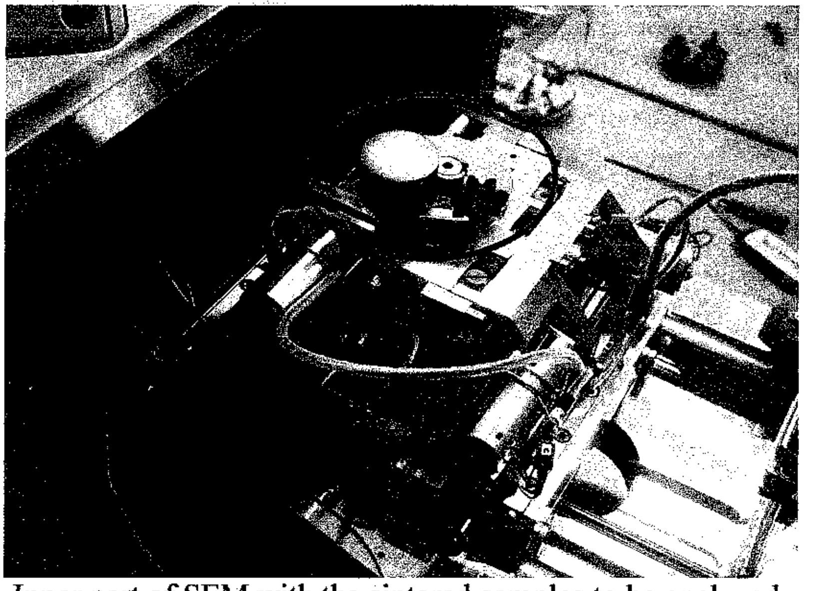
Renishaw- Cyclone Series 2D Digitizer



Process of placing raw material for EDM cutting.



Author is grinding the mounted sintered gear.


Inner part of SEM with the sintered samples to be analyzed.

APPENDIX B: Density calculation

In order to gage the mass of metal powder, some calculations related with aluminium model and original (iron) model of pinion gear must be carried out.

1. Mass = 4. 62089 g
2. Density of aluminium= 2.7 gcm3 at 20°C.
3. Volume = mass/ density = 4.62089/ 2.7 = 1. 71144 cm3
4. Height of aluminium model = 0.9 m, Height of iron model = 0.7 m
5. Volume iron = 0.7/0.9 x 1. 71144 = 1.33112 cm3
6. From density iron = 7.86 gcm3, volume iron = 1.33112cm3, thus ;
7. Mass iron = volume x density = (1.33112 x 7.86) = 10. 46269 g;
8. Say for 5 samples, ΣM = 5 x 10.4626 = 52.313g
9. ΣV = 5 x 1.33112 = 6.6556 cm3
10. V fe = 96g / 7.86 gcm3 = 12.2137cm3
11. V cu = 3g / 8.96 gcm3 = 0.3348 cm3
12. V c = 1g / 2.62 gcm3= 0.3817 cm3
13. V total = 12. 9302 cm3
14. From Rules of Mixtures = 100/ 12. 9302 = 7.73383 gcm3 (almost same to theoretical density)