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Materials And Introduction to Processing

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## Table of Contents

|     |                                                                               |      |
|-----|-------------------------------------------------------------------------------|------|
| 1   | Introduction .....                                                            | iii  |
| 2   | Forging .....                                                                 | iii  |
| 2.1 | Application of open die forging .....                                         | iv   |
| 2.2 | Advantages and disadvantages of open die forging.....                         | iv   |
| 2.3 | Microstructure of forged steel .....                                          | v    |
| 2.4 | Ultimate tensile strength (UTS) of forged steel.....                          | vi   |
| 2.5 | Processing defects of forged steel and how to eliminate them.....             | vi   |
| 3   | Die Casting .....                                                             | vii  |
| 3.1 | Applications of die casting.....                                              | viii |
| 3.2 | Advantages and disadvantages of die casting.....                              | viii |
| 3.3 | Microstructure of die cast aluminium.....                                     | ix   |
| 3.4 | Ultimate tensile strength (UTS) of die cast aluminium .....                   | x    |
| 3.5 | Processing defects of die cast aluminium and how to eliminate them. ....      | x    |
| 4   | Powder metallurgy.....                                                        | xii  |
| 4.1 | Applications of powder metallurgy .....                                       | xiii |
| 4.2 | Advantages and disadvantages of powder metallurgy .....                       | xiii |
| 4.3 | Microstructure of powder metallurgy (aluminium).....                          | xiv  |
| 4.4 | Ultimate tensile strength (UTS) of powder metallurgy aluminium.....           | xiv  |
| 4.5 | Processing defects of powder metallurgy aluminium and how to eliminate them.. | xv   |
| 5   | Conclusion .....                                                              | xv   |
| 6   | References .....                                                              | xv   |

## 1 Introduction

This technical report will look at three main categories under metal fabrication which are forming operations, casting, and miscellaneous operations. Under these categories the report will cover forging under forming operations, die casting under casting, and powder metallurgy under miscellaneous operations. The report will cover these fabrication techniques by defining them, giving examples of their application, advantages and disadvantages and other categories to help further the understanding of these processes.

## 2 Forging

Metal is shaped during the forging process by applying concentrated compressive stresses. The metal is shaped by rolling, pressing, or hammering it into the appropriate shape (Hawryluk *et al.*, 2021). The most common type of forging is said to be open die forging which is when two flat or simply curved dies are hammered or pressed together to shape the metal during the hot forming process. Below is a diagram illustrating the process of open die forging:

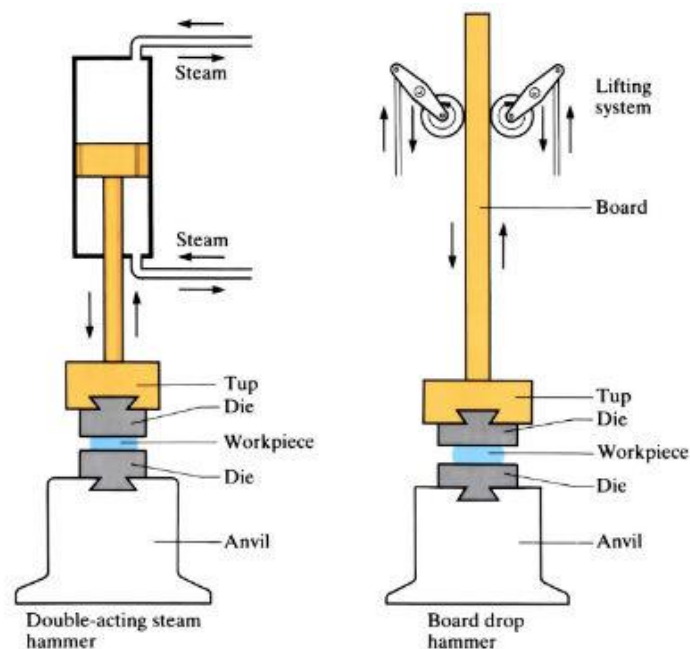


Figure 1: Open die forging with flat dies

The above image shows two type of hammers that can be used in open die forging. These are the double – acting steam hammer and the board drop hammer. Where the double – acting steam hammer uses steam to lift and drop the hammer while the board drop hammer functions with the use of pullies.

## 2.1 Application of open die forging

Components that come from the forging process are used in a lot of engineering fields such as civil engineering and automotive engineering. In automotive engineering open die forging is used in making the engine pistons (Solanki, Sonigra and Vajpayee, 2021). Forging is the first process of the life of a piston. This is usually to get the general shape of the piston which is then followed up by machining to get the piston to its final stage. Forging is also used for other engine components such as the bearing, gears, and chassis components. This is due to forged components being strong, tough, and lightweight (Solanki, Sonigra and Vajpayee, 2021).



*Figure 2: Image of forged engine components.*

## 2.2 Advantages and disadvantages of open die forging

Advantages:

- Versatile: can be used to create a wide spectrum of artefacts of different shapes and sizes such as small hand files.
- Strong: forging improves the grain structure of the material which makes it less prone to fatigue.
- Less expensive: it is more cost-effective because it has lower tooling costs and has less waste materials.

Disadvantages:

- it is not suitable for parts and applications where the part must have remarkably close tolerances meaning it will need to be machined after forging.
- It does not always produce the correct features that are needed or required for the part.

### 2.3 Microstructure of forged steel

The microstructure produced when steel is forged depends on many factors such as steel composition, forging temperature and the cooling rate of the steel (El-Faramawy, Ghali and Eissa, 2012). Although the microstructure depends on many factors, forged steel has some typical characteristics that are common in all forged steel microstructures which are:

1. Refined Grain – Strength and toughness are increased through forging, which transforms the initial coarse grains into elongated, fine grains.

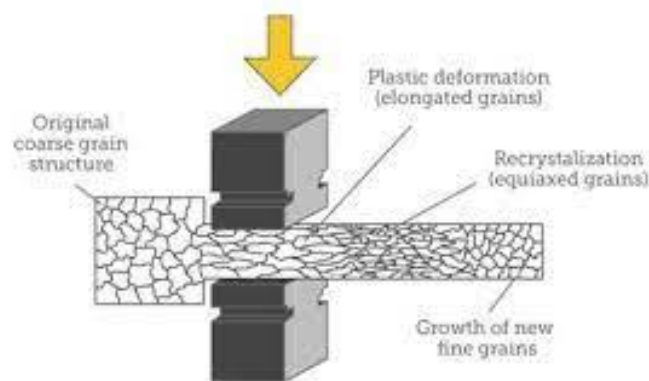


Figure 3: Image of change in grain microstructures after forging.

2. Decarburization - A softer microstructure may result from some carbon diffusing out of the steel at high forging temperatures, which also reduces the amount of pearlite (El-Faramawy, Ghali and Eissa, 2012).

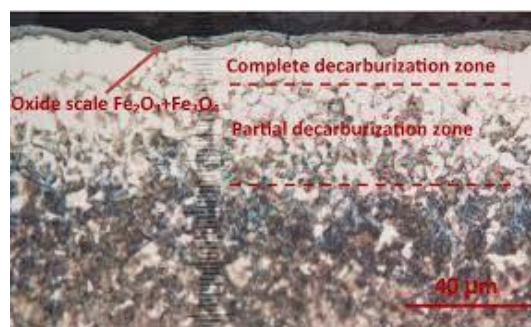


Figure 4: Image showing decarburization of steel microstructures.

## 2.4 Ultimate tensile strength (UTS) of forged steel

The highest stress that a material can bear when stretched or pulled before breaking is known as its ultimate tensile strength. Forged steel's ultimate tensile strength can differ significantly based on several variables which are:

- Carbon content – in general, higher UTS is correlated with higher carbon content. For instance, the UTS of high-carbon steel may exceed 700 MPa, whereas that of low-carbon steel may be just 250 MPa.
- Alloying elements – through the formation of hard phases certain elements such as molybdenum, vanadium, and chromium can further increase the UTS.
- Forging temperature – lower temperatures encourage finer grains and higher UTS, while higher temperatures can result in coarser grains and lower UTS.

## 2.5 Processing defects of forged steel and how to eliminate them.

Below are three common processing errors that can happen when using the open die forging processing method:

- Laps – During forging, laps happen when a piece of the metal folds over upon itself, resulting in an internal seam or crack. This occurs due to inadequate lubrication, high force, or improper forging technique. This defect can be eliminated by using adequate lubrication.

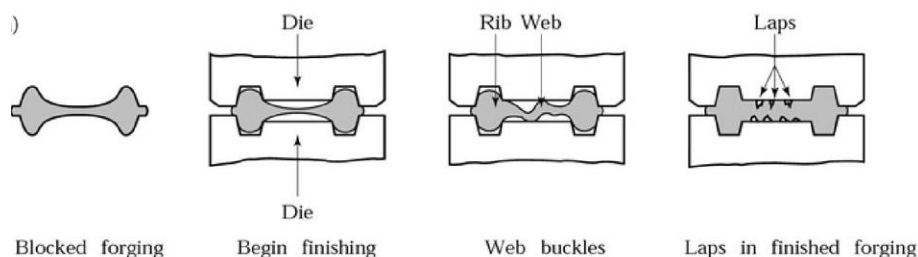


Figure 5: Image showing how laps form from forging.

- Cold shuts – Cold shuts are typically seen around corners or edges of the forging and manifest as tiny, linear fissures or seams. This is caused by incomplete forging of the metal layers, usually because of inadequate heat or incorrect hammer blows. This defect can be eliminated by using adequate heat.

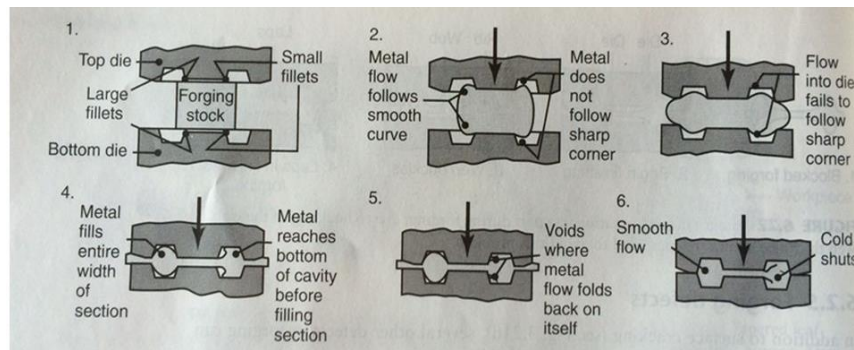


Figure 6: Image showing how cold shuts form from forging.

- Cracking – these are fractures on the outside or inside of the forged component, varying in size from tiny chips to whole fractures. This is caused by Heating the metal over the required temperature for forging and underheating the metal, which would cause it to crack. This can be eliminated by using the required temperature for the metal.

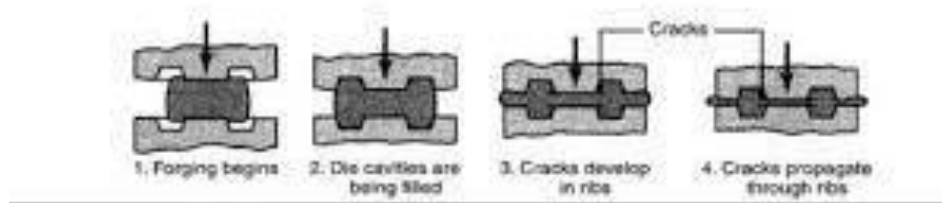


Figure 7: Image showing how cracking forms from forging.

### 3 Die Casting

Die casting is a technical metalworking technique that produces complicated, detailed products with a clean surface finish by filling a perfectly designed mould with pressurized molten metal. Constructing a die, which is a two-piece steel mould that has been carved to take on the final part's required shape is the first step in die casting. Afterwards, the selected metal which are usually alloys of copper, zinc, aluminium, or magnesium are melted in a furnace until it turns into a liquid (Tiwary and Sodhi, ). The molten metal is then pushed via a plunger into the die chamber at high pressure. Within the die, the metal quickly cools and hardens, taking on the shape of the mould cavity. The part created is then taken out and undergoes further machining or polishing. Below is an image showing molten metal being injected into a die chamber (Campbell, 2015).

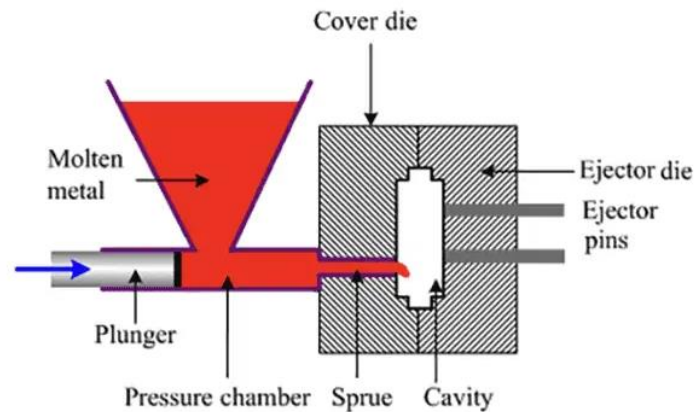


Figure 8: Image showing molten metal being injected into die chamber

### 3.1 Applications of die casting

Many engineering fields, including aerospace and automotive engineering, require components that are produced during the forging process (Jiang, Liu and Liu, 2022). The aerospace industry depends on die casting for a lot of their aluminium parts used on aircrafts such as the landing gear, wing structures and seat structures (Tiwary and Sodhi, ). Below is an image of some of the aluminium die cast components that are made for the aerospace industry.

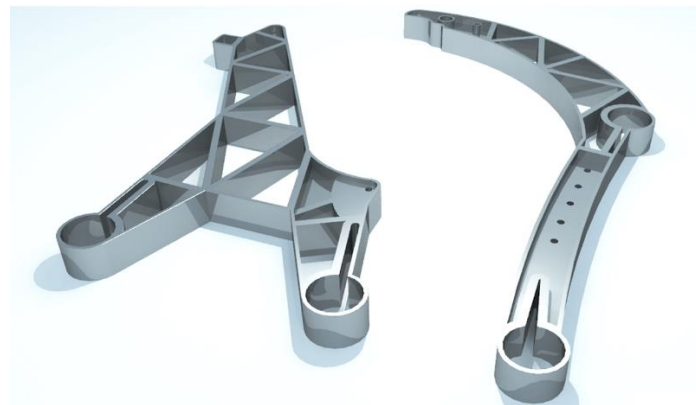


Figure 9: Image showing die cast airline handrail.

### 3.2 Advantages and disadvantages of die casting

Advantages:

- Very precise: die casting eliminates the need for additional machining by producing pieces with significant dimensional accuracy and fine features.
- Fast production: die casting is perfect for mass manufacturing because of its quick cooling and solidification, which enable high production rates.

- Strong and durable: die-cast components are renowned for their durability, strength, and smooth surface finish, which makes them appropriate for a range of uses.
- Lightweight: Many die-casting alloys are lightweight, which enables the aerospace and automobile industries to produce goods that use less fuel.

Disadvantages:

- High capital investment: it might be costly to create the die mould, particularly for complicated patterns.
- Limited part size: die casting has certain limitations, especially when it comes to larger parts, even though it can manage a wide range of sizes.
- Environmental impacts: Metal processing and melting can have an adverse effect on the environment, therefore careful waste management is needed.

### 3.3 Microstructure of die cast aluminium

Grain microstructure is affected by many factors such as alloy composition and casting parameters such as injection rate and die design. The rapid solidification at high pressure after die casting shapes the grain structure of aluminium (Cai *et al.*, 2020). This means that the grain patterns are quite complicated. Grain microstructures in die cast aluminium have general characteristics such as:

1. Dendritic structure – This is the most noticeable feature; it has the appearance of tree branches extending from a central point. The primary aluminium phase solidifies first, forming needle-like crystals that constitute the basis for these dendrites.



Figure 10: Image showing dendritic microstructure.

2. Eutectic regions – these are pockets of a mixture of phases, usually silicon and aluminium or other alloying elements, are found between the dendrites. These areas form a delicate, complex pattern because they solidify last.

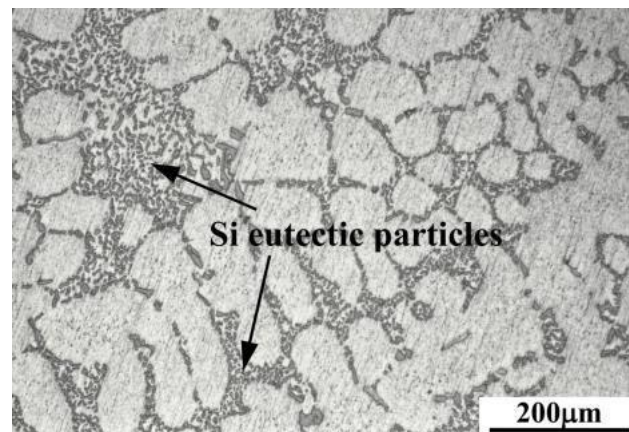


Figure 11: Image showing eutectic regions.

### 3.4 Ultimate tensile strength (UTS) of die cast aluminium

Die cast aluminium's ultimate tensile strength depends by several variables such as the alloy used, how it is heat treated, and the casting procedure. Below is the ultimate tensile strength of two of the most common die cast aluminium alloys:

- A380(copper & aluminium alloy): 250 – 330 MPa
- LM6(Aluminium, silicone & magnesium alloy): 310 – 380 Mpa

The above information show how different aluminium alloys can affect the UTS of the die cast aluminium. It also shows how factors such as heat treatment can affect the UTS as research shows that heat treatment can increase UTS by up to 50%. High pressure die casting can also affect UTS as it is said that it typically produces parts with higher UTS compared to low pressure die casting (Dong *et al.*, 2019).

### 3.5 Processing defects of die cast aluminium and how to eliminate them.

There are many defects that can be created when using die casting. Below are three defects that can be seen when using die casting:

1. Gas porosity – these are tiny gaps or air bubbles in the cast metal that are frequently seen on the product surface. They are caused by trapped air in the mould and moisture in the molten metal. Theses defects can be solved by degassing the molten metal and making sure the die is preheated before use (Avalle *et al.*, 2002).



Figure 12: Image showing gas porosity.

2. Cracking – these are fissures or fractures in the cast metal that vary in size from small cracks to full breaks in the product. It is caused by fatigue in the material and wrong heat treatment processes (Avalle *et al.*, 2002). This can be solved by using alloys that are resistant to fatigue and using the correct heat treatment parameters.



Figure 13: Image showing cracking in the die cast material.

3. Cold shut - these are parts of the material that are weak and unbonded due to inadequate molten metal flow. It is caused by low injection pressure and uneven mould heat (Avalle *et al.*, 2002). It can be solved by making sure the mould is fully heated and that the correct injection pressure is used when injecting the molten metal into the mould.

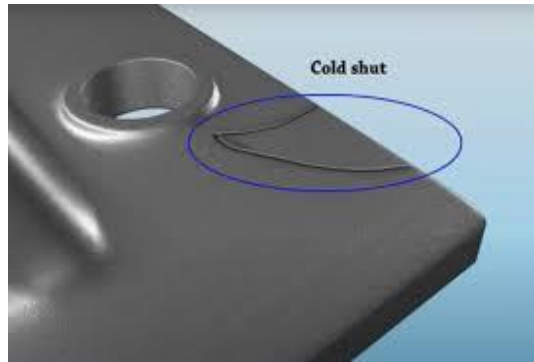


Figure 14: Image showing cold shuts in die casting.

## 4 Powder metallurgy

Powder metallurgy is a versatile metalworking method that involves shaping and melting metal powders into the appropriate shapes to create components. This process starts with creating the metal powder through atomization where molten metal is sprayed into gas making it break into fine particles (Akhtar *et al.*, 2018). The powder is then blended with different metal powders to make it strong, resistant to corrosion or conductive to electricity. It is then pushed with high pressure into a die mould creating what is called a green compact. The green compact is then heated under the metals melting point, this is called sintering. This binds the powder particles together through diffusion forming the final product. The sintered product can then be machined and processed to make it accurate for the application (Akhtar *et al.*, 2018).

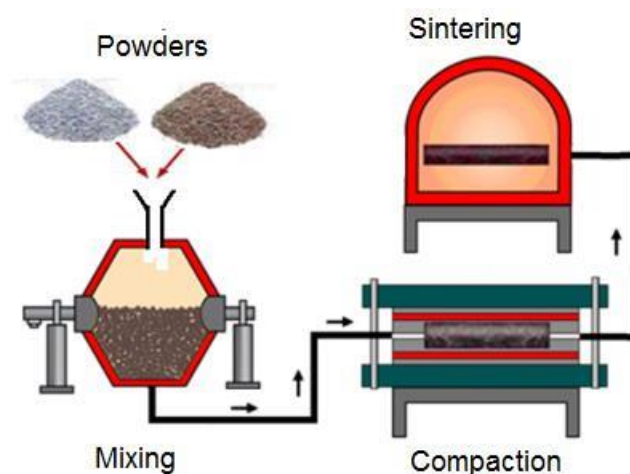


Figure 15: Image showing the process of powder metallurgy.

#### 4.1 Applications of powder metallurgy

Powder metallurgy is used in many different engineering fields such as aerospace, automotive and civil engineering. In the automotive industry powder metallurgy is used to create engine components. This is because it is strong and very light weight which helps with the performance of the vehicle as lighter weight is inversely proportional to fuel efficiency and acceleration (Singh, 2020).



*Figure 16: Image showing car parts made from powder metallurgy.*

#### 4.2 Advantages and disadvantages of powder metallurgy

##### Advantages

- Complex shapes: allows for manufacturing complicated shapes and internal characteristics that are difficult or impossible with conventional processes.
- Waste reduction: reduces costs and impacts on the environment by reducing material waste compared to machining or casting.
- Efficiency: reduces production time and cost through eliminating the need for substantial machining.

##### Disadvantages

- Prone to oxidation: metal powders are more prone to oxidation than bulk metal, handling and processing must be done carefully to preserve quality.
- Slow production rate: Powder metallurgy may be slower than high-volume casting, particularly for complicated products.
- Lower strength: parts made using powder metallurgy might not always be as robust as forged or cast pieces, depending on the material and manufacturing method.

### 4.3 Microstructure of powder metallurgy (aluminium)

Just like processing and forming operations the microstructure of the product is affected by many different factors such as powder mixing ratios (Huo *et al.*, 2011). There are dominant features in the microstructure seen across all products formed from powder metallurgy such as:

1. Granular structure – these structures are made up of individual metal grains created from the particles of sintered powder, this is the most noticeable aspect of the grain microstructure (Huo *et al.*, 2011).
2. Porosity – minuscule air pockets may remain from the initial gaps between the powder particles. The strength and characteristics of the finished item may be impacted by the porosity, which is determined by the sintering conditions (Huo *et al.*, 2011).

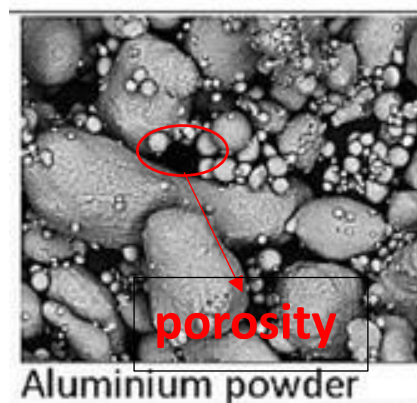


Figure 17: Image showing the microstructure of powder metallurgy aluminium.

### 4.4 Ultimate tensile strength (UTS) of powder metallurgy aluminium

Just like the UTS of casting and processing operations the UTS of powder metallurgy aluminium is dependent on many factors such as powder characteristics, sintering, heat treatment, and porosity. Looking at the factors above in consideration the typical range for powder metallurgy aluminium is between 150 – 400 MPa (Wu *et al.*, 2021). This shows that powder metallurgy aluminium has lower ductility resistance compared to other operation methods due to its porosity. This means that to achieve the desired UTS the powder selection of the alloys plays a big role.

#### 4.5 Processing defects of powder metallurgy aluminium and how to eliminate them.

Powder metallurgy is known for having internal defects due to its porosity. Below are some of the defects that are seen when producing parts using powder metallurgy:

1. Surface defects – these include cracks, pits, bumps, and tears. These are caused by not putting enough lubrication, wearing of the die and too much force when injecting (Wu *et al.*, 2021). These surface defects lead to premature failure of the part. These defects can be avoided by using the correct amount of lubrication and regularly maintaining the die.
2. Delamination – this is the separation of layers at interfaces between powder layers. This can be caused by the mixing of incompatible materials or when powder layers have not bonded fully. These defects can be avoided by using compatible materials with similar characteristics.
3. Warping – this is when there is a deviation from the intended shape such as bending. This is caused when there is uneven heat transfer during sintering. This defect can be solved by controlling heating during the sintering process (Huo *et al.*, 2011).

## 5 Conclusion

In conclusion we see that that the different process produces different results in terms of microstructure and different mechanical properties such as strength. We see that forging is the strongest of the three processes. All three processes have their advantages and disadvantages and will need the user to see which of the processes fits their needs to be able to pick the best suited process.

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