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Manufacturing Processes and Defects

Materials and Introduction to Processing (ACMA 4000)

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1 Abstract

The aim of this assignment is to look at the different manufacturing processes for metal fabrication. The three principal categories that will be looked at are Forming operation, Casting, and welding.

Depending on the product that is to be manufactured, consideration of advantages and disadvantages of the selected process should be taken. This could range from defects caused by each technique and the steps taken to limit them.

Choosing the material is also important when manufacturing. Knowing the ultimate tensile strength and microstructure produced in the processed material is crucial when considering its application.

It was found that during most of the chosen processes that controlling the pressures, speed in which the process is carried out and the temperature required play a pivotal part in the finish quality, strength, and prevention of defects.

2 Forming Operation.

2.1 Extrusion process

The forming operation chosen is Aluminium Extrusion. The extrusion process is a compression process. Where a work metal is forced through a die which can be shaped as desired giving a uniform cross-sectional shape. This process is used to create a wide range of products for several industries such as automotive, aerospace, industrial and many more.

There are many types of extrusion process. The two most common being direct extrusion also known as forward extrusion and indirect extrusion also known as backward extrusion or reverse extrusion. (Groover, 2010, p. 420)

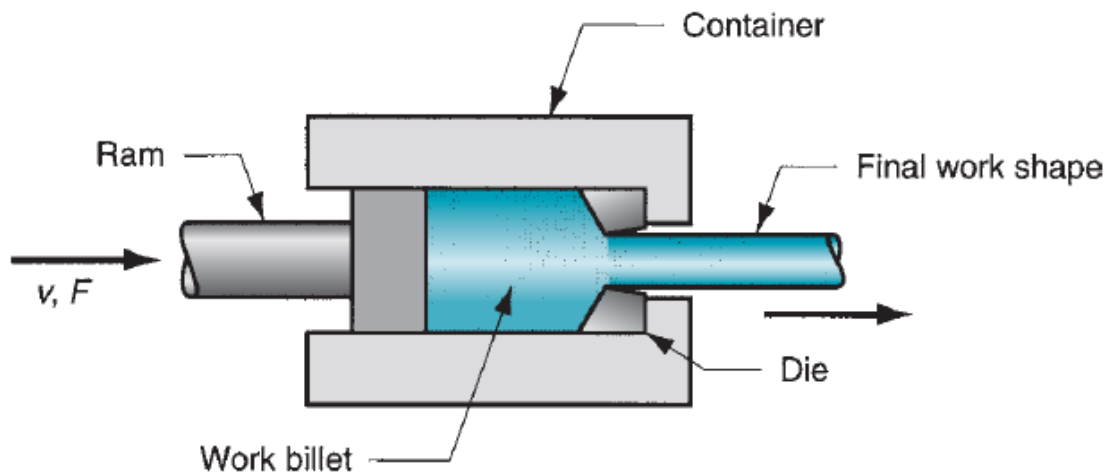


Figure 1 Diagram of Direct Extrusion (Groover, 2010)

The process for direct extrusion as shown in figure 1. At the beginning of the process the billet is cut correct size to be used. The billet is then preheated to around 400-500 degrees above its recrystallization temperature. This makes it more malleable but not molten allowing the billet to be shaped. The die is also preheated to around 450-500 degrees. Lubricant is then applied to prevent reduce friction. A hydraulic ram is used to compress the billet within the container causing the billet to expand and fill the container. With this continuous force applied. The billet is forced through the die opening forming the extrusion to the desired shape. The aluminium now reaches the quenching stage where the material is cooled evenly, improving its

mechanical properties. The aluminium is then cut, stretched and aligned to its desired specification.

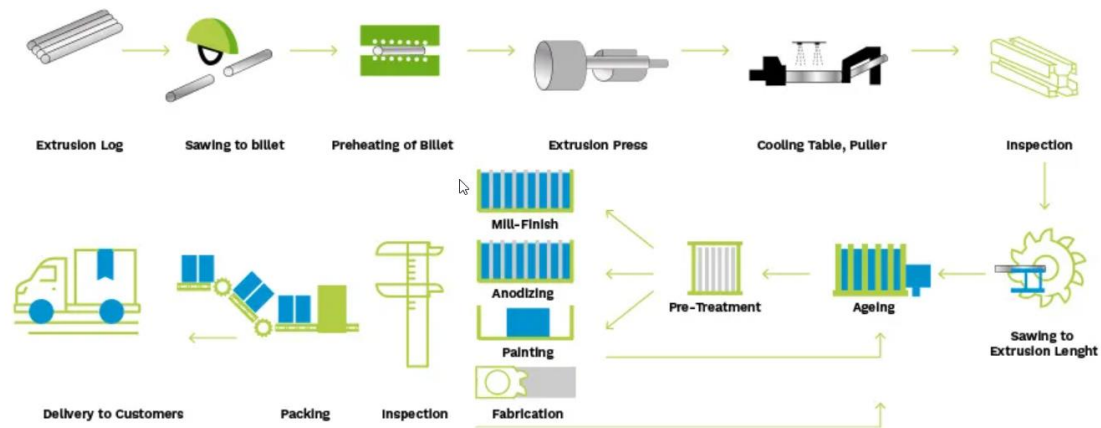


Figure 2- Extrusion process flow (Atieuno, 2023)

2.2 Advantages and disadvantages of the extrusion process

There are many advantages of the extrusion process as follows:

1. Eco-friendly as it can use recycled materials and generates minimal waste.
2. Cost effective compared to other processes as they require fewer resources and materials.
3. When controlled correctly. A high-quality surface finish with dimensional accurate product can be achieved.
4. A wide variety of shapes and sizes can be allowing flexibility of design.

Disadvantages are as follows:

1. After extrusion, what is known as the “butt end” of the billet remains in the die opening. This is considered as waste material.
2. The extrusion die is susceptible to high temperatures and pressures causing the die to easily wear.

2.3 Process defects and preventative measures.

Consideration into the process is needed to prevent any defects. Incorrect chamber temperature, extrusion pressure, ram speed also the friction generated can issues. The addition of lubrication is to minimise the effects of friction.

Due to the extrusion normally being a non-continuous process where only one billet is loaded at a time. The fluctuation in temperatures of the billet can cause a non-steady state of flow.

The friction between the billet and the container, and between the dummy block and billet influence metal flow. The two most dominating factors being billet-container-die friction and billet thermal gradients (A.F.M. Arif, 2002)

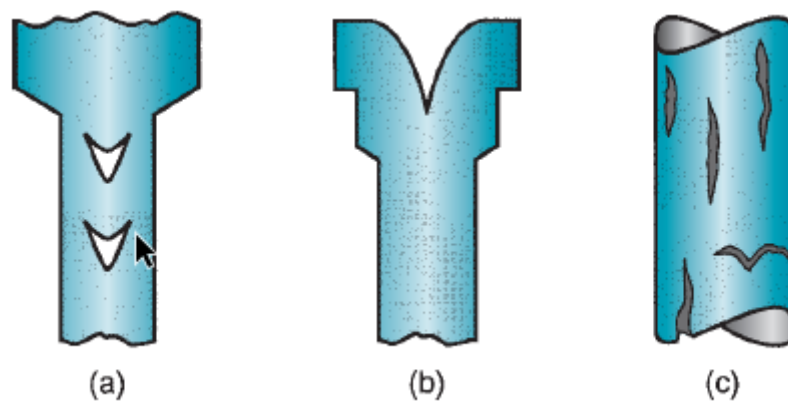


Figure 3. Common defects. (a) centerburst, (b) piping, and (c) surface cracking (Groover, 2010, p. 429)

Centreburst (a) in figure 2 can be described as cracks that develop internally of the worked part cause by tensile stresses. This causes the material to stretch on the outer regions. When the stresses get too high, centreburst occurs. Causes are high die angles, low extrusion ratio and impurities in the work metal. Detection of centre burst is difficult to detect as the issue occurs internally of the worked metal.

Piping (B) in figure 2 Normally associated with direct extrusion. Also known as fishtailing. Found at the end of a worked billet. Where a sink hole forms. Preventative measures for this anomaly are to use a dummy block which has a slightly smaller diameter than the billet.

Surface cracking (C) in figure 2 as the name suggest is where cracks appear in the surface. Caused by high work temperature and extrusion speed being too high. This causes high strain rates and more heat caused by increased friction due to the speed of extrusion. Preventative measures to consider are extrusion speed rate and temperature control.

2.4 Microstructure, properties, and tensile strength.

Table 1- Yield strength and tensile strength for selected metals. (Groover, 2010)

Metal	Yield Strength		Tensile Strength		Metal	Yield Strength		Tensile Strength	
	MPa	lb/in ²	MPa	lb/in ²		MPa	lb/in ²	MPa	lb/in ²
Aluminum, annealed	28	4,000	69	10,000	Nickel, annealed	150	22,000	450	65,000
Aluminum, CW ^a	105	15,000	125	18,000	Steel, low C ^a	175	25,000	300	45,000
Aluminum alloys ^a	175	25,000	350	50,000	Steel, high C ^a	400	60,000	600	90,000
Cast iron ^a	275	40,000	275	40,000	Steel, alloy ^a	500	75,000	700	100,000
Copper, annealed	70	10,000	205	30,000	Steel, stainless ^a	275	40,000	650	95,000
Copper alloys ^a	205	30,000	410	60,000	Titanium, pure	350	50,000	515	75,000
Magnesium alloys ^a	175	25,000	275	40,000	Titanium alloy	800	120,000	900	130,000

Table 1 shows the yield strength and tensile strength for selected metals. During the extrusion aluminium alloys are often used.

As per the table the Aluminium alloy is given and yield strength of 175 MPa and a tensile strength of 350MPa.

The behaviour of metals during forming can be seen from the stress-strain curve. Most stress-strain curves for metals are divide into two regions. The plastic region and the elastic region. The plastic region is of most interest during forming. As during the forming process the material is plastically and permanently deformed.

During the warm and cold extrusion, the grain structure and strength properties are Enhanced. In extrusion, dynamic recrystallization occurs, and the size of the recrystallized grain is a function of the extrusion parameters and the heat treatment after extrusion. It was possible to demonstrate that the extrudate is more homogeneous in the direct extrusion process, resulting in a more uniform grain structure, when indirectly extruded billets were extruded into a quasistatic state. Theoretical analysis in addition to the experimental work. (M. Schikorra, 2007)

Fig.4 show the experiment conducted by (Nadja Berndt, 2017) where billets of aluminium alloy AA6060 were used. The material was characterised by an average grain size of approximately 100 µm and an equiaxed grain shape. It was heat treated for 3h at 530 °C and then water-quenched to room temperature. The material was then subjected to backward extrusion in a horizontal extrusion press with a maximum

press capacity of 8MN. The billet diameter of the cast and container was 107 or 110 mm.

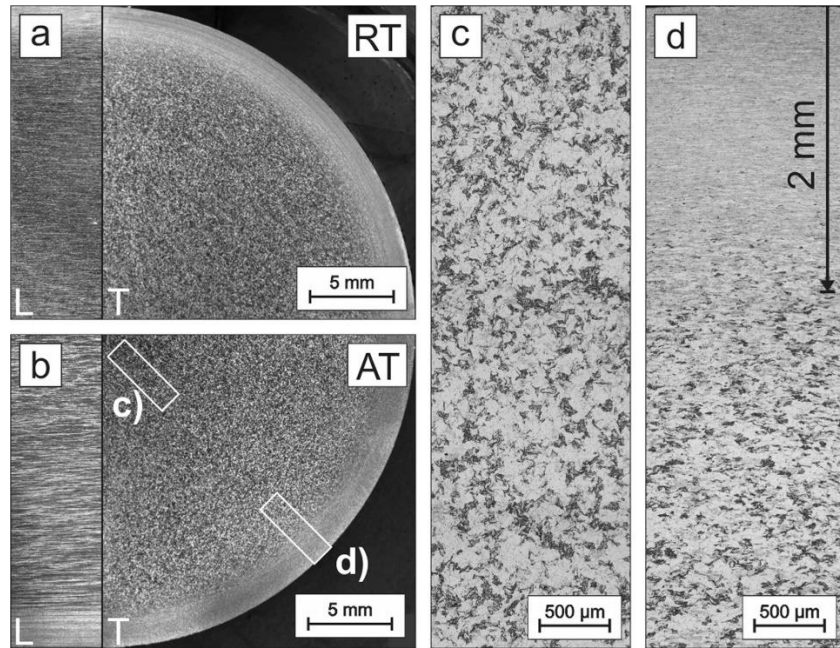
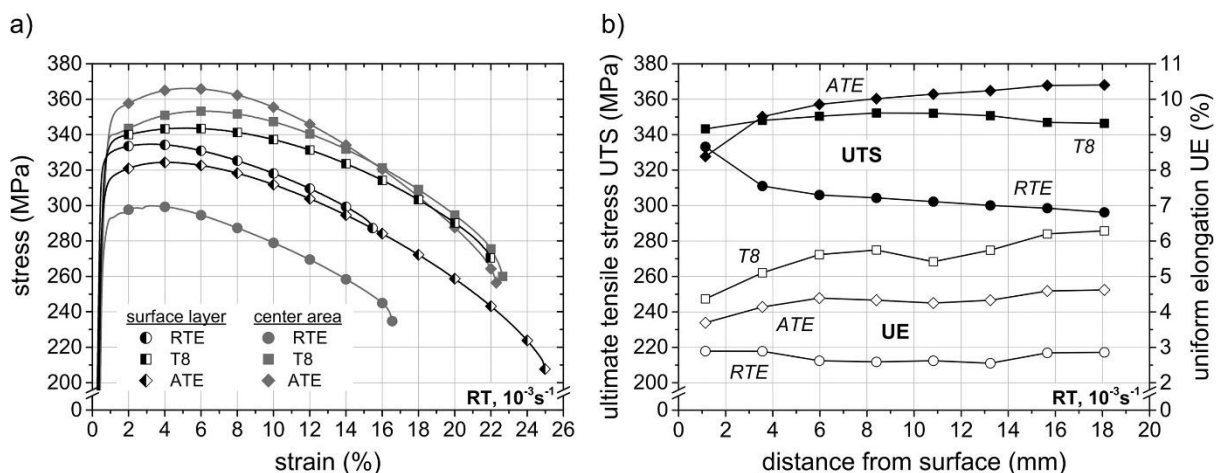


Figure 4-Optical micrograph of AA6060 aluminium alloy

Fig. 4. Optical micrographs of (a) RT- room temperature and (b) AT- aging temperature extruded material. Both extrudates exhibit a typical cold extrusion microstructure: a fibrous core (c) consists of rather coarse grains. (d) exhibits severely sheared grains. It is composed of severely sheared grains after cold and warm extrusion. The severe shear deformation of the near-surface areas results in a fine-grained pancake microstructure. The surface layer width is approximately 2 mm extrudates in both cases. heterogeneous microstructures occur on both processing routes with a rather coarse texture with elongated grains in the central areas and a texture of both fibres (Nadja Berndt, 2017)



Graph 2a shows stress vs strain curves for the surface layers and centre areas of the RT-extruded, AT-extruded. While the surface layer's tensile properties are quite similar from neck to neck, more pronounced differences can arise. observed for the centre areas specifically, the RT-extruded condition exhibits a reduced strength.

3 Casting operation

3.1 Die Casting

Die casting is carried out using the die casting machine to hold two molds of the desired shape and keep held while molten metal is forced into the cavity of the molds. There are typically two main types of die casting machines. A hot-chamber and cold-chamber. The difference between the two types is how the liquid metal is injected into the mold cavity. Hot chamber the metal is melted in the chamber shown in figure 5 (1). The plunger then compresses the liquid metal and injecting along the goose neck and through the nozzle into the cavity. Typical injection pressures are 7 to 35 MPa (Groover, 2010, p. 239) a high volume of parts production can be achieved using this method. The molds are then separated leaving the intended mold which is by now solidified. Most of the injection system is submerged in molten metal. Therefore, the metals used are those with low melting points such as Zinc, Tin, Lead and magnesium. The process is susceptible to flash. This is where the pressurised liquid metal is forced between the space between the two molds. The flash must then be trimmed.

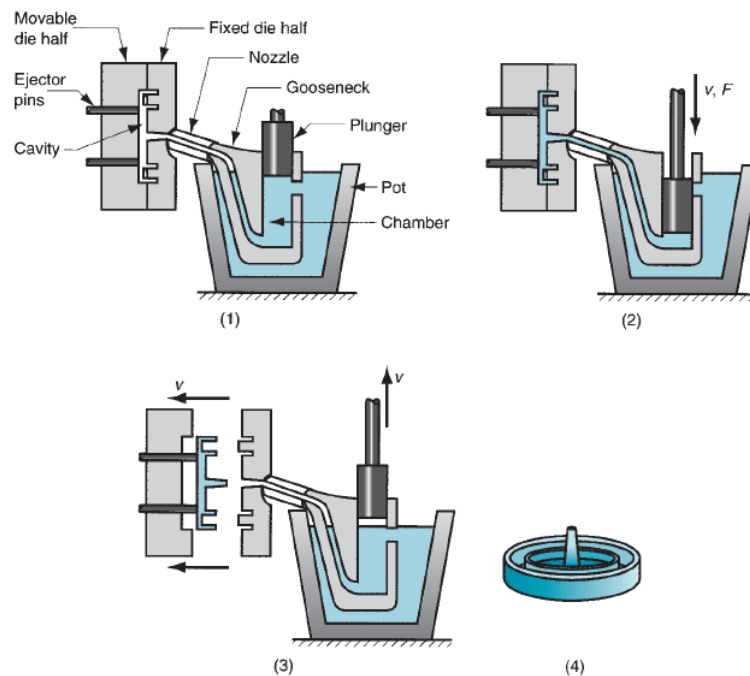


Figure 5 Hot chamber casting. (Groover, 2010, p. 240)

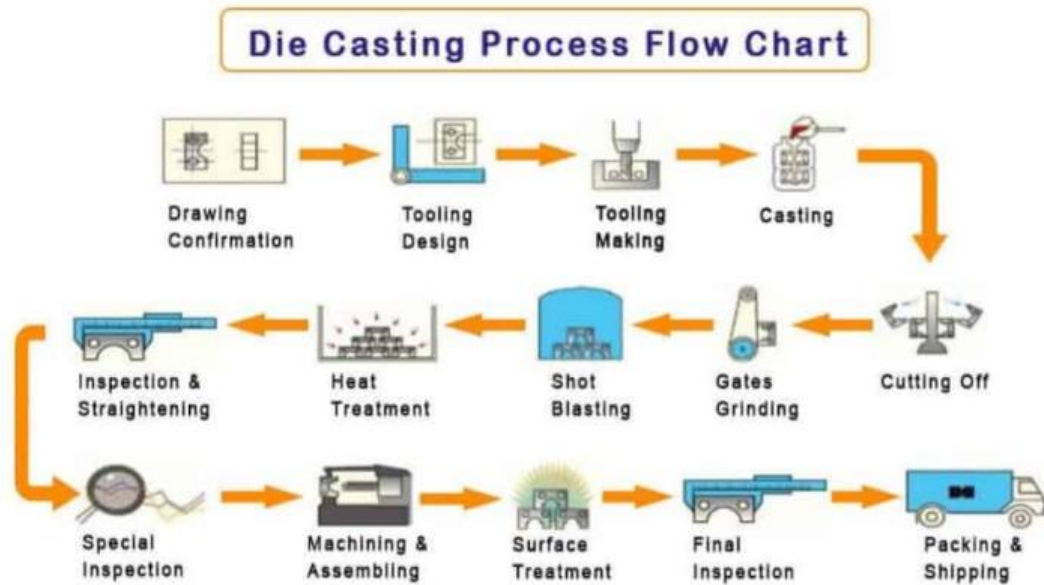


Figure 6 Die casting process flow. (precise-cast, n.d.)

Examples of Die Casting Applications

Power train components, including cylinder blocks and transmission cases; body and chassis components, including shock towers and subframes; and components for electric vehicles. Ryobi supplies a wide variety of components to automobile manufacturers worldwide and is highly regarded for its technological capabilities and quality.

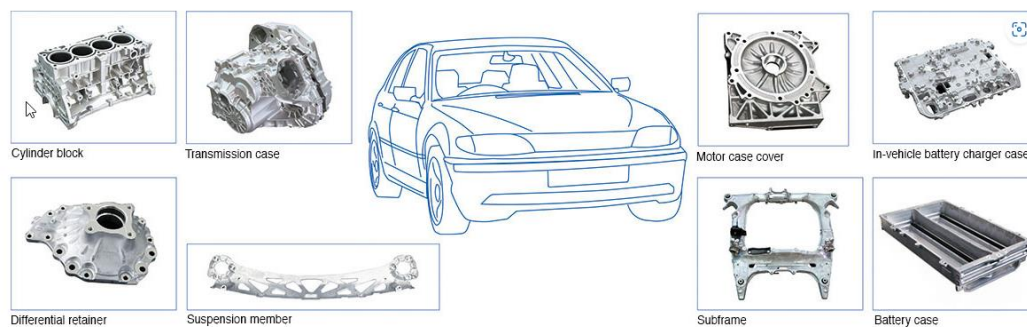


Figure 7- examples of Die casting applications. (Ryobi, n.d.)

Die casting is used to produce many components within the automotive industry. Fig.7 shows examples. From cylinder blocks to subframe components. Due to the variety of complex components that can be produced. This method is favourable.



Figure 8-Rear subframes for Aston Martins DBX SUV. (Purnell-Whitehead, 2024)

Fig 8 shows the rear subframes used by Aston Martin for its SUV DBX that is produced in St Athan South Wales. The component which is required to be made of a strong material as this subframe will be connected to the running gear of the car as well as the rear drive train.

3.2 Advantages and Disadvantages

In recent years, the use of die casting aluminum alloys in the production of critical safety parts in the automotive industry has been significantly reduced. The advantages of die casting are high productivity and the possibility to cast components with thin walls and complicated geometry. The material strength may be reduced due to internal defects in die casting components. Internal defects such as porosity, solidification shrinkage and abnormal microstructures (or the scattered chill microstructure). Porosity is a typical defect in high pressure die casting products, which is created by either entrapped gasses or involved air during the casting process. The effects of internal defects on the tensile properties of cold chamber die cast aluminum alloys demonstrated that the tensile strength decreases linearly with increasing the fraction of the area of defect on the fracture surface. Furthermore, abnormal structures can significantly reduce the tensile strength compared with other defects. (M. Okayasu, 2009)

Diagram of the mentioned defects can be seen in Fig.9.

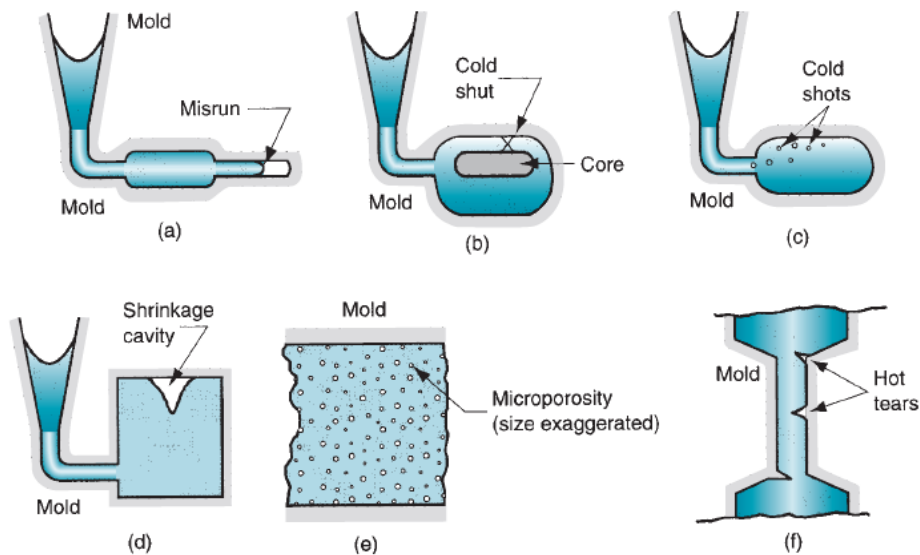


Figure 9 Defects in Die casting (Groover, 2010, p. 250)

Advantages of Die casting are as follows:

1. High productivity

2. Good dimensional accuracy
3. Good surface finish
4. Economical process at high volume
5. Fine grain structure and good mechanical properties are achieved.
6. Intricate shapes can be cast.
7. Small size parts can be produced.

Disadvantages are:

1. Not applicable for high melting point metals and alloys such as steel.
2. Large parts are more difficult to cast.
3. High die cost.
4. Gasses can be entrapped in the process causing porosity.

3.3 Microstructure, properties, and tensile strength

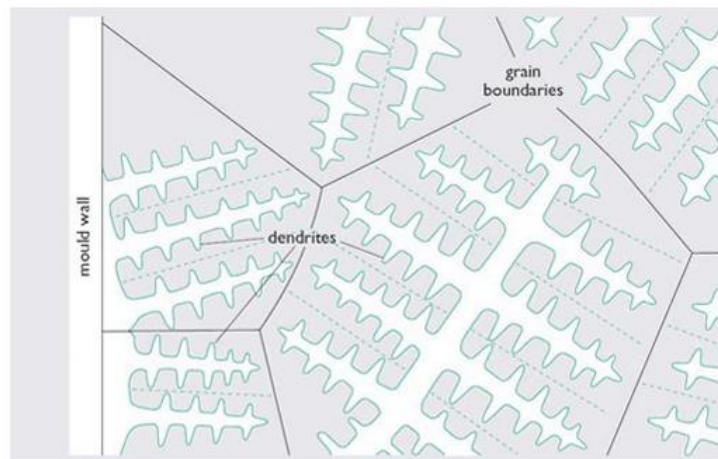


Figure 10- Schematic of dendritic formation (The Open University, n.d.)

There are very special microstructures in metal castings. When the liquid metal cools and begins to solidify in a mold, grains of crystallization are formed both on the walls of the Mold as well as within the bulk of the Liquid Metal. Figure 10 show they grow dendritically.

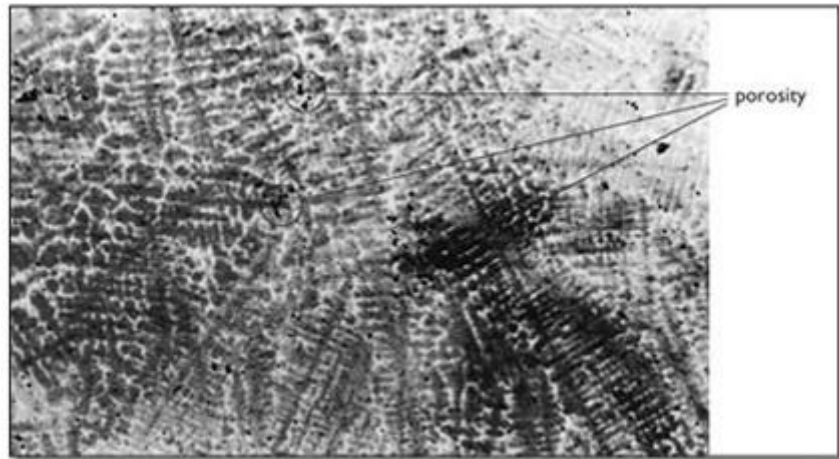


Figure 11-Cast microstructure. (The open university, n.d.)

There are two other common defects in the cast microstructure seen in fig.11 are particles of impurities known as inclusions and porosity, which are small holes in the cast.

Table 2-Mechanical properties of Aluminium alloy A380 (Dynocast, n.d.)

Material	Alloy	Elongation ▮▮	Tensile Strength ▮▮	Yield Strength (0.2%) ▮▮	Impact Strength ▮▮	Shear Strength ▮▮	Hardness ▮▮	Process
		% in 50mm	MPa	MPa	J	MPa	Brinell (HB)	
Aluminum Die Casting Metals	Aluminum Alloy A380	3.5	324	160	4	190	80	Cold Chamber Die Casting

Aluminium alloy A380 is a commonly used. It offers a good combination of mechanical and thermal properties. With a tensile strength of 324MPa and yield strength of 160MPa.

4 Welding

Welding is a manufacturing process where two surfaces of different or the same type of material is fused together with or without the application of heat, pressure, and filling material. The most important metal joining process used is said to be arc welding. Used in automobiles, nuclear reactor pressure vessels, boilers, and economizers.

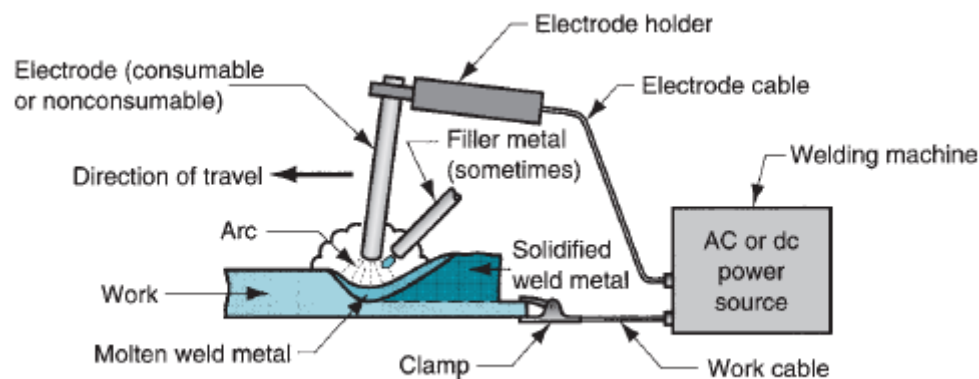


Figure 12-Arc welding process. (Groover, 2010)

Arc welding is a fusion-welding process. The fusion of the metals is caused by a coalescence achieved by the electric arc between and electrode and the work. (Groover, 2010) the heat produced can produce temperature of 5500°C melting the metals. As the electrode is moved along the metal the molten weld pool solidifies together.

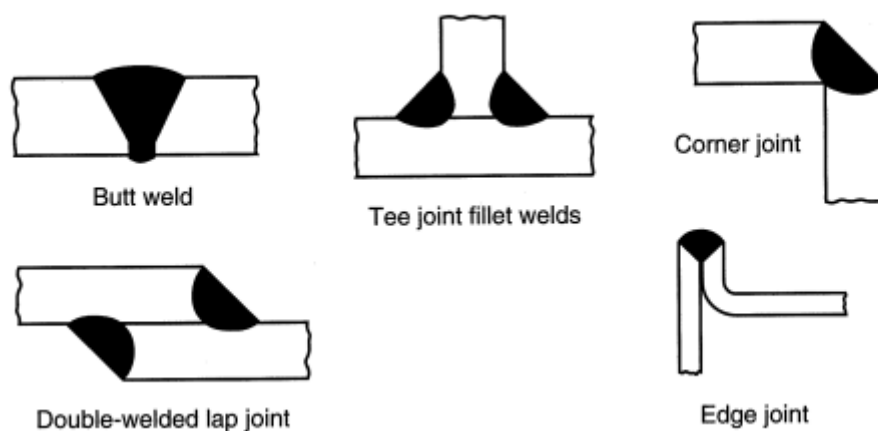


Figure 13-Basic types of welded joints (George E Dieter, 2020)

Fig.12 Shows basic types of welding joints. In which Fig 13 shows a sketch of the grain structure from an electric arc weld.

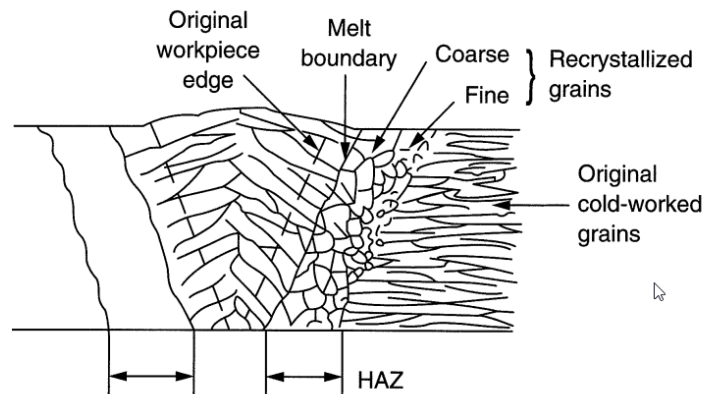


Figure 14- Sketch of grain structure through an electric arc weld in two rolled metal plates (George E Dieter, 2020, p. 647)

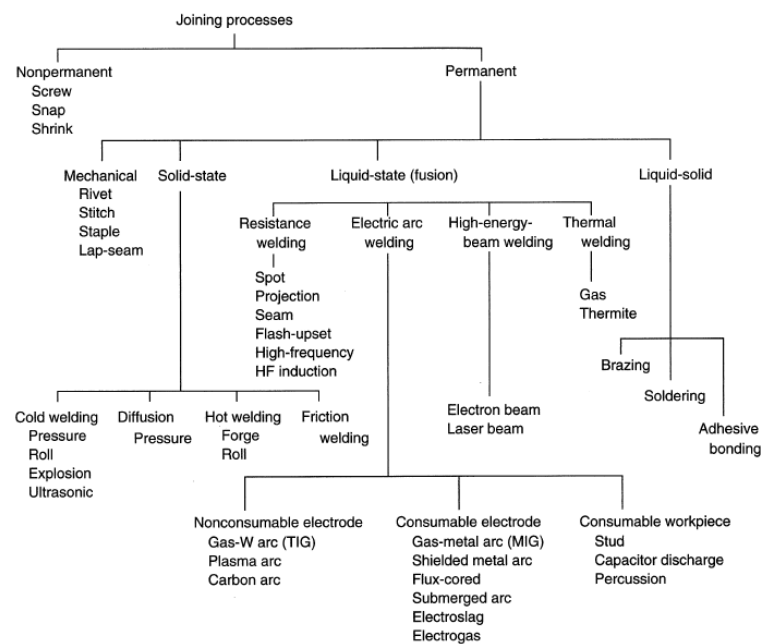


Figure 15- Joining processes (George E Dieter, 2020)

There are many types of joining process and mamani types of welding which is shown in fig.14

4.1 Advantages and disadvantages

Advantages of welding are:

1. Permanent joint
2. No change in cross sectional area
3. Various shapes can be joined.
4. Leak proof.
5. Dissimilar joining is possible (different metals).

Disadvantages are:

1. Change in metallurgical properties.
2. Residual stress generation
3. Distortion
4. Inspection is difficult.

4.2 Microstructure, properties, and tensile strength.

Unlike in casting, during welding, Where the molten pool moves through the materials, the growth rate and temperature gradient vary considerably across the weld pool.

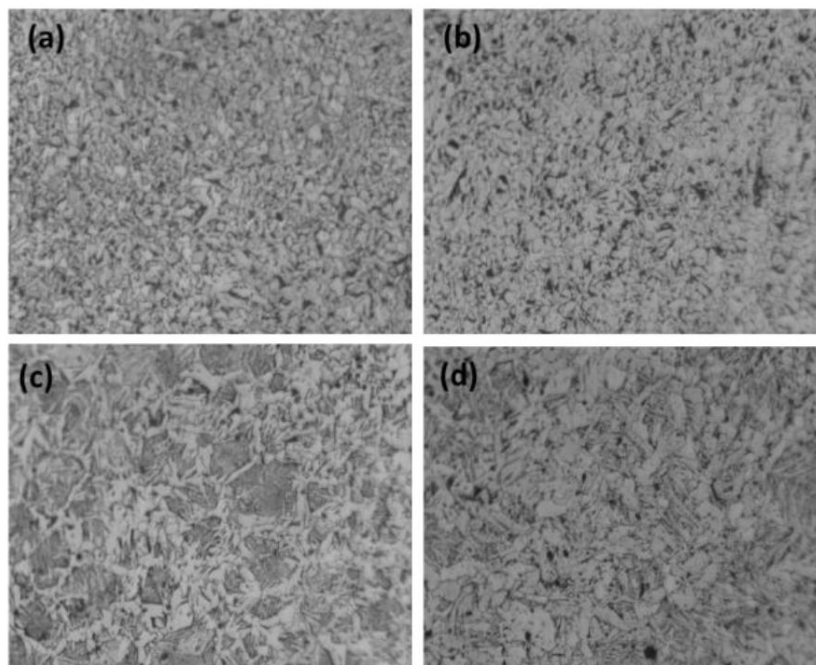


Figure 16-Microstructures of welded mild steel. (M Muzibur Rahman, 2022)

Figure 16 shows the microstructures of welded mild steel in (a) unaffected zone, (b) transition zone, (c) coarsened zone, (d) fusion zone. The microstructure observations show very homogeneous isentropic configuration of normal grains with clear boundaries of uniformity in mild steel. The mild steel is about 8% weaker than seamless mild steel. (M Muzibur Rahman, 2022) The UTS of mild steel is 300MPa and has a yield strength of 175MPa

5 Bibliography

A.F.M. Arif, A. K. S. S. Q. M. R. K. A.-F., 2002. *PRODUCT DEFECTS IN ALUMINUM EXTRUSION*. Dhahran, s.n.

Atieuno, 2023. *Atieuno*. [Online]

Available at: <https://www.atieuno.com/2023/07/17/aluminium-extrusion-process-guide/> [Accessed 25 01 2024].

Dynocast, n.d. *Dynocast*. [Online]

Available at: <https://www.dynacast.com/en/knowledge-center/material-information/aluminum-die-casting-metals/aluminum-alloy-a380> [Accessed 31 1 2024].

George E Dieter, L. C. S., 2020. *Engineering design*. 6th ed. Maryland: McGraw-Hill College.

Groover, M. P., 2010. *Fundamentals Of Modern Manufacturing 4th ed*. Hoboken, NJ: JOHN WILEY & SONS, INC..

Hatch, J. E., 2005. *Aluminium properties and physical metallurgy*. 10th ed. Ohio: American society for metals.

M Muzibur Rahman, M. N. P. M. A. H. S. R. A., 2022. *INVESTIGATION OF ARC WELDING JOINING EFFECTS ON MECHANICAL*. Dhaka, SSRN.

M. Okayasu, S. Y. M. M. M. H. a. H. Y., 2009. Comparison of mechanical properties of diecast aluminium alloys: coldv. hot chamber diecasting and highv. low speed filling diecasting. *International Journal of Cast Metals Research*, 22(5), pp. 374-380.

M. Schikorra, L. D. L. ' . A. E. T., 2007. Microstructure analysis of aluminum extrusion:. *Journal of Mechanical Science and Technology* , Volume 21.

Nadja Berndt, P. F. M. B. M. F.-X. W., 2017. Microstructure and mechanical properties of an AA6060 aluminum alloy. *Materials Science and Engineering: A*, 707(ISSN 0921-5093), pp. 717-724.

P.G Ahire, U. P. M. K., 2018. *Genetic algorithm based optimization of the process parameters for manual metal arc welding of dissimilar metal joint*. Auranganad, procedia manufacturing.

precise-cast, n.d. *precise-cast*. [Online]

Available at: <https://precise-cast.com/casting-process-summary/>

[Accessed 24 01 2024].

Purnell-Whitehead, S., 2024. *Rear subframe of an Aston martin DBX. Photographed at the St Athan facility..* St Athan: s.n.

Ryobi, n.d. *Ryobi-group*. [Online]

Available at: <https://www.ryobi-group.co.jp/en/diecasting/features/>

[Accessed 25 01 2024].

The open university, n.d. *Open learn*. [Online]

Available at: <https://www.open.edu/openlearn/science-maths-technology/design-innovation/manufacturing/content-section-2.7>

[Accessed 31 01 2024].