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Manufacturing Processes and Defects
Materials and Introduction to Processing
AMCA4000

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Abstract

This report covered a variety of different processing methods with examples from casting, forming, and joining; along with how each technique influences material characteristics, and related merits and demerits. It aimed to draw information from as wide a variety as possible; to provide a clear and compact view of these, and how they're implemented in industrial environments. Each was analysed with information on its grain/micro-structure, typical tensile strength, and use cases were explored. In addition to benefits and drawbacks, methods to deal with common defects relevant to each process were discussed.

1 Introduction

Metal fabrication encompasses various techniques to shape, manipulate, and assemble metals, vital across industries like construction, automotive, and manufacturing. Processes like welding, casting, and forming are used to meet various specific requirements. Combining skill and technology, these techniques play a pivotal role in creating diverse metal structures and components essential in modern infrastructure and production.

Casting and forming are pivotal in metal fabrication, offering diverse avenues to shape materials. Casting utilises moulds and molten metal, through methods like sand or investment casting, facilitating precise shapes and large-scale production. Forming encompasses bending, rolling, and stamping, shaping metals into desired forms, crucial in industries such as the automotive. These techniques, combining precision and versatility are key to metal fabrication, and enable the creation of everything from industrial components to everyday objects.

2 Welding – Joining

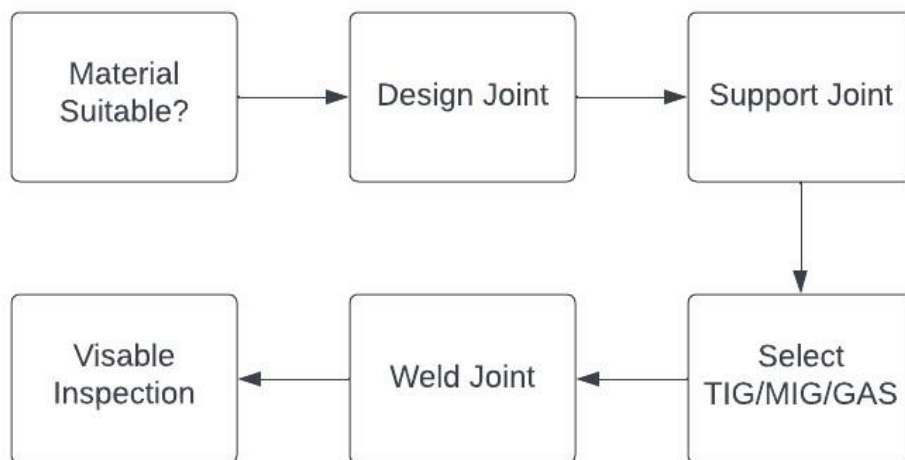


Figure 1 Flow Diagram of Welding Process

Welding is a method of joining two materials, usually metals. This is done by generating a molten pool of the material which, when solidified, becomes the bond between joining parts (Weman, 2011). When arc welding, a 'shielding' gas is often used to protect the weld site. This is done to remove the chance of oxidation around the site which would lower the strength of the weld (TWI, 2023). Additionally, gas welding using consumable gas to melt the material, is an alternative process type to arc welding.

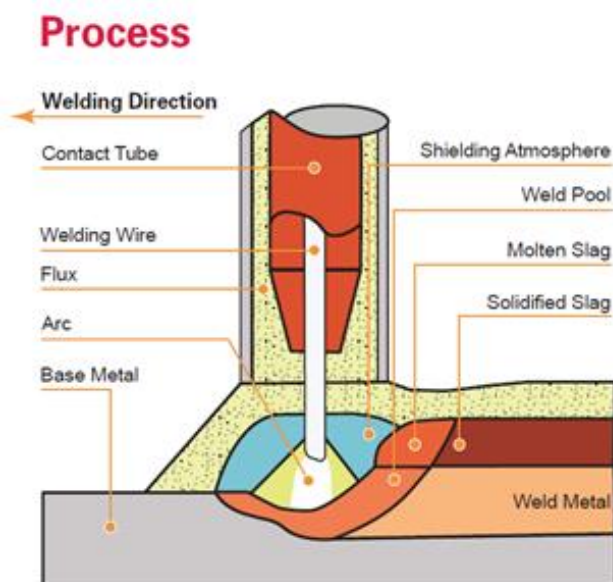


Figure 2 Process Diagram of MIG Welding (Jyoti Prakash, 2003)

Welding is a common way to bond like materials, generally mild steel. Welding is often used in the automotive industry to assemble car bodies permanently without the need for extra fixings. Arc welding includes TIG and MIG welding, the key difference being the use of a non-consumable tungsten electrode in TIG welding, which gives better results (S.A. David, 2003). TIG welding gives a more focused arc due to the high-quality electrode which causes fewer defects. TIG welding is more costly and time-consuming, but gives higher quality final welds, better suited for jobs that require strong finished joins or higher quality aesthetics. MIG welding is generally more economical and requires less skill than TIG welding.

Some general welding benefits include:

Welding doesn't cause structural damage to the components being bonded together, such as pre-drilled holes or other forms of non-uniform weak points. It also provides superior strength to other bonding or fabrication techniques, fusing the two materials unlike mechanical fasteners (FORGEWAY, 2023). Finally, welding is a highly flexible process, capable of a wide variety of shapes and forms.

However, welding needs skilled operators to get good results, and consumes large amounts of energy. Additionally, the heat changes the microstructure of the material altering its properties, as discussed below.

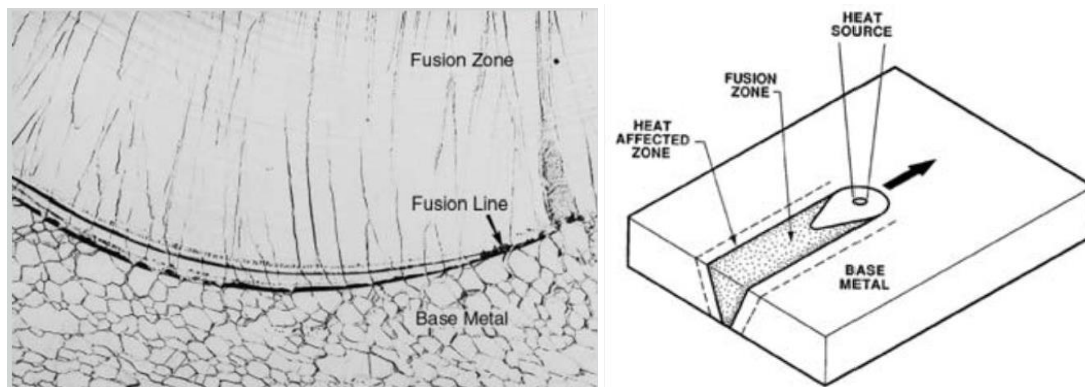


Figure 3 Weld Pool Diagram with Microstructure (Z Boucherzoug, 2010)

Welded microstructures tend to be weak between the base material, and the fusion zone where the metal has re-solidified, as shown. These re-solidified grains are often larger and orientated along the direction of heat flow, and there tend to be significant grain lines at the fusion line (above) (TWI, 2014). Generally, depending on the temperature used, the tensile strength of mild steel welds is 99MPa (P Baloyi, 2021). As the grains are orientated along the fusion line, this makes the weld anisotropic. This also leads to the join and the heat-affected zone not being as malleable and flexible as the base material due to grain size, and therefore vulnerable to vibrations (FORGEWAY, 2023).

Some defects which can affect the welding process include:

Porosity, this is a defect which occurs when air is trapped and mixed into the molten pool (TWI, 2014). This can be caused by contaminants like moisture or inadequate gas shielding. To prevent this, make sure there is sufficient shielding gas over the work area and the base metal is clean.

Incomplete fusion is a defect which can arise if a weld doesn't fully fuse with the base metal. Parameters like heat and joint layout can lead to this defect (Messler, 2019). Travel speed across the workpiece can also be adjusted to improve the joining of the parts. The joint geometry should allow for ease of welding.

Spatter is tiny molten droplets of material that scatter around the weld area, caused by droplets forming on the electrode and being blown off due to peaking current. This can be mitigated by reducing the rapid up-slope of peak current (T. Ito, 1998). The use of anti-spatter sprays on the workpiece can also reduce spatter.

3 Rolling – Forming

Rolling reduces the thickness of metal passing through rollers on either side, generally used to form large quantities of stock material in the form of sheet metal. Many sets of rollers are often used in series to reduce the material down to the desired gauge. This process can happen 'hot' or 'cold', referring to whether the material is above or below its re-crystallisation temperature. This distinction produces differences in the final properties and quality of the material. During hot rolling, steel is heated to between 1090°C and 1350°C. (Kennedy, 2017).

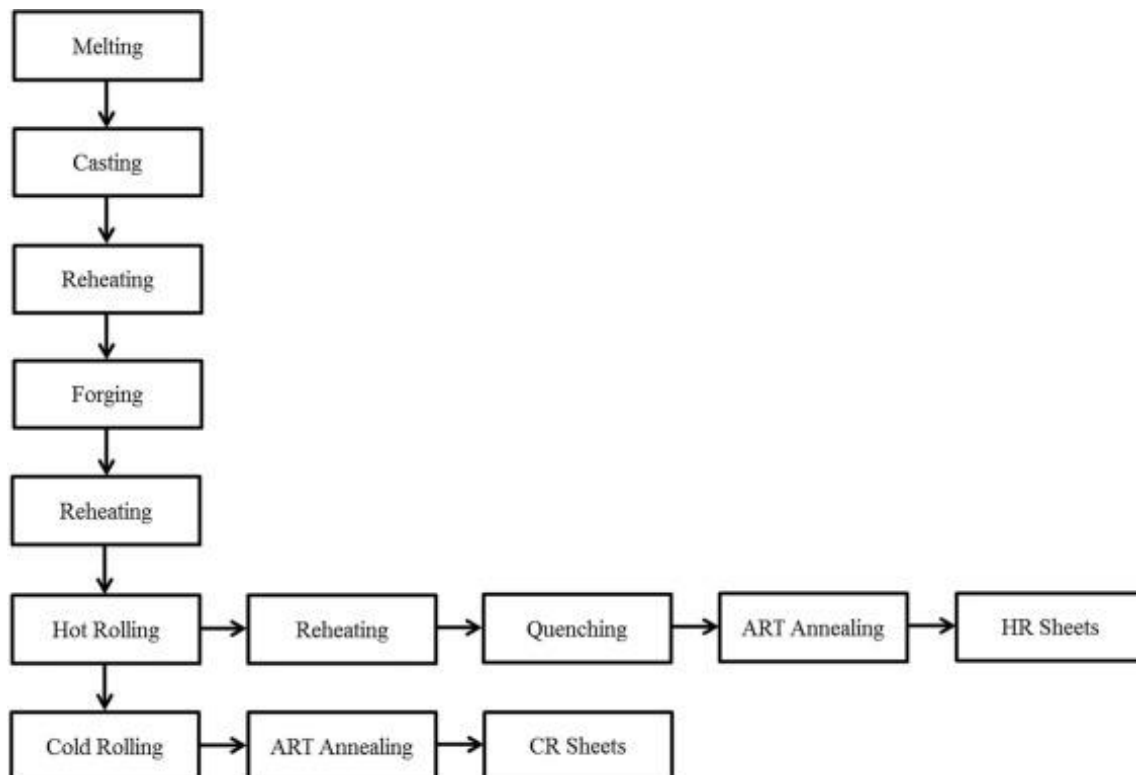


Figure 4 Flow Diagram of Rolling Process (G Mishra, 2017)

Hot rolling mild/low carbon steel allows grain movement during and just after the rolling process. Once the shape of the material is compressed, it is often observed that the grains are smaller than before rolling, and so grain refinement takes place (E.L Brown, 1981). Additionally, these grains are of equiaxial shape, meaning re-crystallisation has taken place. This is in contrast to cold-rolling, where the grains are elongated (Maribel de la Garza, 2007) as the material is below its re-crystallisation temperature. Hot-rolled mild steel undergoes grain refinement as the material re-crystallises. The equiaxial shape of the hot-rolled steel means it is more malleable and less brittle. Whereas; cold-rolled mild steel is harder and has higher tensile strength and surface hardness:

- CR mild steel 85,000 psi tensile strength
- HR mild steel 67,000 psi tensile strength

(Wanzhi Steel, 2022)

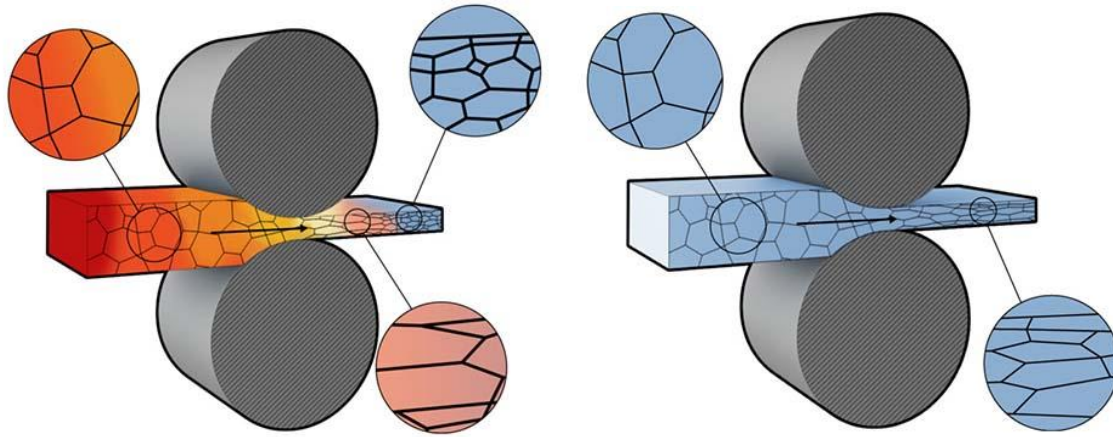


Figure 5 Hot Rolling and Cold Rolling Microstructure Diagram (Wanzhi Steel, 2022)

Purely hot rolled steel, although as shown above has a lower tensile strength, is more ductile and less prone to brittle fracturing due to a longer fatigue propagation. Cold-rolled steel has an improved surface finish, whereas hot-rolled steel oxidises during the process. This is because the steel is heated to extremely high temperatures, which speeds up the oxidization of the surface. When cold rolling, lubricant can be used to reduce the friction between the rollers and the material. This coolant reduces surface roughness and therefore improves finish (Sutcliffe, 2002).

A key advantage of hot rolling is that the grain refinement can remove/reduce defects from the initial casting of the metal. These might include removing coarse grains and changing the distribution of inclusions in the metal (Tech, 2020). A disadvantage of cold rolling is that the steel isn't as malleable at room temperature, so cold rolling has a more limited deformation per pass and requires more energy than an equal rolled deformation. Comparing hot and cold rolling, hot rolling has an increased wearing on the rollers used in the process. This can lead to extra costs associated with maintenance. In general, rolling has a very limited variety of final geometries, and hot rolling is only cast billets into a sheet metal stock form. Cold roll-forming can be used in some applications to create a wider variety of forms, but with a fixed cross-section. Long lengths of metal can be formed and then cut into significantly large quantities (NMC, 2020).

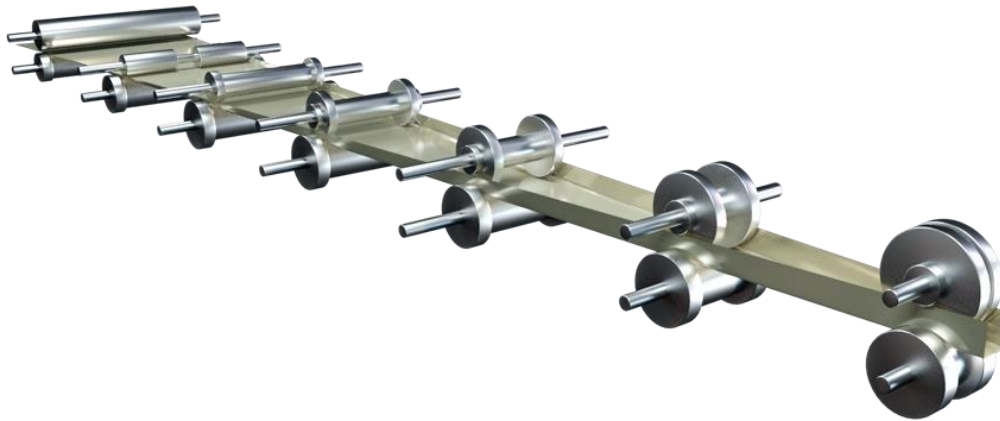


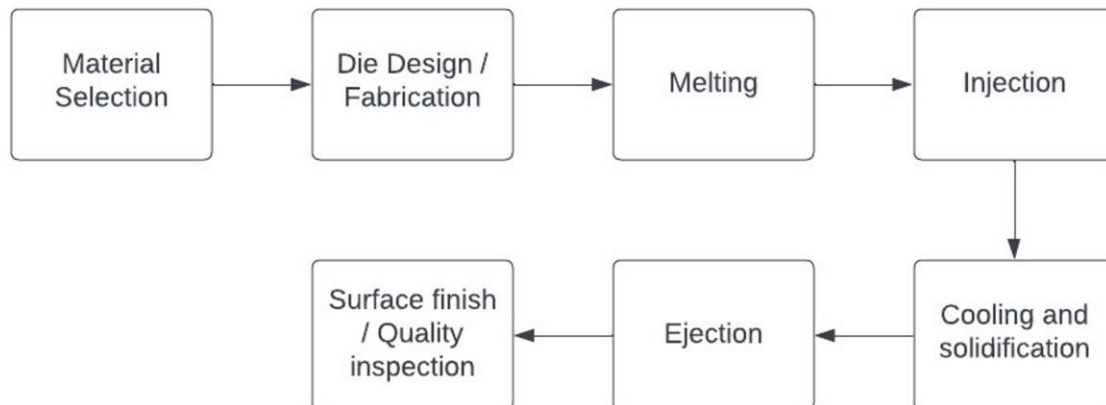
Figure 6 Example of Roll-forming Operation (NMC, 2020)

Edge cracking is a common rolling defect caused by uneven cooling in the rolled material. Additionally, it can be caused by the rollers being poorly calibrated. This can be controlled by reducing the speed at which material is processed, and the rate at which it cools. Additionally, the material can split. This happens if it is rolled too thin, or the material cannot handle the force from the rollers. To control this, reduce the speed and force on the material. Finally, marks on the material can be left from the rollers. Often the rollers have debris and surface marks, which emphasises the need to properly cool and lubricate the rollers.

4 Die-Casting

Die-casting is a manufacturing process in which molten metal is injected into a mould or die. The process can be broadly split into hot-chamber and cold-chamber casting. Cold chamber casting involves the metal being melted in a separate furnace and being brought over to the die-cast. This is better suited to higher melting point materials such as aluminium alloys. (K.L. Narayana, 2018).

Figure__ below shows this difference.



Once the metal solidifies within the mould, the part is ejected. Die-casting is best used in mass-production situations involving intricate, detailed, and dimensionally consistent components made from non-ferrous metals. An example of die casting was on the 2017 Chrysler Pacifica, which replaced nine parts and allowed a 50% weight reduction (Weiler, 2019).

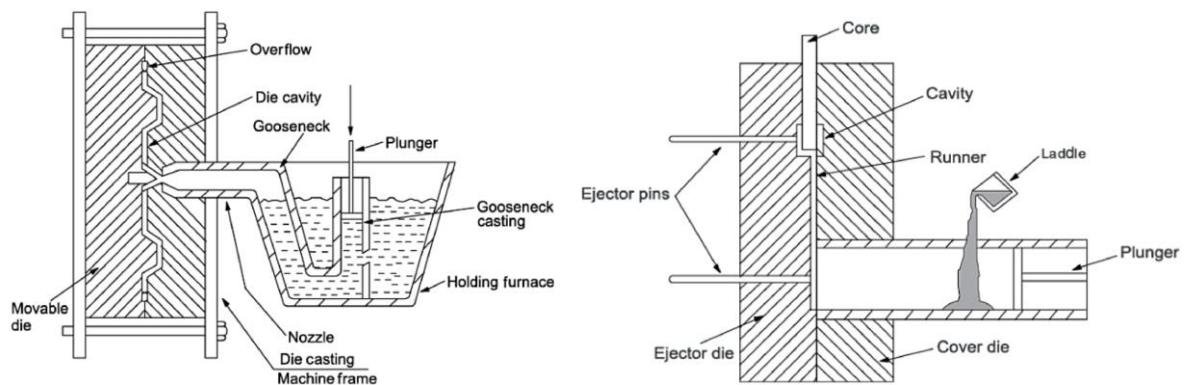


Figure 7 Diagram of a) Hot Chamber die casting and b) Cold Chamber Die Casting (K.L. Narayana, 2018)

General advantages of the die-casting process include:

- High dimensional accuracy and consistency of the components and produced.
- Mass-production suitability for otherwise complex and difficult geometry for metallic components.
- Smooth and good quality finishes for components, reducing or eliminating extra machining.

(RYOBI, 2022).

These advantages make die casting well suited to intricate and complex parts; which would otherwise be extremely hard to produce with other traditional processing techniques. However, die casting can generally only be used with non-ferrous metals (Bury, 2023). This is due to the high melting point of these metals compared to other more commonly die-cast metals including aluminium, zinc and tin alloys; the high temperatures needed make using steel dies un-feasible. Additionally, producing a die for casting is a high initial investment (Bury, 2023).

The microstructure of cast aluminium alloy forms crystal grains throughout the material as it cools; the material can be inferred to cool from the walls inward, and so the grains will start to form at the surface first. As the metal grains form, dendrites form within the grains (The Open University, 2021). Dendrites represent concentrated areas of impurities; these reduce the plasticity/ductility of the material (Safaie, 2015). Another common defect in the casting process is porosity, caused by the material naturally shrinking as it solidifies, creating voids in the finished part (The Open University, 2021). In other processing methods, casting is followed by another processing technique. This removes these voids by grain refinement and re-distributes impurities (see rolling process above). When casting finished parts, these impurities and defects must be left within the microstructure of the component.



Figure 8 Fractures in Cast Aluminium due to cooling during shrinking. (S Otarawanna, 2009)

Above is an example of voids being created by the material shrinking during the cooling process. In addition to the crack at the edge; smaller spherical voids proliferate the rest of the material. These pockets weaken the material. The tensile strength of cast aluminium alloys tends to lie between 324 and 295 MPa; this is dependent on the specific alloy used, e.g. A380 has a tensile strength of 324 MPa (DYNACAST, 2022).

A wide variety of problems can affect components being die-cast. Misruns happen when the molten metal fails to fill the entire mould cavity properly, leaving portions of the component incomplete. This

can be avoided by ensuring proper pouring temperature and flow rate to encourage complete filling of the mould. Additionally, employing additives in the molten metal to lower its viscosity, which reduces the likelihood of misruns.

Porosity is the appearance of small voids or holes in the cast metal, due to gas entrapment during solidification. To prevent this, the mould's design can be edited to allow gas to escape easily during the casting process. Removing impurities from the molten metal can also reduce the likelihood of air getting trapped in the component.

Defects also occur when the metal contracts upon cooling, leading to voids or deformities in the cast.

Controlling the cooling rate of the material, and redesigning thick sections prone to shrinkage can help to control material changes during cooling, regulating solidification and minimizing shrinkage.

5 Conclusion

In conclusion, this study on materials processing has covered various techniques and their impact on material properties, and effective application. Factors such as temperature, pressure, and material composition determine material properties through its grain structure, influence strength, hardness, and flexibility. These factors are optimized based on the needs of a given process or product.

Die-casting, rolling and welding effectively demonstrate the types of processes that give priority to different properties. More importantly however, the analysis of these techniques separately shows how these might be combined in order for engineers to benefit from each's strengths and make up for weaknesses. The skilful combination of these, and many other manufacturing techniques, is what makes brilliantly engineered products.

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