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Basic Material Guidelines

Choosing a Material

There are many factors that influence material choice. The two main factors are material cost and material properties. The materials properties may narrow down a choice but there are many occasions when an alternative material with similar properties may be a better decision when the financial costs of large scale production runs are considered. Another factor that needs to be considered is machinability. The properties of the material being considered may fit the purpose; but machining the part could be difficult or cost prohibitive. This is especially true of composite materials like glass nylon and carbon fiber.

Material Properties

There are quite a few properties to consider when choosing a material. These can include:

- Thermal conductivity
- Electrical conductivity
- Chemical reactivity
- Strength
- Durability
- Failure mode
- Density

In most cases you will only be looking to fulfil a few absolute requirements for your part or product. Narrowing down which properties are necessary and those that improve a part but are not required (relative requirements) can help highlight materials that may not have previously been considered.

Additionally, if you have not considered the product design at all, the process of material selection may deliver a material that is unsuitable for the use case. For example, the process required to produce the part could depend on a milling. The material selected may not be suitable for milling resulting in damage or unreliable dimensions.

Four basic material groups

Four basic material groups

There are four main material groups to consider when choosing a material. Often the properties between these groups will differ greatly. The four material categories include:

- Ceramics
- Metals
- Polymers
- Composites

It is important when choosing a material to be clear about the properties you are looking for as it will help narrow down the type of material you want. Other important factors to choosing a material category are related to manufacturing procedures some materials may require significant work to process resulting in a very expensive part.

Choosing a Material

Choosing based on Qualitative or Quantitative Approach

Choosing a material to fulfil specified performance criteria can often be done qualitatively with experience. Sometimes an application may not be as straight forward requiring a number of unusual properties in order for the product to perform correctly. In this case it may be better to compare materials quantitatively to avoid being subjective. This process will hopefully avoid problems at the engineering stage when testing the part for points of failure.

Quantitative Approach

The most important step to choosing a material for your product on a quantitative basis is to outline the absolute requirements and relative requirements you wish to encompass. If you are designing a part that will be in tension you will likely choose a material that has high performance under tension loads with a high stress limit and a suitable strain limit allowing for significant elongation.

This step is important to the successful selection of a suitable material. If an absolute requirement is ignored it could result in a material being selected that is not suitable for the application.

Using the dimensions of your part you can develop a metric by selecting relevant properties. Two relevant properties alluded to above for the tension member is strength (the materials ability to withstand a load) and toughness (the ability of the material to plastically deform without fracturing). These two properties help make sure the material chosen will perform safely in the application.

These criterions are important and help generate equations which can later be used in Ashby Charts. Ashby Charts are used to depict a selection of material types and regularly used materials in reference to material properties. An Ashby Chart generally compares materials based on disired properties on the x and y axes.

As a result there are a large array of charts each with a different combination of properties listed on the axes. A commonly used chart is the Ashby strength to density chart.

Materials have a wide range of properties here is an example of some ABS exhibits.

Physical Properties of ABS	Value	Unit
Density	1.07	g/cc
Water Absorption at Equilibrium	0.204	wt%
Water Absorption at Saturation	0.734	wt%
Mechanical Properties of ABS	**Value**	**Unit**
Hardness	107	Rockwell R
Tensile Strength	43	MPa
Young's Modulus	2.32	GPa
Elongation	2.98	%
Flexural Strength	67.6	MPa
Flexural Modulus	2.34	GPa
Impact Strength (IZOD) Notched	2.23	J/cm

Thermal Properties of ABS	Value	Unit
Heat Deflection Temperature	95	oC
Vicat Softening Point	99.6	oC
Thermal Expansion Coefficient	90	µm/moC
Electric Properties of ABS	**Value**	**Unit**
Electrical Resistivity	2.13E+16	ohm-cm
Dielectric Constant	2.93	
Dielectric Strength	20	kV/mm
Chemical Properties of ABS	**Description**	
Resistance to acids/bases	Fair	
Resistance to organic solvents	Poor	

Polymers-Plastics

Types of Plastic

Plastics make up a subunit of polymers. A polymer is referred to as a plastic if it can be shaped while in a soft state and later solidified, typically around room temperature.

There are two different categories of plastics to consider when designing a part for manufacturing. These two categories are called thermoset and thermoplastic.

Thermoset: A thermoset plastic is a plastic that after it is initially formed it cannot be remelted and reformed into a different shape. Thermoset plastics offer better performance in high temperature environments in which a thermoplastic would readily melt. The bonds holding the thermoset plastic together are much stronger than those present in thermoplastics.

Thermoplastic: A thermoplastic can be reformed many times as the bonds between molecules is far weaker than those in thermoset plastics. When heated the bonds are broken allowing for the molecules to easily move past one another.

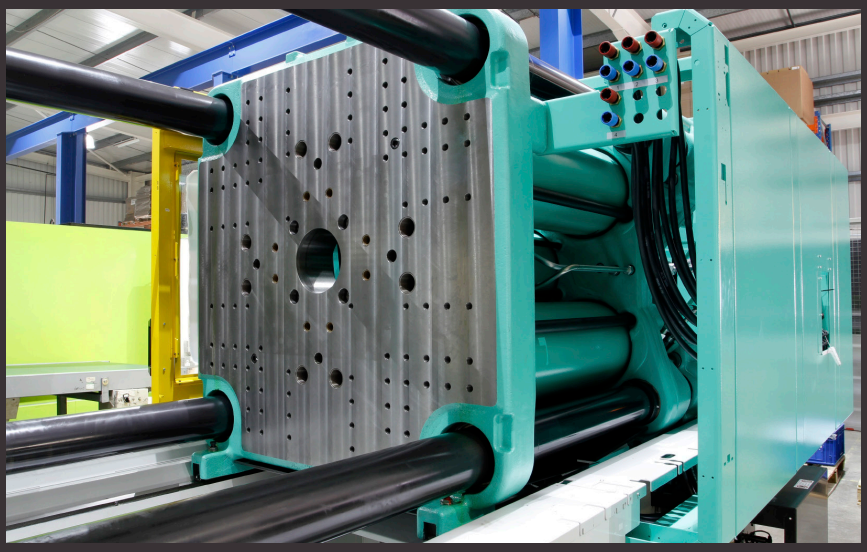
Processes

There are quite a few options when it comes to producing plastic parts as they can be easily formed due to the relatively low melting temperatures required. Below are some examples of processes that can be used successfully to form plastic parts.

- 3D Printing
- Blow Moulding
- Plastic Extrusion
- Plastic Injection Moulding
- Milling and turning
- Vacuum Forming

These processes are expanded upon in the manufacturing process primer.

Injection Moulding Machine



Polymers-Plastics

Plastics Offered

Plastics are an extremely versatile set of materials offering a wide range of properties that are suitable for many applications. Due to their wide range of capabilities plastics are used extensively. Below is a list of plastics offered by Ideatolife for use in products at the manufacturing stage.

- ABS – ABS is used in applications that require high strength. It also has a moderate chemical resistance and resists significant shrinkage during cooling making it a good choice for injection moulding. It can also be used in vacuum forming and extrusion processes. UV additives must be added to prevent UV degradation.
- HIPS – High Impact Polystyrene. HIPS resists fracturing and impacts. It is used frequently in everyday items such as shopping displays and disposable cutlery as well as packaging as it can be easily worked. Injection moulding, vacuum forming, and extrusion processes are suitable in forming HIPS products. HIPS is not UV resistant.
- HDPE – High Density Polyethelene. HDPE is relatively flexible and quite tough allowing it to deform without breaking. HDPE is readily recyclable.
- LDPE – Low Density Polyethelene. LDPE is found in a range of household items including plastic bags and often packaging.
- PA6 (Nylon 6) – Nylon 6 which is also referred to as Polyamide, is a plastic used in high temperatures and rough applications as it is tough. Nylon 6 also has a low friction coefficient allowing it to be used readily in mechanical parts like gears and sliders which frequently rub on other materials. The plastic does not fare well outdoors as it is susceptible to chemical damage and absorbs water.
- PA66 (Nylon 6,6) – An improvement on Nylon 6, Nylon 6, 6 is stronger, stiffer and can tolerate more heat. The plastic still handles chemical and water damage poorly. An example use would be a V belt pulley.
- PBT – Polybutylene Terephthalate is a tough plastic. It offers impact and abrasion resistance. It does not absorb water and is suitable in high temperature applications. PBT is also suitable as an insulator for electronics as well as use in gears and bearings. It is also UV resistant, resisting significant degradation over extended periods of time.
- PC – Polycarbonate is a very high impact strength plastic. It has a clear appearance making it suitable for use in personal protective equipment and safety guards. It is used frequently in other applications that make use of its high level of toughness and strength.
- PEEK – Polyetheretherketone is a rigid high-performance plastic which is resistant to high temperature and wear. It has limited chemical resistance. PEEK is often substituted for metal gears and bearings due to its wear resistance. Its electrical resistivity makes it a perfect candidate for wire insulation.
- PEI – Polyetherimide is regarded as having high strength, heat resistance and chemical resistance. It is suitable for cooking utensils and equipment as well as in electronics stemming from its strong dielectric properties (insulative properties).
- PET – Polyethelene Terephthalate otherwise known as polyester is used frequently for plastic bottles. PET is lightweight while remaining strong. As a result, it resists deformation. PET will plastically deform instead of shattering. It is resistant to chemicals and is therefore suitable for application involving food. It is still susceptible to UV degradation.
- PETG – Polyethelene Terephthalate Glycol is a plastic similar to PET. Due to the inclusion of glycol, PETG is softer than PET. This means that less stress can be applied to PETG before plastic deformation occurs. The inclusion of glycol alters a few other properties of the plastic causing it to be more ductile and less sensitive to heat. PETG like PET is still food safe as it does not chemically react with food. UV exposure will degrade PETG products over time.
- PMMA (Acrylic) – Acrylic is often utilized for its clear glass like appearance. It is stiff but also quite brittle. It is often used as a replacement for glass, lights and various stationary items. Acrylic is not suitable in products that experience large forces as it will break without warning. Polycarbonate due to its toughness would be more suitable for that use case.
- POM (Acetal) – Acetal is a plastic with high tensile strength and hardness. Along with a low coefficient of friction. Acetal is perfect for mechanical applications requiring precision parts that frequently contact each other. An example of a mechanical application is plastic zippers used in clothing and other products. Like many other plastics Acetal will degrade due to UV exposure.
- PP – Polypropylene is another chemically inert plastic with low moisture absorption. Defining characteristics of Polypropylene is that it is clear and strong with the ability bend without inducing fractures or significant deformation due to its toughness. Different grades of PP exist to provide better performance in specific applications. An example of a product made from Polypropylene is the ubiquitous bottle cap.
- PPS – Polyphenylene Sulfide is most notable for its high heat deflection and chemical resistance. It is frequently used in plastic bearings and electronics as well as in hydraulics.

Polymers-Plastics

- PPSU – Polyphenylsulfone is a strong plastic highly resistant to temperature and impacts. It is also highly resistant to chemicals and water (hydrolytic stability). The plastic is generally used in aerospace, automotive applications as well as in the plumbing and electrical sectors.
- PSU – Polysulfone is a transparent plastic that is strong, tough and rigid. Like PPSU, PSU is resistant to chemicals allowing it to be used in applications where it is in contact with acids and bases. PPSU however is stronger that PSU and may be a better choice for structural parts. Examples of the use of PSU include printer cartridges, coffee machines and battery housings. UV degradation is only minor causing damage to the appearance and minor mechanical damage.
- PS (Polystyrene) – Polystyrene appears transparent. It is used frequently as it is inexpensive, for example polystyrene is used in disposable ball point pens and food containers. Polystyrene is rigid, hard and resistant to chemical degradation. The major disadvantage to polystyrene is that it is extremely brittle and can easily break from impacts. Foamed polystyrene provides an option for handling impacts a bit better for packaging although it is still brittle.
- PTFE – Polytetrafluoroethelene otherwise referred to as Teflon. Teflon has a high resistance to heat and chemicals. The plastic also has self-lubricating properties which is particularly useful in specialised applications. PTFE's chemical resistance make is suitable as a container for chemical storage. It has also been used in bearings and as a solid lubricant like graphite for use on mechanical parts like linear rails and threaded rods.
- PVC – Polyvinyl Chloride is a strong plastic with good impact strength. It is fire retardant but can deform at relatively low temperatures. PVC is rigid and quite brittle although it is also highly resistant to chemicals. Due to PVC's properties and the materials inexpensive cost it is widely used in housing for plumbing purposes and in electrical as wire insulation and conduit. Other examples of PVC's use include bottles. PVC itself is relatively UV stable taking considerable time to breakdown.
- PVDF – Polyvinylidene difluoride is a highly chemical resistant plastic with moderate heat resistance. It is lightweight and regarded as being moderately flexible allowing for distortion without incurring plastic deformation. PVDF is frequently used in chemical storage, piping and in electrical components for its electrical properties.
- SAN – Styrene Acrylonitrile is a transparent plastic that shares quite a few similarities to ABS. Overall SAN is less impact resistant but better at handling chemicals and heat. It is frequently used in plastic jugs and disposable lighters.
- TPI – Thermoplastic Polyimide. TPI is a strong and durable plastic with quite a few desirable properties. As a result, TPI is relatively expensive and is usually reserved for occasions when multiple properties need to be addressed. It is well known for its high heat resistance and fire resistance despite being a thermoplastic. It is strong enough to replace glass and steel in certain applications. TPI is also resistant to chemicals.
- TPU (Polyurethane) – TPU is considered as a highly tough and elastic material. It can significantly distort its shape without causing permanent plastic deformation. As a result, it is often used in tubing. The material itself can be altered to achieve different desired properties. Its flexibility can be used to the advantage of designers looking for a soft damper material.

ABS plastic building blocks

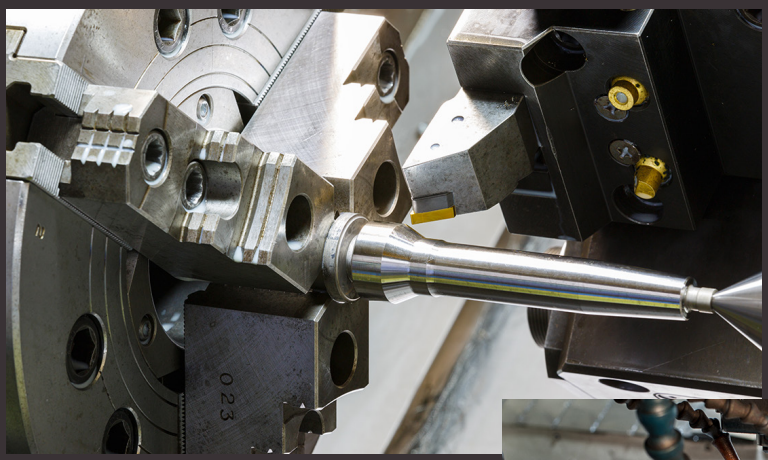
Metals

Most metals used in industry applications are alloys utilizing a base metal and additives used to modify the base metals properties. The most common alloys in use today are steels, a combination of iron and carbon. The carbon content of steel is incredibly low ranging from less that 0.1% to 2.14%. The amount of carbon present, duration and temperature at which the alloy is cooled can affect the internal microstructure resulting in different properties. Carbon content higher than 2.14% produce what is commonly known as cast irons.

Other additives such as rare earth metals can also be added to further modify the internal structure and assist in developing desired properties.

Metals like Aluminium and copper are processed in similar ways to produce alloys with enhanced properties as well.

With such a wide range of properties to choose from it is important that the raw product is processed correctly to reduce both the time and costs required to manufacture the part in question. An example of this is tool steel. It is very strong and will wear down tooling extremely fast. Instead of operating on tool steel it may be easier to mill the part and then temper it. Different process may be required for different metals and alloys to allow for easy manufacturing.



CNC Turning

CNC Milling

Metals

Metal Processing

Metals can be processed in a variety of ways. Here is a short list of manufacturing metals that could be used to produce parts. Please see the manufacturing process primer for more information.

Casting and Forging
- Investment Casting
- Pressure Die Casting
- Sand Casting
- Metal Forging

CNC Machining
- Milling
- Turning

Fabrication
- Welding Fabrication
- Sheet and Plate metal Fabrication
- CNC Laser cutting and Turret Punching
- Pipe and Section Bending

Wire Cutting
- EDM Wire Cutting

Most standard metals are available for the above processes. Due to the wildly different properties between different metals some metals are better suited to particular operations.

An example of a part produced from EDM wire cutting.

Metals

Metals Offered

Ferritic based metals

Iron and its alloys are extremely versatile due to the degree at which its properties can be altered to achieve desirable characteristics. Steel can be used in a wide range of applications such as structural components and small mechanical parts that benefit from the high strength while remaining low cost. Processes to form these products out of steel can include investment casting, sand casting, forging, CNC milling and turning as well as welding and other fabrication methods.

- Low Carbon Steel: Low carbon steel tends to be more ductile than other forms of steel with higher carbon content as it allows for the formation of regions of ferrite. As a result, low carbon steel is used in the production of car bodies as it can be easily shaped with a large press and die. Low carbon steel cannot be tempered easily.

- Medium Carbon Steel: Due to the increased carbon content medium carbon steels are significantly stronger than low carbon steels and are able to support higher loads. Medium carbon steels are less ductile and deform significantly less before failure. The increased carbon content allows for tempering in order to improve hardness.

- High Carbon Steel: High carbon steels are much stronger than medium and low carbon steels. They also tend to be much harder, resisting wear and abrasion. As a result however, they are significantly more brittle and cannot resist as much elongation before failing. Due to the large carbon content high carbon steel can be further hardened through tempering processes.

- Stainless Steel and Duplex Steel: Stainless steel alloys are desirable due to their resistance to corrosion through rusting. Stainless steel is not just a single alloy, but a group of alloys comprising many steels with similar properties resulting from the inclusion of rare earth metals during production.

- Alloy Steel: Steel which contains significant alloying elements to improve processing and other properties.

- Engineering Steel: Engineering steels are special alloys designed to respond well to both environmental and physical conditions.

- Tool Steel: Tool steel is a special alloy including tungsten which increases the melting point of the steel. The properties of the metal such as its hardness and heat resistance make it ideal for use in tooling such as end mills and drill bits.

- Cast Iron contains significantly more carbon that steels. There are a few different types of cast iron. Some cast irons are relatively ductile while others like white cast iron can be extremely hard and brittle. Generally, cast iron is used for large cast parts especially machine bases for its dampening properties.

Metals

Non-Ferritic based metals

- Aluminium and Aluminium Alloys: Aluminium is generally selected for its light weight and resistance to corrosion while remaining strong.

- Brass: Brass is an alloy of copper and zinc with a mixture of properties from each. It is ductile and resistant to corrosion. Brass can be used for a variety of mechanical devices.

- Bronze: Bronze is a copper and tin based alloy that is harder than pure copper. Bronze is often used for bushings due to its low metal coefficient of friction. It is also used in applications where there is a high risk of corrosion due to its high corrosion resistance.

- Magnesium: Magnesium can be alloyed with other materials to form an extremely lightweight and strong structure. Magnesium alloys are a very popular material for small electronics chassis like laptops.

- Titanium: Titanium is generally used for aerospace due to its low density and high strength. Titanium is often used when a parts features are limited dimensional by its design resulting in a need for a high strength material. Titanium although high strength is rather brittle and is often alloyed to improve its properties. It is also heavily used for medical implants.

- Nickel and Cobalt Alloy: Nickel and Cobalt are generally alloyed to improve strength and corrosion resistance especially at high temperature making them useful for applications like turbines and heat exchangers.

- Zinc and Zinc Alloys: Zinc is often used to protect other metals due to the oxidation layer formed when in contact with air. Zinc Alloys are generally stronger and have higher wear resistance. Zinc alloys can be easily cast and machined making them suitable for a range of applications such as plumbing fittings, mechanical parts, and electrical devices.

- Copper: Copper is generally used for its electrical properties and corrosion resistance. Pure copper is relatively soft and pliable. It is often alloyed with other elements to improve its overall strength.

- Lead: Lead is generally used in very specific applications due to its toxicity. Like tin and zinc, lead displays significant corrosion resistance and is often used to line containers for storing specific chemical compounds.

- Tin: Tin is often used as an alloying element for its corrosion resistant properties. It can also be used to plate metals. Tin can be alloyed with other elements such as rare earth metals for more exotic properties.

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