Relationship between Material Selection and Processing

Section 1. Review to Material Selection Factors

The following sections introduce some important factors that must be considered in material selection for small, complex components.

1- Materials Properties:

Corrosion resistance. Corrosion is a major concern that dictates material selection in many operating environments. For example, chloride ions cause stress corrosion cracking (SCC) in stainless steels, so a material like titanium is selected because of its ***chloride-resistant properties***. These factors are critical because corrosion in equipment can result in a number of negative effects, including fires, explosions and both brittle and mechanical failures, as well as the release of hazardous gases, liquids or vapors.

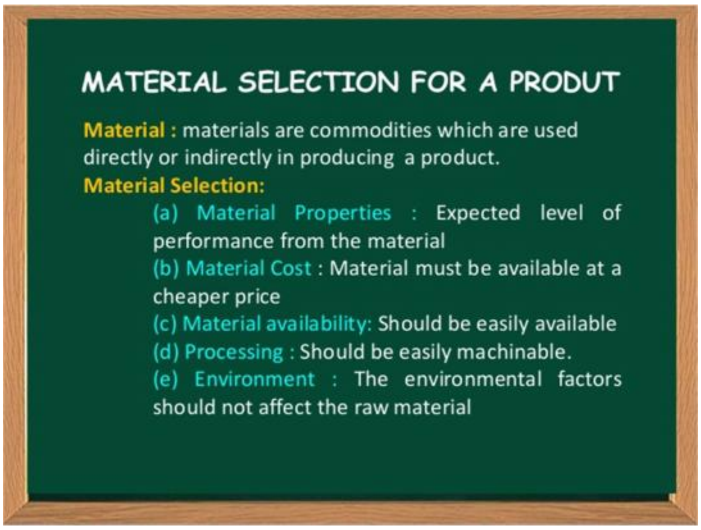
Oxidation is commonly observed in materials like the stainless-steel alloys. These metals naturally form oxide layers for ***corrosion protection***, which can cause uneven surfaces. This occurrence requires passivation treatment to reduce the negative effects of these oxide layers and to keep the surfaces smooth and free of imperfections that can cause equipment failure.

Exposure to chemicals. Materials can have adverse reactions to chemicals in various environments. Environmental chemical factors can include high acidity and the presence of oxygen or aqueous solutions, or even harsh cleaning or sanitizing agents. Although the production environment may be non-corrosive, the presence of these chemicals can cause materials to react, so a designer should consider the risks when selecting materials.

Temperature resistance. The engineer should be aware that the mechanical limits of materials can be negatively affected by high temperatures, potentially causing thermal failure or deformation. Materials are also selected based on temperature resistance because the effect of extreme temperatures on materials can cause increased corrosion rates. High-temperature materials include iron-, nickel- and cobalt-based metal alloys.

2- Materials Cost and Availability. A major factor in the materials-selection decision typically involves the ***initial cost*** of the material, the ***ease of machining*** and ***repair*** and ***the availability*** of the material. Cost influences the balance between ***materials and machining*** in the case of material grades. For example, if an engineer chooses Inconel as the material for the product, the grade affects the machining cost. Since Inconel 600 is much easier to machine than Inconel 718, the time and cost of machining can change considerably depending on which grade is chosen. However, note that cost is usually secondary to the other considerations that involve consistent and reliable operation of the part in its application. In addition, materials should also be easily available.

In Summary



MATERIAL SELECTION FOR A PRODUT

Material : materials are commodities which are used directly or indirectly in producing a product.

Material Selection:

- (a) Material Properties : Expected level of performance from the material
- (b) Material Cost : Material must be available at a cheaper price
- (c) Material availability: Should be easily available
- (d) Processing : Should be easily machinable.
- (e) Environment : The environmental factors should not affect the raw material

Section 2. Aims of Material processing

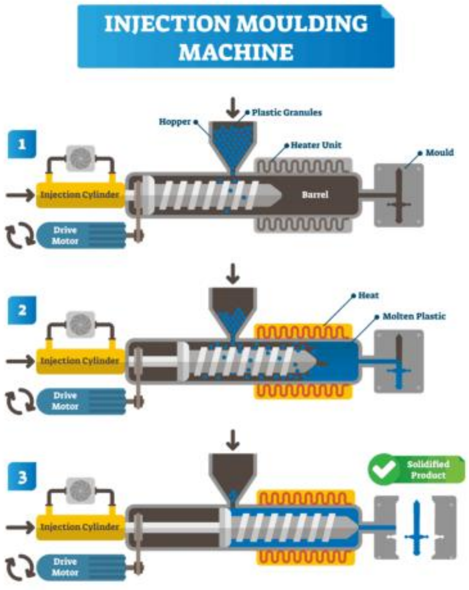
Materials processing has three principal aims. *These are the achievement of (1) shape and dimensions, (2) properties, and (3) finish (this last in the sense of ready-to-use quality).*

(1)Shape and dimensions

These are obtained by three basic methods: (1) rheological (flow) processes, (2) fabrication (the assembly of ready-made constituent parts by joining), and (3) machining.

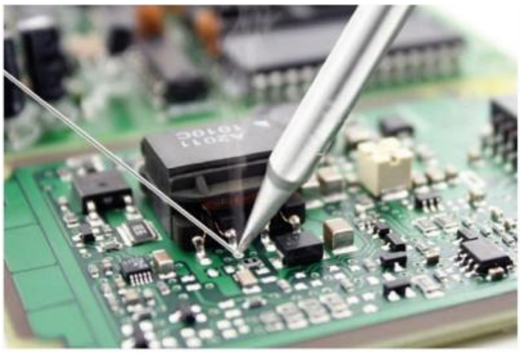
(i) Flow processing

This method can be used to shape ***liquids, fluids and solids***: it includes the liquid casting of metals, injection moulding of plastics, slip casting of ceramics, mechanical working of metals and the densification of powder-metallurgy compacts.



(ii)Fabrication

This is accomplished by mechanical, metallurgical or chemical methods of joining. Mechanical methods, include riveting and bolting and other diverse methods of clipping and fixing. These methods are widely used, sometimes because of the need for a demountable joint, or because of the simplicity and convenience of assembly (e.g. self-tapping and hammer-driven screws); some alloy systems are, in any case, unweldable. Metallurgical techniques embrace welding, brazing and soldering and each has a range of applications in which it is the preferred method of permanent assembly: thus, welding for heavy engineering, soldering for electrical circuits.



Chemical methods involve the use of adhesives, glues or cements (the terms have the same meaning; adhesive is preferred as it reflects the physical principle involved). For timber and metallic materials, adhesion is a well-established method of fabrication and for most joint pairs within these groups of materials it is possible to specify a suitable adhesive. However, some materials, notably plastics, are difficult to join by adhesives; ***special surface pretreatments*** are invariably required to raise the surface energy and improve wetting.

(iii) Machining

In normal manufacturing, machining has the ability to combine high quality with large through put. Its technical flexibility is such that almost any shape can be produced from a solid block of material provided the price can be paid (although hollow shapes are limited), and machining is frequently adopted for the manufacture of prototypes and one-off items. Sometimes, machining is used for the bulk manufacture of a part which has a shape inappropriate for any other forming process: in this case redesign should be sought if at all possible.

(2)Properties

The properties of an engineering part derive mainly from the basic nature of the material of which it is made, but where metallic materials are concerned, properties can generally be greatly modified during the successive stages of a manufacturing process. This is impossible with unprocessed natural materials such as timber and stone, but the approach of modifying structure by processing can be applied to products where the basic ingredient is wood or mineral (e.g. chipboard, plywood, reconstituted stone and cement products). It is also an approach which is increasingly applied to non-metallic manufactured materials, i.e. ceramics, glasses and plastics.

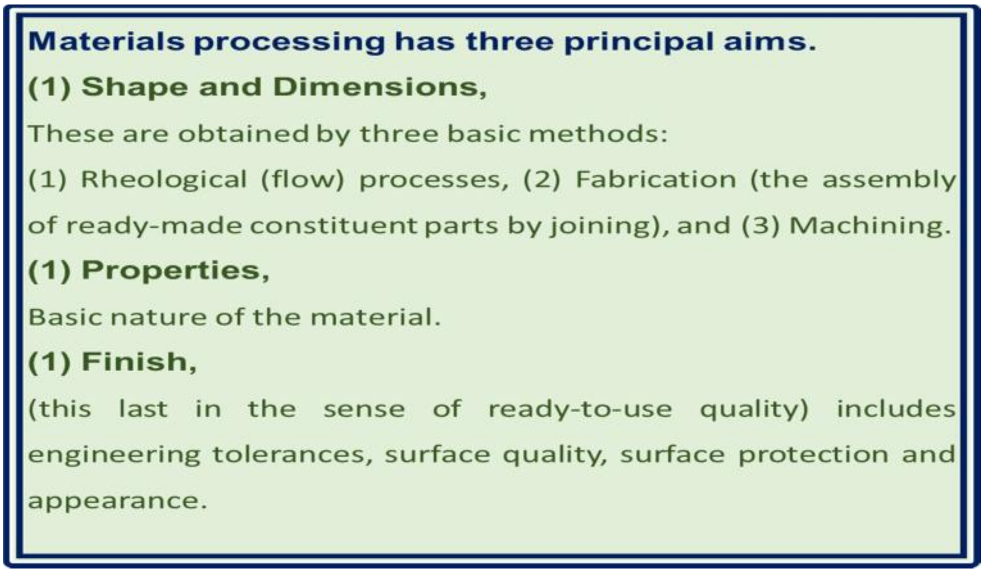
(3)Finish

This includes engineering tolerances, surface quality, surface protection and appearance.

Desirable levels of surface protection and appearance are a little more difficult to quantify and the choice between, say, galvanized or cadmium-plated steel and anodized aluminium or chromium-plated plastics may present problems, notwithstanding the easily- determined variations in cost.

Surface processing purely for appearance is entirely a subjective matter, and decisions can hardly be taken without the benefit of market research. However, for light reflectors, and other applications requiring highly finished surfaces, quality can be assessed quantitatively in terms of the relative proportions of specular and diffused reflection, using standardized methods of measurement.

In Summary



Materials processing has three principal aims.

(1) Shape and Dimensions,

These are obtained by three basic methods:

(1) Rheological (flow) processes, (2) Fabrication (the assembly of ready-made constituent parts by joining), and (3) Machining.

(1) Properties,

Basic nature of the material.

(1) Finish,

(this last in the sense of ready-to-use quality) includes engineering tolerances, surface quality, surface protection and appearance.

Section 3. Why processing may influence material selection?

For technical reasons, selecting a manufacturing process is frequently not an entirely free choice. Many metallic alloys - for example, permanent magnet materials and advanced creep-resisting nickel-base alloys - are too hard and strong to be mechanically worked and must, therefore, be formed by casting or by powder metallurgy; timber can sometimes be shaped by steaming and bending but more normally only by cutting and adhesive joining; concrete can only be cast; natural stone can only be cut.

Processing also influences material properties. For example, short fibre reinforced plastics will tend to display regions of anisotropy when injection moulded; rolling of metals will alter the grain structure; casting conditions will influence the grain structure, and so on. But these are not disqualifications, merely limitations within which the materials engineer must work.

Section 4. Process selection criteria

Before choosing a process for the manufacture of a given article, apart from taking into account the material selection, it is necessary to know: *(1) how many are required, (2) the size and weight per piece, (3) the geometrical complexity, (4) the required dimensional tolerances and (5) the desired surface finish.*

(1)Effect of numbers required

Except for a prototype, it is rare to manufacture only one of a given part: usually larger numbers are required, varying from, say, ten to hundreds of thousands. A large production reduces the unit cost, i.e. the cost of each individual piece, since larger numbers permit the use of more complex machinery and more advanced manufacturing methods. However, coping with a large production demands more highly developed techniques of inspection and quality control, not only of manufacturing methods throughout the factory but also of incoming material. To achieve overall benefit, the additional costs thereby incurred must be smaller than the savings accomplished by high-volume production.

The effect of production numbers on costs can be analysed as follows: The total cost, P, of a batch of N pieces can be expressed as

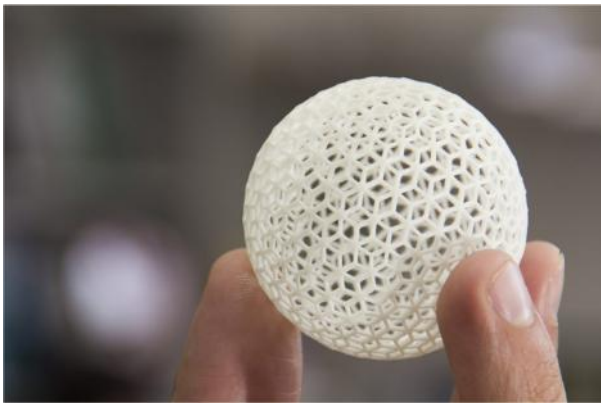
$$P = T + xN \qquad (L4.1)$$

In which T is the cost of tools and equipment and x represents the costs associated with each individual piece.

((Equation 1, is the simplest one, other equations and more information are also described in Ref. 1)

(2)Complexity of shape

There appears to be no single parameter which can give quantitative assessment of complexity of shape. Factors which contribute to complexity are: (1) minimum section thickness, (2) presence of undercuts, (3) presence of internal hollows.



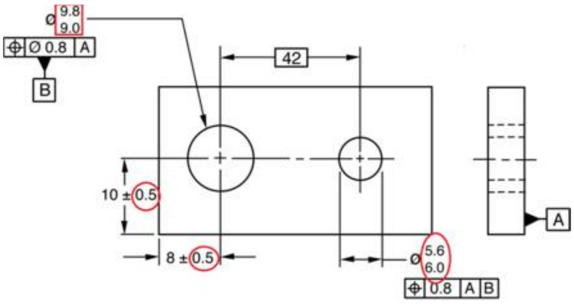
(3)Dimensional tolerances

Different manufacturing processes vary widely in the dimensional tolerances of which they are capable. Reynolds (In Ref. 1) has presented evidence that in practice designers tend to use certain constant values of tolerances, such as 0.010in, 0.020in, etc., regardless of the overall magnitude of the dimensions to which they apply.

ISO propose empirical relationships of the following type:

Tolerance (microns) = $0.45X^{1/3} + 0.001X$

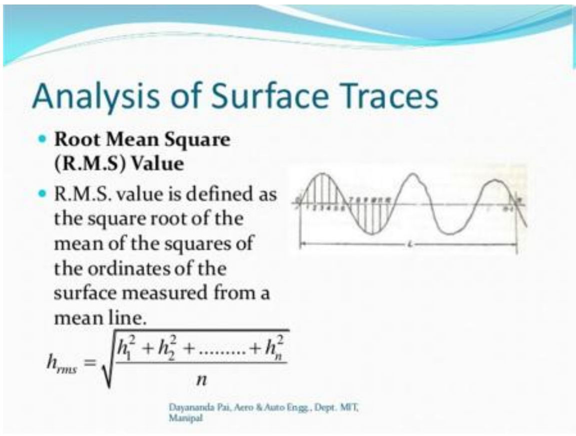
Where x is the nominal dimension in millimetres.



(4) Surface finish

Surface finish, or the degree of approach to perfect smoothness of a surface, is generally expressed as some sort of average measurement of the surface profile about a central mean, either centre-line-average (CLA) or root-mean-square (RMS). Once again, pressure die casting and sand casting offer the extremes of results, with possible figures of 1 and 25 µm RMS, respectively.

Some alloys are much worse than others: sand-cast phosphor-bronze produces especially rough castings. Poor surfaces due to metal mould reaction are obtained from several combinations of metal and mould.

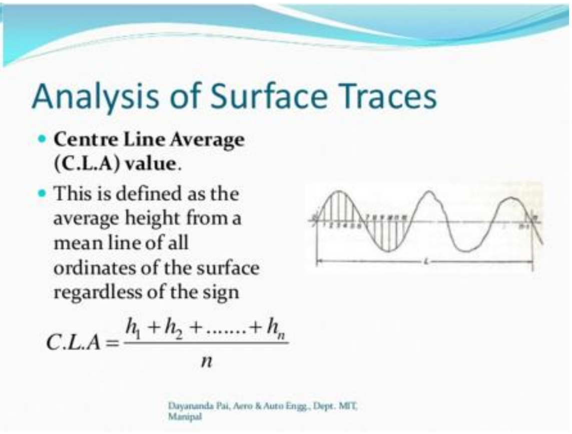


Analysis of Surface Traces

- **Root Mean Square (R.M.S) Value**
- R.M.S. value is defined as the square root of the mean of the squares of the ordinates of the surface measured from a mean line.

$$h_{rms} = \sqrt{\frac{h_1^2 + h_2^2 + \dots\dots\dots + h_n^2}{n}}$$

Dayananda Pai, Aero & Auto Engg., Dept. MIT, Manipal



Analysis of Surface Traces

- **Centre Line Average (C.L.A) value.**
- This is defined as the average height from a mean line of all ordinates of the surface regardless of the sign

$$C.L.A = \frac{h_1 + h_2 + \dots\dots\dots + h_n}{n}$$

Dayananda Pai, Aero & Auto Engg., Dept. MIT, Manipal

References

(1) *Selection and Use of Engineering Materials; Third edition; J. A. Charles, F. A. A. Crane, J. A. G. Furness MA.*

Questions

1. *Give three examples of how the materials properties play a key role in materials selection.*
   (Example; corrosion resistance of the superheater tubes made of stainless steel.
2. *Does material cost matter in material selection?*
3. *What are the main material processing aims providing an example for each?*
4. *What are the factors which contribute to complexity and is there any relationship between complexity and the numbers required.*
5. *Differ between centre-line-average (CLA) or root-mean-square (RMS) by definitions and equations?*