Material Science

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Chapter 18. Economic, Environmental and Social issues of material usage

Learning objectives:

- To understand special issues of material that related to their cost, production cost, environmental and social issues like pollution, disposal, recycling, etc. and materials selection.

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Highlights, Motivation and Critical Concepts:

Engineering materials are important in everyday life because of their versatile structural and physical properties. Selection of the engineering materials is dependent on these properties. However, choice of material has implications throughout the life-cycle of a product, influencing many aspects of economic and environmental performance. In other words, different material issues are needed to be dealt with during material selection if the product is to be commercially successful and competitive in the market. These special considerations are related to their cost, production cost, environmental and social issues like pollution, disposal, recycling, etc. This chapter deals with these special issues of material selection.

Multiple Choice Questions' Bank:

1. Usually _____ is the initial stage of a component manufacturing.

(a) Design (b) Conception (c) Material selection (d) Testing

2. Important waste management techniques

(a) Disposal - biodegradable (b) Recycling (c) Land-fills (d) All

Answers:

1. b
2. d

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18.1 Economic considerations

Engineering profession deals with utilization of scientific and technological advances to design and manufacture components and systems that perform reliably and satisfactorily. However, there are economics as the driving force behind it. Economics of engineering a component / system depends on three factors: component design, material usage, and manufacturing costs. These three factors are inter-related in the sense that one or two might influence the choice of others.

Initially any component / system need to go through conception and then design stage. This includes generation of concept about the component / system. Later on design stage takes care of its size, shape, and configuration which will influence the performance of it during the service. Usually engineers deal with not a single component, but with complex assembly of components / a system. Thus, each component needs to be designed for greater efficiency of the system. This may some times act as constraint to optimal design of a component. Hence, design of a component is usually an iterative process. Less the number of iterations, lower will be the cost of the component / system.

Design stage is followed by material selection. Material is selected depending on its properties, which are suitable to serve the purpose during the service. Other than the properties, cheaper materials are preferred, if choice is available. Thus, usually a family of materials is selected that satisfy the design constraints, then comparisons are made on the basis of cost per unit. This cost also includes unavoidable material wastage during manufacturing stage.

After design and material selection, it is up to manufacturing method to reduce the product cost. Usually manufacturing includes both primary stage and secondary stage. The cost considerations include the capital on tooling, maintenance cost, labor, repair costs, and material wastage. More the number of manufacturing stages, higher will be the product cost. Inspection, assembly, and final packaging will add-on to the product cost.

18.2 Environmental and Social considerations

Manufacturing of a product does have impact on environment and also on society in many ways. This is because resources required to produce a product comes from different parts of the world, and the industrial wealth and prosperity are shared by more the one region. Along with these, detrimental effects of industrialization also spread its wings to various parts of the world.

A material used to produce a product goes through number of stages / phases. These include extraction of raw materials from natural resources through production, use during the service, and finally its disposal. It is some times known as cradle-to-grave life cycle of a material. A schematic life cycle model has been presented in the *figure 18.1*.

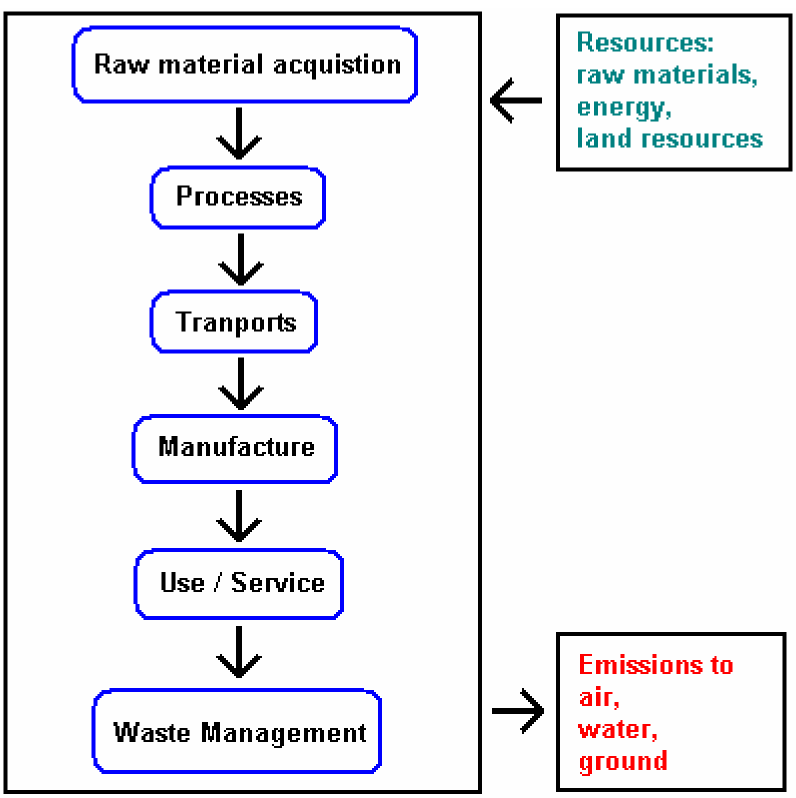

Figure-18.1: *Life cycle model.*

As depicted in the above figure, raw materials are first extracted from natural earthy resources through drilling, mining, etc. later-on these are subjected to purification, refining to convert them into metals, ceramics, rubber, fuel, etc. These primary products are further processed to obtain engineered materials like metallic alloy, glass, plastics, semi-conductors, etc. Now the engineered materials are shaped, heat treated to make components which are assembled into products, devices that are ready for use by society. During the service, products become old, out fashioned, break down, or may not serve the purpose efficiently. So they are discarded. Upon this, they go as waste into land fills, or some times recycled and some components may be reused. This competes the life cycle.

Earthy resources are, unfortunately, limited. However, some are renewable while majority are not! As society and thus population grows, resources per head become lesser and lesser. Hence, there is a great and in fact immediate attention must be paid to the better and effective use of earthy resources. It will be even better if we stop using the resources, which is of course impractical. In addition to this, energy is used at every stage of material cycle, which it self is a resource. That means that energy supply is limited, and energy need to be used conservatively, and effectively. Moreover, during extraction and production of materials / products, interaction with environment is usually detrimental to the society in many ways. It includes – water pollution, air pollution, and landscape spoilage. Thus great care needs to be taken during extraction, manufacturing, and use of a material / product. At end of its service, product may be recycled instead of disposal. There are many benefits from recycling those include: to conserve raw material resources and to conserve energy required to extract and refine. Recycling also avoids environmental pollution. Hence, final products are needed to be designed and manufactured such that they are environmentally friendly, and easy to recycle with minimum usage of raw materials and energy. In case of disposal into environment, products need to be bio-degradable. This shows that material life cycle involves interactions and exchanges among materials, energy and the environment including the society.

There is a need for better solutions to the environmental problems. Thus there is additional cost to the product if it is required to be produced under conditions such that detrimental environmental effects are kept to minimum i.e. green product cost more than usual products. Industrial approach to assess the environmental performance of products is termed as *life cycle analysis / assessment* (LCA). LCA is explained in detail in forth coming sections.

18.3 Recycling issues

As stated in earlier section, recycling of a product is important for many reasons. Recycling and disposal plays an important role in material selection and design of modern products. Recycling can be defined as unflawed entry of material into its cycle after completion of life as a product for infinite number of times. Environmentally friendly means product after disposal into the environment, must interact with it and get deteriorated so that material returns to the same state from where it is extracted and put into life cycle. For ease of disposal and recycling, product design should ease the dismantling of system. Different engineering materials are recycled and/or bio-degradable up to different extents.

Metals and alloys tend to get corroded up to some extent i.e. bio-degradable. However, some of them are toxic. On the other hand, most metals and alloys are recyclable. Ceramics / glasses are, however, are hardly recycled. It is because their raw materials are inexpensive, and recycling process is time consuming and expensive. Plastics and rubber are highly popular among public because of their inertness to the environment and moisture. This same inertness makes them hard to bio-degrade. Thus, plastics are mostly recycled, and just disposed through land-fills. Thermo-plastic polymers are easily recycled up on heating to higher temperatures. On the other hand recycling of thermo-set plastics is much more difficult. Hence these are usually disposed. Thus, there is a trend to use alternative materials which are recyclable. Ex.: thermo-plastic elastomers in place of traditions rubber.

18.4 Life cycle analysis (LCA) and its use in design

Materials extracted from the earth are needed to be taken care of for one prime reason - to conserve material and energy. However, materials, energy and environment effects are interrelated i.e. each one has impact on another either directly / indirectly. Industrial approach to assess the environmental performance of products is termed as *life cycle analysis / assessment* (LCA). In other words, LCA is the assessment of environmental impact of a product across its life cycle. The complex interaction between a product and the environment is dealt with in the Life Cycle Assessment (LCA) method. It is also known *Ecobalance*. LCA systematically describes and assesses all flows to and from nature, from a cradle to grave perspective.

Environmental life cycle of a product consists of all stages from raw material extraction to its waste management. In environmental life cycle assessment, natural resource use and pollutant emission are described in quantitative terms. One important reason for undertaking an LCA study is that there are growing concerns about a variety of environmental issues as expressed by public opinion, political bodies, and industry. Environmental concern may be related to the long-term resource base of human societies or may be more health related or it may be a concern for the natural environment as such. The strength of LCA is that it studies a whole product system. Since a whole life cycle is studied, LCA is not site specific. Thus, environmental impact cannot be modeled at a very detailed level. Economical and social aspects are not included in LCA other than when used as a basis for comparison. Risk is another aspect not dealt with in LCA.

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by

- complaining an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs;

- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

LCA is not only product-orientated; it is also quantitative and thus seemingly objective. Thus, it was no longer necessary to reply on simple rules of thumb. With LCA came the notion that it was possible to possible to quantitatively compare alternatives in order to identify the environmentally preferred option. Moreover, it could deal with environmental issues in a structured way and it could handle several environmental issues at a time. Quantitative description of the environmental impacts of emissions and resource using the three categories – resources use, human health, and ecological consequences – is not an uncomplicated affair. Environmental problems are complex and still not fully understood. As a consequence, different attempts at developing models to describe environmental impacts have led to different results.

LCA can be used in many different ways in product development. Life cycle assessment is a technique for assessing the environmental aspects associated with a product over its life cycle. The most important applications are: (1) Analysis of the contribution of the life cycle stages to the overall environmental load, usually with the aim to prioritise improvements on products or processes, (2) Comparison between products for internal or internal communications.

Product design and development has been seen as the principal area of application of LCA since the early days of LCA. The focal point of LCA, the product, coincides with that of the product design and development process. This explains in part why LCA has been brought forward as a tool for environmental adoption of product designs. The other part is that product development is seen as a decisive activity for achieving sustainability in industrial society – most of the environmental attributes are determined and built into the product during the design stage when materials are selected and constructions designed.

With respect to product design, there is a need to understand how a product impacts on the environment. To develop truly sustainable products, it must be possible to assess which design solution is environmentally preferable. LCA tools can help in this difficult area of *eco-design*. Ten simple guide lines for eco-design are:

1. Do not design products, but life cycles;
2. Natural materials are not always better;
3. Energy consumption often underestimated;
4. Increase product life time;
5. Do not design products, but services;
6. Use a minimum of material;
7. Use recycled materials;
8. Make sure product is recyclable;
9. Ask stupid questions i.e. be suspicious about the established result;
10. Become member O2: an international network for sustainable design.

As the whole product lifecycle should be regarded at once, representatives from design, production, marketing, purchasing, and project management should work together on the eco-design of a new product as they have together the best chance to predict the holistic effects of changes of the product and their environmental impact. Environmental aspects which ought to be analyzed for every stage of the lifecycle can be seen as:

1. Consumptions of resources (energy, materials, water or ground)
2. Emissions to air, water or the ground
3. Waste and waste products
4. Miscellaneous (noise and vibration)

Having made up a list on which phase of the lifecycle has which particular environmental aspect, these aspects are evaluated according to their environmental impact on the basis of a number parameters such as extend of environmental impact potential for improvement or potential of change. The evaluations can also take marketing and marketing issues into account. According to this ranking the recommended changes are carried out and are reviewed after a certain time. It must be done regularly to keep up with annual review of environmental legislation by national and international watchdogs.

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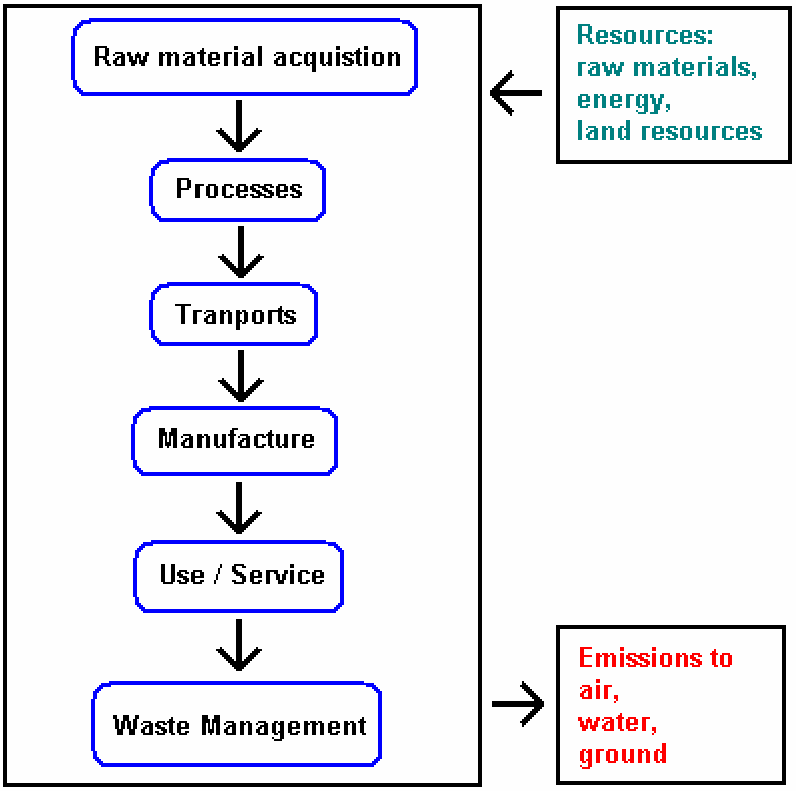
Economic considerations

- Economics of engineering a component / system depends on three factors:
  - component design,
  - material usage, and
  - manufacturing costs.
- All these three factors are inter-related i.e., one or two might influence the choice of others.
- Manufacturing of a component starts from conception, design, material selection.
- Material life starts from extraction, forming into a component, service, and disposal.
- Inspection, packing, and transportation adds onto the increase the cost of a product.

Environmental considerations

- Manufacturing of a product does have impact on environment in many ways.
- This is because resources required to produce a product comes from different parts of the world.
- Along with these, detrimental effects of industrialization also spread its wings to various parts of the world.
- A material used to produce a product goes through number of stages / phases.
- These include extraction of raw materials from natural resources through production, use during the service, and finally its disposal. It is some times known as *cradle-to-grave life cycle* of a material.

Life cycle model



Material life cycle

- Raw materials are first extracted from natural earthy resources through drilling, mining, etc.
- Later-on these are subjected to purification, refining to convert them into metals, ceramics, rubber, fuel, etc.
- These primary products are further processed to obtain engineered materials like metallic alloy, glass, plastics, semi-conductors, etc.
- Now the engineered materials are shaped, heat treated to make components which are assembled into products, devices that are ready for use by society.
- During the service, products become old, out fashioned, break down, or may not serve the purpose efficiently. So they are discarded. This competes the life cycle.

Social issues

- Raw materials and energy are prime components for manufacturing a product.
- However, they are limited in nature.
- Hence, materials and energy need to conserved.
- Material life cycle involves interactions and exchanges among materials, energy and the environment including the society.
- Social issues of material usage relates to weather distribution, and safe waste disposal.

- Products are needed to be designed and manufactured such that they are environmentally friendly, and easy to recycle. In case of disposal into environment, products need to be bio-degradable.

Recycling issues

- Metals and alloys tend to get corroded up to some extent i.e. bio-degradable. However, some of them are toxic. On the other hand, most metals and alloys are recyclable.
- Ceramics / glasses are, however, are hardly recycled. It is because their raw materials are inexpensive, and recycling process is time consuming and expensive.
- Plastics are mostly recycled, and just disposed through land-fills. Thermo-plastic polymers are easily recycled up on heating to higher temperatures. On the other hand, recycling of thermo-set plastics is much more difficult. Hence these are usually disposed. Thus, there is a trend to use alternative materials which are recyclable. Ex.: thermo-plastic elastomers in place of traditions rubber.

Life Cycle Analysis

- Industrial approach to assess the environmental performance of products is termed as *life cycle analysis / assessment* (LCA).
- The complex interaction between a product and the environment is dealt with in the Life Cycle Assessment (LCA) method. It is also known *Ecobalance*.
- One important reason for undertaking an LCA study is that there are growing concerns about a variety of environmental issues as expressed by public opinion, political bodies, and industry.
- LCA systematically describes and assesses all flows to and from nature, from a cradle to grave perspective.
- LCA is not only product-orientated; it is also quantitative and thus seemingly objective. Thus, it was no longer necessary to reply on simple rules of thumb.

LCA use in design

- LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by
    - complaining an inventory of relevant inputs and outputs of a product system;
    - evaluating the potential environmental impacts associated with those inputs and outputs;
    - interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.
- With respect to product design, there is a need to understand how a product impacts on the environment. To develop truly sustainable products, it must be possible to assess which design solution is environmentally preferable. LCA tools can help in this difficult area of *eco-design*.

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Answers:

1. b
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