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INTRODUCTION

1.1 GENERAL

Material/Matter. All matters/materials are considered to be composed of unit substance known as chemical elements. These are the smallest units those are distingusihed on the basis of their chemical activity and physical properties. The elements are composed of atoms which have a distinct structural charactersitcs of each element. While each element is composed of atoms, it is the difference of atomic structure that gives the element its charactersitcs properties.

Three states of any matter are gas, liquid and solid. In case of gaseous state, the atoms occupy a great deal of space because of their rapid motion. This motion is entirely random and as they travel, they collide with each other inside the walls of the container. At some lower temperature, the kinetic energy of the atoms decreases. As such attractive forces become large enough to bring these atoms close together in a liquid state. Here also some atoms remains in the form of vapour above the liquid and there is continual interchange of atoms between the vapour and liquid across the liquid surface. In a confined vessel, at a definite temperature, the interlocking of atoms reach equilibrium and there is a constant value of vapour pressure of the gas above the liquid.

As the temperature decreases, the motion of atoms is less vigorous and attractive forces pull the atoms closer together until liquid solidifies. Most materials contract upon solidfication indicating a closer packing of atoms in the solid state. The atoms in the solid are not stationary but are in vibrating stage around fixed point giving rise to the ordinary arrangement of crystal structure. Crystallization is a process of transmission of matter from liquid state to the solid state.

Mankind has been confronting with the problem of materials since Adam and Eve felt the need of some sort of apparel in the garden of Eden after eating the prohibited apple. Earlier the problems were easy *i.e.* only of clothing and shelter. But with the advancement of civilization, uses of materials became manifold. These constitute the backbone of modern civilization. In every field of human activity engineering materials are used in one form or the other. In order to cater to the needs of higher standard of performance and reliability required for modern civilization; material science has developed tremendously to provide right materials in complex industrial situations and serve service requirements.

Selection of right material is an important problem which an engineer has to face. Hence one must have thorough knowledge of nature and behaviour of material. Nature of material means its chemical composition, behaviour under different environmental conditions. The nature of solid materials involve their atomic and molecular structures, which in turn depends on the bending forces and energy associated with the solid state.

Engineering materials are classified broadly.

1. According to mode of occurrence :
   (*a*) Metal and their alloys.
   (*b*) Non-metals *i.e.* carbon, sulphur etc.
   (*c*) Ceramics and glasses, cement, silica etc.
   (*d*) Organic polymers-nylon, PVC, cotton rubber etc.
2. According to major areas of use :
   (*a*) Structures — Dams, oil refineries.
   (*b*) Machines — turbines, jet engines, motors etc.
   (*c*) Devices like transistors, pressure gauges etc.

In this book, materials classified as per mode of occurrence and used particularly for construction are dealt.

Before a material is used for any specific or general work a thorough knowledge regarding its properties must be made in following points.

1. Physical—shape, size, colour, specific gravity, density, porosity etc.
2. Mechanical—strength properties.
3. Thermal properties—specific heat, coefficient of expansion etc.
4. Electrical properties.
5. Chemical—corrosion, atomic structure etc.
6. Magnetic properties.
7. Optical—colour, Lustre etc.
8. Technological—Hardness, weldability, mechanibility etc.
9. Durability.

1.2 SELECTION OF MATERIAL

Selection of right material is an important problem which an engineer has to face everywhere. This problem leads him to have a thorough knowledge of nature and behaviour of material. Selection of materials depend upon their properties in relation to intend use : Mechanical strength, if significant loads are to be supported, thermal conductivity if high temperatures are to be encountered. The Engineer should keep on the alert for new materials that may be developed but he should also keen his mind respective to the possible new ways of using existing materials. The next important considerations are economy and availability. Some times inferior but availability and possibility of new ways of using existing materials make them to use not only economically but also found feasible to use. Some times inferior but available material is used because right material is too costly. A high material cost may be accompanied by easier fabrication, with a significant saving in labour. In other words overall economy of material should be considered. Ease of handling and fabrication are usually desirable. Besides, these appearance is also considered essential property.

As such the important engineering requirements of a material for its selection are as follows:—

1. Its mechanical, thermal, electrical, chemical, magnetic, physical or radiological properties.
2. Appearance and aesthetic appeal
3. Suitability to the methods and techniques of manufacturing.
4. Availability in commerical quantities and as and when required.
5. Absence of undesirable properties in it.
6. Cost

All above considerations are inter-related and hence decission to be taken depends on other considerations also. Selection of material, therefore, depends on :

1. Properties in relation to intended use
2. Mechanical strength if significant; loads are to be supported.
3. Magnetic properties if magnetic fields are envolved.
4. Thermal conductivity if high temperature are to be encountered.
5. Corrosion resistance if corrosive environment is involved.
6. Economy and availability
7. New materials envolved; one must have knowledge of these new materials.
8. Useful life desired.

1.3 STRUCTURE OF SOLID

Solid materials are made up of many particles of many sizes held together by internal cohesive forces. These particles of building blocks of matter may be fibers, crystals, atoms etc. It is the cohesive forces and the energy associated with them that determing the reaction of a given material of external influences such as those imposed by mechanical, electrical, chemical or thermal action.

The structure of material can be classified as under depending upon the level.

1. Macro-structure - visible to naked eye *i.e.* wood, concrete.

2. Micro-structure - optical microscope with magnification of 75 to 1500 is used. Structure looks like dust particles.

3. Sub-structure - microscope with higher magnification of 100000 is used called electron microscope.

4. Crystal structure - details of atomic arrangement within a crystal obtained by X-rays and electron diffraction.

5. Electronic structure - It provides information about electrons in the outermost shell of individual atoms forming the solids. It is determined by spectroscopic techniques.

6. Nuclear structure - studied by nuclear spectroscopic technique like nuclear magnetic resonance.

1.4 PROPERTIES OF MATERIALS

The quality of a material, its characteristic features and stability for a particular application in construction cannot be studied without taking into account the conditions under which the material is to serve. The durability of a structure can not be evaluated if it is considered as an isolated problem independent of quality of materials and the conditions of construction, and also of the service conditions for the material. For example, the behaviour of concrete cast using ordinary portland cement will be altogether different if it is used for buildings located at ordinary normal place or for a building to be used for production of sulphuric acid plant or used for any construction at sea shore. The quality of cement for different places will be different from durability consideration taking into account the environment under which it is to serve. Quality is determined by the chemical-mineralogical composition, external appearance, texture, structure and a combination of many properties by which one material differs from another. During the course of usuage, all the articles are subjected to actions of external changes which desire the material to possess certain properties to withstand the impact of various changes likely to influence its usuage. The knowledge of the basic properties of engineering materials is a must so as to be guided in the selection of the material, deciding manufacturing procedures and to bring in economy in overall operations.

To manufacture different materials as per their use, following considerations are made.

1. Kind of material available.
2. Properties of various materials.
3. Service requirement for materials.
4. Relative economy.
5. Method of preparation/Manufacture.
6. Specifications required for material.
7. Method of testing, regarding its desired properties.

"Property" is the quality that determines the specific characteristics of the material. The properties required are discussed here briefly.

1. Chemical Properties. It is one of the important property of any material and comprises of many. "Solubility" is one of the chemical property. It means, formation of homogeneous systems (true solutions), having the same chemical composition and physical properties, resulting from the interaction of some material (of one component) with an aqueous solution (another component) or with other solutions (components). The solubility of a material varies depending on the composition and temperature of the aqueous solution and the state of the material. "Crystallisation" is a property of a substance (material) to form crystals when passing from a fluid state to solid state. Crystallization of hardening cement ensures its strengthening whilst crystallization of water which freezes in the capillaries of cement-concrete causes its destruction. Crystallization is accompanied by a change in the volume of the material.

Corrosion resistance is a property of a material to resist desctruction or decay when exposed to and acted upon by corrosive media. It is assessed by chemical analysis. Weather proofness *i.e.* durability is the property of a material to resist decay when exposed to weathering agents like air, temperature, rains, snow, gases, solar radiations and atmospheric environment. Durability of concrete is a very important property. Concrete must be durable under severe and adverse environmental conditions.

Cohesion is the property of a material to be strong enough to the attraction between molecules. Hardening is a result of physico-chemical processes. Ageing is the property of materials to change from one state into another due to physico-chemical processes and thus to become incapable of offering resistance to loads and corrosive surrounding. Due to ageing, ductile materials convert to brittle one and therefore cracks develops. This is very common in case of bitumen pavements or asphalt-concrete pavements. Expansion and contraction are other important chemical property of a material. Liberation and absorption of heat is also one important property. Stones ; particularly if used absorb heat during day and liberates it out in evening hours and create uncomfortable conditions. Decay or rot is a property of timber and many other materials. Combustibility is also a property of many materials. All materials are classed as per their combustibility resistance. Softening temperature is the temperature at which materials softens due to heating. Toxicity is the property of some materials to cause poisoning. Special precautions are required when handling toxic materials. These all are chemical properties, depend on chemical composition of a substance.

2. Mechanical Properties. These are the properties that determine the behaviour of engineering materials under applied forces and loads. The response of material to applied forces will depend on the type of bonding and the structural arrangement of atoms or molecules in the solid.

Inspite of considerable structural complexity of engineering materials, all load carrying materials can be divided into three main divisions as per mechanics involved in their deformation under applied load *viz.*

(*a*) Elastoplastic materials - structural metals.

(*b*) Viscoplastic materials - Rubber, plastic, glass, concrete etc.

(*c*) Elastic material - crystals.

Most of the engineering materials are isotropic *i.e.* they have same properties in all the directions, but some material exhibit marked anisotropy, like crystals show marked anisotropy which depends on the symmetry of the crystal. However polycrystalline materials such as metals or granite can be regarded as isotropic on the macroscopic scale because of random distribution of crystals. Amorphous materials like glass and other polymers are isotropic. Materials like concrete, asphalt are hetrogeneous but are considered as isotropic from the point of view of their response to applied forces. On the other hand, materials like wood and laminated plastics and various composite materials are highly anistropic.

Most engineers are primarily concerned with the development and design of machines, structures and prodcuts of various kinds. Since these constructions are usually subjected to internal forces and deformations called stresses and strains for various environments, it becomes an important engineering consideration. Hence mechanical properties can be dealt in according to behaviour of it under load *viz.* (*a*) Elastic properties and (*b*) plastic properties.

(*a*) ELASTIC PROPERTIES. Any force or load applied on the material will result in stress and strain in the material. Stress represent the intensity of reaction force at any point in the body as imposed by

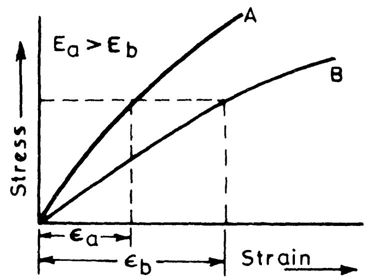

Fig. 1.1

service loads, assembly conditions, fabrication and thermal changes. Stress is measured as force per unit area. On removal of the load, the body tries to recover its original shape and size. Elasticity is therefore a property possessed by the material of resuming its original shape upon removal of any force, which has modified its form by stretching compressing, twisting etc. "Proportion limit" is defined as stress value beyond which the stress is no longer proportional to strain. Elastic limit is defined as the maximum stress that can be applied to a material without producing a permanent plastic deformation when the load is removed.

A material has high stiffness value when its deformation in the elastic range is relatively low. For the two alloys *A* and *B* with elastic stress-strain-diagram as shown in Fig. 1.1, striffness of material *A* is greater than that of *B*, because strain (εa) in material *A* is less than strain (εb) in material *B* for the same stress. Stiffness in tension is measured by modulus of elasticity *E*. Greater the modulus of elasticity less the deformation hence higher the modulus, stiffer the material $E_{steel} = 2.1 \times 10^5$ N/mm^2 while $E_{Aluminium} = 7 \times 10^4$ N/mm^2; this indicates that steel has more stiffness than aluminium for same stress. Another measure of deformation is Poisson's ratio *i.e.* ratio of lateral strain to longitudinal strain. Hardness is the property of the material by which it offers resistance to scratching or identification. It is very important property for the materials subjected to friction and scratching. Stiffness is reverse of hardness.

Resilience is the property of material which shows the amount of energy absorbed by material in elastic limit. A material has high resilience if its ability to absorb internal work or energy in the elastic range is high. It is measured by the modulus of elastic resilience which is internal work or energy (strain) per unit volume of the material required to stress the material to the proportion limit. It is measured by area under stress strain curve; hence the modulus of elastic resilience is high when proportional limit or yield stress is high and modulus of elasticity is low *i.e.*, resilience of aluminium is about three times the resilience of steel. Resilience is an important property in member where it is necessary to resist high deformation and high stress which occur simultaneously. Springs of various kinds used as transportation equipment require high resilience.

(*b*) **PLASTIC PROPERTIES.** The plastic properties of a material are those which define the ability to resist loads and deformations and the capacity to absorb energy in the plastic range. The mechanical properties are called plastic strength, ducility and toughness and correspond respectively to elastic strength, stiffness and resilience in elastic range.

A material has a higher plastic strength if it resists load without fracture. Plastic strength may be designated either by ultimate strength corresponding to ultimate stress or rupture, breaking or fracture strength corresponding to rupture, breaking or fracture stress.

Ductility represents ability of material to deform in plastic range. The usual measures of ductility in tension is the percentage elongation which is percentage strain corresponding to fracture. It is also measured in terms of percentage reduction in area; but difficult to find and hence is not used. Ductility is a very important property, it gives considerable deformation to occur before fracture takes place. If ductility is small, an unforseen overload, may cause fracture sudden.

A material has high toughness if it can absorb high value of strain energy in the plastic range. It is measured by modulus to toughness or the amount of energy absorbed per unit volume on stressing to fracture. It is the area under stress-strain curve and approximately equal to ultimate stress times the fracture strain. This measure of toughness is called toughness Index number or merit number. It is desirable property to resist shocks or impact such as axles, gears, frames of automobiles, crushers etc. A high toughness occurs in materials with high value of fracture strain or ductility or high value of ultimate load.

3. **ELECTRICAL PROPERTIES.** Materials may be designed as conductors with low electrical resistance *i.e.* from 1.6×10^{-8} to 1.4×10^{-6} ohm at room temperature and insulators *i.e.*, with resistance 10^{11} to 10^{20} ohm and material with resistivity in between are designated as semi-conductors. Resistance may be defined as the property of a substance due to which it offered the flow of electricity (electrons) through it. Resistance is measured in ohms.

Effect of the temperature is to increase the resistance of pure metal and alloys and decrease resistance to electrolytes and partial conductors.

Reciprocal of electrical resistivity is known as electrical conductivity expressed in mho/cm. It is ability of a material to conduct as electric current. It is due to movement of electrons or ions or both through lattice. Capacitance is the property of a system of conductor and dielectric which permits the storage of electricity when potential difference exists between the conductors.

Dielectric strength is the property of a material to resist a electrical break down. The significance of this property is that suppose voltage is applied between two conductors and is large enough to start a flow of current by breaking free insulatives, so offered in between the two. The dielectric strength is the voltage per unit thickness of material above which the breakdown occurs.

Insulation resistance represents combined effect of volume and surface resistance of a material. Surface resistance is affected by humidity of the air which reduces net insulation. An insulator should have a low dielectric constant, a high dielectric strength and a high insulation resistance.

4. **THERMAL PROPERTIES.** These properties determine their behaviour when subjected to thermal changes. This includes heat resistance; heat capacity; thermal expansion, conductivity; thermal shock resistance etc.

Specific heat is defined as the ratio of the heat capacity of the material to that of water. Since the heat capacity of water is unity, in all units, therefore, the specific heat of any material has numerical value whether measured as a dimensionless ratio or in any of the system of units. The specific heat of a material depends upon the condition of measurement *i.e.* constant pressure or constant volume and accordingly it is named as specific heat at constant pressure and specific heat at constant volume.

Thermal capacitance or capacity is the amount of heat required to raise the termperature through 1°C of the whole body. It is equal to $m \times s$ calories where 'm' is the mass of the body in gm and 's' specific heat in cal/gm°C.

The stresses developed in the material when its expansion or contraction is partially or wholly prevented due to a temperature change by rigidly fixing its two ends, are known as thermal stresses. These stresses may due to the external bodies connected to a body under stress *i.e.* in welded structures, railway lines etc or due to the non unifrom expansion of the body itself as bimetallic strips in thermostatical controls. The failure of the structures may be caused due to the thermal stresses produced exceeding its elastic limit or the breaking strength. Therefore, the provision should be made to provide free expansion and contraction due to change of temperature on heating or cooling of the material producing compressive stresses and tensile stresses respectively. In case of bridges (steel) one end of the span is rigidly fixed while the other end rests on rollers. The cracking of brittle material caused by thermal stresses on the surface is known as spalling.

The effect of repeated or fluctuating thermal stresses caused by repeated heating and cooling is also responsible for fatigue failure known as 'Thermal Fatigue'. This failure is caused mainly by thermal stresses of a lower magnitude. The failure caused in a material by an application of thermal stress due to a sudden change of temperature is called thermal shock. To withstand the thermal stresses developed at the surface of a solid material due to sudden and severe change in temperature forces required to resist this failure known as 'Thermal shock resistance.'

5. **MAGNETIC PROPERTIES.** The magnetic properties of materials arise from spin of electrons and orbital motion of electrons around the atomic nuclei. Since moving charge sets up magnetic field around it, the moving and spinning electrons act as tiny magnet except for ferro-magnetic materials which can be permanent magnets, however, all substances exhibit electromagnetic effect when subjected to an external magnetic field.

All the materials can be characterised as :

(*i*) Dimagnetic. (*ii*) Paramagnetic.

(*iii*) Ferro-magnetic.

Depending on their behaviour under the influence of magnetic field. Dimagnetic substances are composed of atoms which do not have permanent magnetic moments but only weak induced magnetic moments. In paramegnetic substances, atoms possess an odd number of electrons which give rise to residual permanent magnetic moments. Ferro-magnetic substances exhibit a spontaneous magenetic moments which exists in the absence of applied magnetic field. Iron, nickle and cobalt and some of their oxides exhibit pronounced ferro-magnetism.

Magneto motive force is a force which tends to derive flux through a magnetic circuit. Reluctance is a measure of resistance offered to the passage of magnetic flux. Permeance is opposite of reluctance and implies in the case with which magnetic flux is devoted.

6. **TECHNOLOGICAL PROPERTIES.** These are very important properties and give an idea about the method to be adopted to give shape to the different materials.

Machinability is a measure of ease and the success of the operation such as turning, milling, drilling, threading etc. can be carried on one metal in comparison with the other. Other technological properties are castability, resistance to corrosion which decides the life and economy of the part in use, resistance to wear and tear, weldability etc.

7. **OTHER PROPERTIES.** Chemical composition, atomic weight, valance, molecular weight, acidity, alkalinity, atomic number etc., determine the chemical properties of the materials. Physical properties determine the shape, finish, density, specific gravity, or macro, micro-structures etc. The optical properties of engineering materials like colour, lustre often help in their identification; but are of little impor-

tance. When light rays strike a non luminous body, they either transmit, reflect or absorbed. The degree of absorption, reflection and transmission affect its colour. Lustre is selective reflection of certain wavelengths and can only be seen on a clean surface.

1.5 Durability of Building Materials

A number of alternative building materials have been developed through research and investigations. These materials are used in construction by builders. However there is an in built resistance in the minds of engineers or builders for adoption of these materials for construction as they are hesitant to diversify from time tested traditional materials like cement, timber, clay bricks etc. The durability and service life prediction of building products and the building itself are receiving a greater attention than ever before. An overall concept that means a lot to this increasing interest is sustainable Development. The inter-relation between durability and life cycle cost have therefore become very important.

Concept of durability has been identified in a number of ways. It is defined as performance with time of a building material or product component, element and of building itself. The durability of building material can also be defined in terms of resistance to change in state or property with time. It is also associated with service life. But neither durability nor service life are necessarily synonymous with economic life. Materials may for example remain in service long after they have ceased to be economically attractive to use or operate. A materials economic life is influenced by technical obsolescence, changing tastes, changing in building codes or other standards and by the arrival in the market of a technically equivalent substitute with lower initial and in service cost.

In economic terms the durability is a relative rather than an absolute concept. It involves life cy: e costing. It requires that the materials competing for use in a particular application be ranked using initial, operating and repair costs while meeting the given objectives of the building. As such it can be said that durability of a material can be defined as the time period over which it continues to meet the objectives of the building in which it is used at the minimum life cycle cost.

Durability and Life Cycle Cost :- It is becoming common to consider not only the initial cost of a new building but also the net percent value of the cost likely to be incurred for maintenance and repair, renovation etc. during expected life time. Using life cycle cost criteria, the building having the lowest initial cost may not necessarily be economical to use.

The durability of the materials used in building will influence its life cycle cost. This is illustrated in Fig.1.2 in which D_0 and D_1 represent repair cost curve for less and more durable materials respectively. As in the case of the buildings the cost of repairing materials declines as they approach the end of their life times. The difference between T_0 and T_1 represents the extended life time possible using D_1 and the area under D_1 curve representing the life time repair cost, will be at least smaller than the area under D_0 curve at worst equal to it.

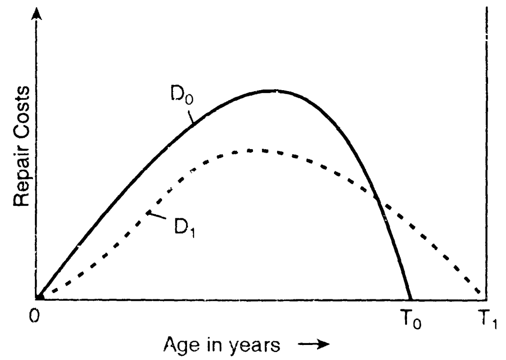

Fig. 1.2. Relation Between Durability and Deterioration of Building Materials

Another way of representing the economic consequences of Material durability is shown in Fig. 1.2. In this case two materials Y and Y' begin their service life with similar physical properties represented by Y_o. Now Y' deteriorates at the rate r' which is slower than r. The Curves $Y_t = Y_0 e^{-n}$ and $Y_t' = Y_0 e^{-n}$ represent the process of deterioration or loss of durability. Clearly Y' should have a larger service life than Y. The area between the two curves indicates potential savings that will occur using Y_1 rather than Y during the period from t_0 to t_2. Initially Y' may cost more per unit to produce than Y off setting at least some of the potential savings over the years but reducing the life cycle costs.

1.6 Economic Aspect, Social Cost & Energy

From the economic stand point construction materials may be classified under the following categories.

- Basic or Primary Materials which require little or no processing before use such as clay, sand.
- Semi processed Material which require limited amount of processing such as Cement, Timber
- Fully processed Materials which require manufacturing such as Fabricated Steel, Plastic, Composites, Bricks & Tiles.

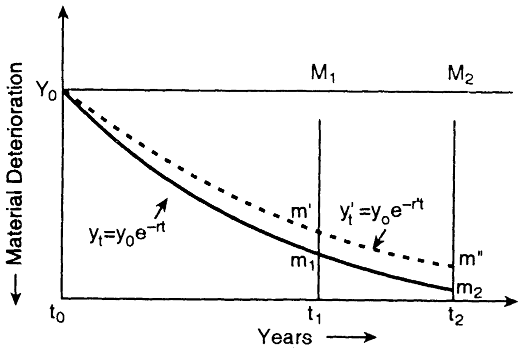

Fig. 1.3. Relation Between Durability and Deterioration of Building Materials

This break down is significant because the economic resources used in the form of capital and labour are usually proportional to the amount of processing required. With time durable dwelling increase in monetary value and conserve materials; non-durable dwellings diminish in value and spoil materials which, if used differently, could have a longer operating life. This is illustrated in Fig. 1.4.

There is also another important linkages between energy, economics and durability. For example, durability should help reduce the consumption of both energy and materials as well as completion expenses when materials can be required for use in new or rehabilitated buildings. On the other hand the degree of durability of a material may be linked directly to the consumption of energy in its production. Hence energy used to produce building materials is another area where waste should be avoided. Adjustments are also needed in the long run not only to avoid wastage of materials resources but also to reduce the waste generated during production process as much as possible.

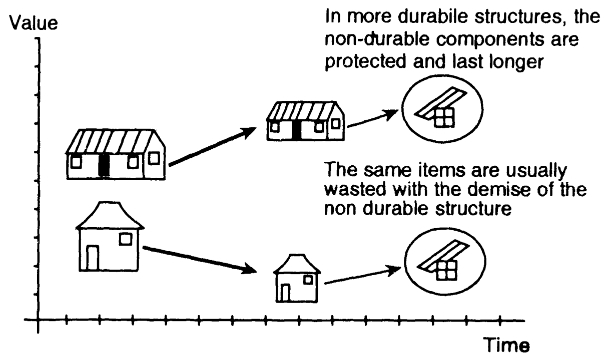

Fig. 1.4.

Social cost which is paid by the society as a whole during the production of the building materials is also very significant from the economic point of view. One example of such cost is the environmental pollution resulting from production process, another is the damage caused when the waste materials degrade over a period of time in disposal sites. The use of more durable materials may thus reduce social cost over a long period of time. Durability is therefore strongly related to saving of natural resources.