UNIT 1 PRODUCT CYLCLE

ENGINEERING DESIGN

What is design? If you search the literature for an answer to that question, you will find about as any definitions as there are designs. Perhaps the reason is that the process of design is such a common human experience. Webster's dictionary says that to design is "to fashion after a plan," but that leaves out the essential fact that to design is to create something that has never been. Certainly an engineering designer practices design by that definition, but so does an artist, a sculptor, a composer, a playwright, or many another creative member of our society.

THE ENGINEERING DESIGN PROCESS

The engineering design process can be used to achieve several different outcomes. One is the design of products, whether they be consumer goods such as refrigerators, power tools, or DVD players, or highly complex products such as a missile system or a jet transport plane. Another is a complex engineered system such as an electrical power generating station or a petrochemical plant, while yet another is the design of a building or a bridge. However, the emphasis in this text is on product design because it is an area in which many engineers will apply their design skills.

Moreover, examples taken from this area of design are easier to grasp without extensive specialized knowledge. This chapter presents the engineering design process from three perspectives. The design method is contrasted with the scientific method, and design is presented as a five-step problem-solving methodology.

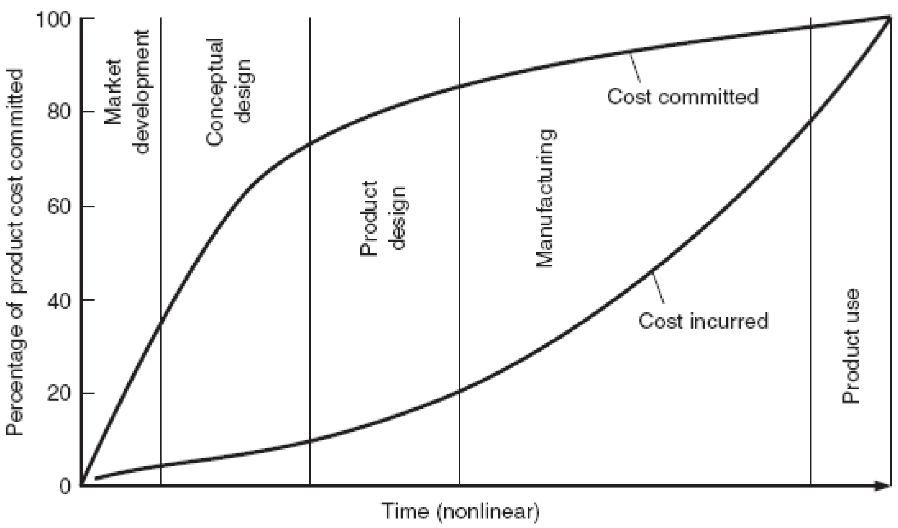


FIG
Product cost commitment during phases of the design process. (*After Ullman.*)

TOTAL LIFE CYCLE

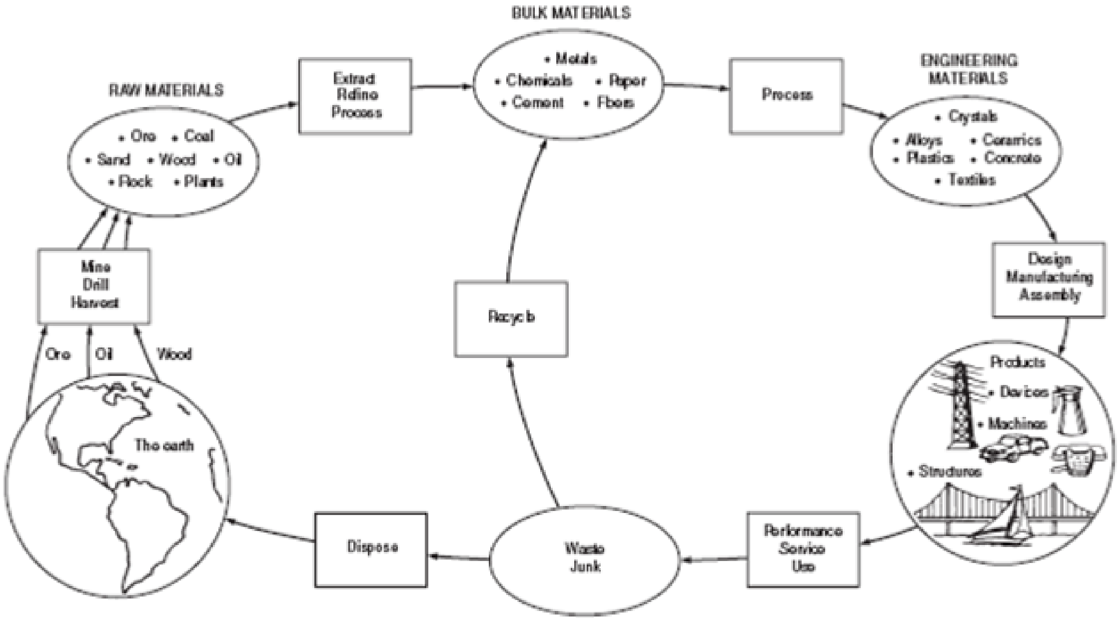
The total life cycle of a part starts with the conception of a need and ends with the retirement and disposal of the product. Material selection is a key element in shaping the total life cycle. In selecting materials for a given application, the first step is evaluation of the service conditions. Next, the properties of materials that relate most directly to the service requirements must be determined. Except in almost trivial conditions, there is never a simple relation between service performance and material properties.

The design may start with the consideration of static yield strength, but properties that are more difficult to evaluate, such as fatigue, creep, toughness, ductility, and corrosion resistance may have to be considered. We need to know whether the material is stable under the environmental conditions. Does the microstructure change with temperature and therefore change the properties? Does the material corrode slowly or wear at an unacceptable rate? Material selection cannot be separated from manufacturability. There is an intimate connection between design and material selection and the manufacturing processes.

The objective in this area is a trade-off between the opposing factors of minimum cost and maximum durability. Durability is the amount of use one gets from a product before it is no longer useable. Current societal issues of energy conservation, material conservation, and protection of the environment result in new pressures in the selection of materials and manufacturing processes. Energy costs, once nearly ignored in design, are now among the most prominent design considerations. Design for materials recycling also is becoming an important consideration.

The life cycle of production and consumption that is characteristic of all products is illustrated by the materials cycle shown in Figure. This starts with the mining of a mineral or the drilling for oil or the harvesting of an agricultural fiber such as cotton. These raw materials must be processed to extract or refine a bulk material (e.g., an aluminum ingot) that is further processed into a finished engineering material (e.g., an aluminum sheet).

At this stage an engineer designs a product that is manufactured from the material, and the part is put into service. Eventually the part wears out or becomes obsolete because a better product comes on the market. At this stage, one option is to junk the part and dispose of it in some way that eventually returns the material to the earth. However, society is becoming increasingly concerned with the depletion of natural resources and the haphazard disposal of solid materials. Thus, we look for economical ways to recycle waste materials (e.g., aluminum beverage cans).



The total materials cycle. (*Reproduced from "Materials and Man's Needs," National Academy of Sciences, Washington, D.C., 1974.*)

DESCRIPTION OF DESIGN PROCESS

Morris Asimow was among the first to give a detailed description of the complete design process in what he called the morphology of design. His seven phases of design are described below, with slight changes of terminology to conform to current practice. Figure 1.7 shows the various activities that make up the first three phases of design: conceptual design, embodiment design, and detail design. This eight-step set of design activities is our representation of the basic design process. The purpose of this graphic is to remind you of the logical sequence of activities that leads from problem definition to the detail design.

Phase I. Conceptual Design

Conceptual design is the process by which the design is initiated, carried to the point of creating a number of possible solutions, and narrowed down to a single best concept. It is sometimes called the feasibility study. Conceptual design is the phase that requires the greatest creativity, involves the most uncertainty, and requires coordination among many functions in the business organization. The following are the discrete activities that we consider under conceptual design.

- *Identification of customer needs*: The goal of this activity is to completely understand the customers' needs and to communicate them to the design team.
- *Problem definition*: The goal of this activity is to create a statement that describes what has to be accomplished to satisfy the needs of the customer. This involves analysis of competitive products, the establishment of target specifications, and the listing of constraints and trade-offs. Quality function deployment (QFD) is a valuable tool for linking customer needs with design

requirements. A detailed listing of the product requirements is called a product design specification (PDS). Problem definition, in its full scope, is treated..

- *Gathering information:* Engineering design presents special requirements over engineering research in the need to acquire a broad spectrum of information.
- *Conceptualization*: Concept generation involves creating a broad set of concepts that potentially satisfy the problem statement. Team-based creativity methods, combined with efficient information gathering, are the key activities.
- *Concept selection*: Evaluation of the design concepts, modifying and evolving into a single preferred concept, are the activities in this step. The process usually requires several iterations.
- *Refinement of the PDS*: The product design specification is revisited after the concept has been selected. The design team must commit to achieving certain critical values of design parameters, usually called critical-to-quality (CTQ) parameters, and to living with trade-offs between cost and performance.
- *Design review*: Before committing funds to move to the next design phase, a design review will be held. The design review will assure that the design is physically realizable and that it is economically worthwhile. It will also look at a detailed product development schedule. This is needed to devise a strategy to minimize product cycle time and to identify the resources in people, equipment, and money needed to complete the project.

Phase II. Embodiment Design

Structured development of the design concept occurs in this engineering design phase. It is the place where flesh is placed on the skeleton of the design concept. An embodiment of all the main functions that must be performed by the product must be undertaken. It is in this design phase that decisions are made on strength, material selection, size, shape, and spatial compatibility. Beyond this design phase, major changes become very expensive. This design phase is sometimes called preliminary design. Embodiment design is concerned with three major tasks—product architecture, configuration design, and parametric design.

- *Product architecture*: Product architecture is concerned with dividing the overall design system into subsystems or modules. In this step we decide how the physical components of the design are to be arranged and combined to carry out the functional duties of the design.
- *Configuration design of parts and components*: Parts are made up of features like holes, ribs, splines, and curves. Configuring a part means to determine what features will be present and how those features are to be arranged in space relative to each other. While modeling and simulation may be performed in this stage to check out function and spatial constraints, only approximate sizes are determined to assure that the part satisfies the PDS. Also, more specificity about materials and manufacturing is given here
- *Parametric design of parts :* Parametric design starts with information on the configuration of the part and aims to establish its exact dimensions and tolerances. Final decisions on the material and manufacturing processes are also established if this has not been done previously. An important aspect of parametric design is to examine the part, assembly, and system for design

robustness. *Robustness* refers to how consistently a component performs under variable conditions in its service environment

Phase III. Detail Design

In this phase the design is brought to the stage of a complete engineering description of a tested and producible product. Missing information is added on the arrangement, form, dimensions, tolerances, surface properties, materials, and manufacturing processes of each part. This results in a specification for each *special-purpose part* and for each *standard part* to be purchased from suppliers.

Phase IV. Planning for Manufacture

A great deal of detailed planning must be done to provide for the production of the design. A method of manufacture must be established for each component in the system. As a usual first step, a *process sheet* is created; it contains a sequential list of all manufacturing operations that must be performed on the component. Also, it specifies the form and condition of the material and the tooling and production machines that will be used.

The information on the process sheet makes possible the estimation of the production cost of the component. High costs may indicate the need for a change in material or a basic change in the design. Close interaction with manufacturing, industrial, materials, and mechanical engineers is important at this step.

Phase V. Planning for Distribution

Important technical and business decisions must be made to provide for the effective distribution to the consumer of the products that have been produced. In the strict realm of design, the shipping package may be critical. Concepts such as the shelf life of the product may also be critical and may need to be addressed in the earlier stages of the design process.

A system of warehouses for distributing the product may have to be designed if none exists. The economic success of the design often depends on the skill exercised in marketing the product. If it is a consumer product, the sales effort is concentrated on advertising in print and video media, but highly technical products may require that the marketing step be a technical activity supported by specialized sales brochures, performance test data, and technically trained sales engineers.

Phase VI. Planning for Use

The use of the product by the consumer is all-important, and considerations of how the consumer will react to the product pervade all steps of the design process. The following specific topics can be identified as being important user-oriented concerns in the design process: ease of maintenance, durability, reliability, product safety, and convenience in use (human factors engineering), aesthetic appeal, and economy of operation.

Obviously, these consumer-oriented issues must be considered in the design process at its very beginning. They are not issues to be treated as afterthoughts. Phase VI of design is less well defined than the others, but it is becoming increasingly important with the growing concerns for consumer protection and product safety. More strict interpretation of product liability laws is having a major impact on design. An important phase VI activity is the acquisition of reliable data on failures, service lives, and consumer complaints and attitudes to provide a basis for product improvement in the next design cycle.

Phase VII. Planning for Retirement of the Product

The final step in the design process is the disposal of the product when it has reached the end of its useful life. Useful life may be determined by actual deterioration and wear to the point at which the design can no longer function, or it may be determined by technological obsolescence, in which a competing design performs the product's functions either better or cheaper. In consumer products, it may come about through changes in fashion or taste.

PRODUCT DEVELOPMENT PROCESS

This text emphasizes the design of consumer and engineered products. Having defined the engineering design process in considerable detail, we now turn to the consideration of the product development process. The engineering design of a product is a vital part of this process, but product development involves much more than design. The development of a product is undertaken by a company to make a profit for its shareholders. There are many business issues, desired outcomes, and accompanying strategies that influence the structure of the product development process (PDP). The influence of business considerations, in addition to engineering performance, is seen in the structure of the PDP

A generally accepted model of the product development process is shown in Figure. The six phases shown in this diagram generally agree with those proposed by Asimow for the design process (see Sec.1.5) with the exception of the Phase 0, Planning, and the omission of Asimow's Phases VI and VII. Note that each phase in Fig. 2.1 narrows down to a point. This symbolizes the " *gate* " or review that the project must successfully pass through before moving on tothe next stage or phase of the process. This stage-gate product development process is used by many companies in order to encourage rapid progress in developing a product and to cull out the least promising projects before large sums of money have been spent. The amount of money to develop a project increases exponentially from Phase 0 to Phase 5. However, the money spent in product development is small compared to what it would cost in sunk capital and lost brand reputation if a defective product has to be recalled from the market. Thus, an important reason for using the *stage-gate process* is to "get it right."

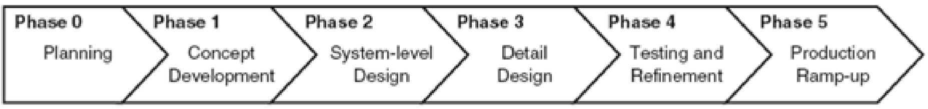
Phase 0 is the planning that should be done before the approval of the product development project. Product planning is usually done in two steps. The first step is a quick investigation and scoping of the project to determine the possible markets and whether the product is in alignment with the corporate strategic plan. It also involves a preliminary engineering assessment to determine technical and manufacturing feasibility. This preliminary assessment usually is completed in a month. If things look promising after this quick examination, the planning operation goes into a detailed investigation to build the *business case* for the project. This could take several months to complete and involves personnel from marketing, design, manufacturing, finance, and possibly legal. In making the business case, marketing completes a detailed marketing analysis that involves market segmentation to identify the target market, the product positioning, and the product benefits.

Design digs more deeply to evaluate their technical capability, possibly including some proof-of-concept analysis or testing to validate some very preliminary design concepts, while manufacturing identifies possible production constraints, costs, and thinks about a supply chain strategy. A critical part of the business case is the financial analysis, which uses sales and cost projections from marketing to predict the profitability of the project.

Typically this involves a discounted cash fl ow analysis (see Chap. 15) with a sensitivity analysis to project the effects of possible risks. The gate at the end of Phase 0 is crucial, and the decision of whether to proceed is made in a formal and deliberate manner, for costs will become considerable once the project advances to Phase 1.

The review board makes sure that the corporate policies have been followed and that all of the necessary criteria have been met or exceeded. High among these is exceeding a corporate goal for return on investment (ROI). If the decision is to proceed, then a multifunctional team with a designated leader is established. The product design project is formally on its way.

Phase 1 , Concept Development, considers the different ways the product and each subsystem can be designed. The development team takes what is known about the potential customers from Phase 0, adds its own knowledge base and fashions this into a carefully crafted *product design specification (PDS).* This process of determining the needs and wants of the customer is more detailed than the initial market survey done in Phase 0.



The product development process.

Phase 2 , System-Level Design is where the functions of the product are examined, leading to the division of the product into various subsystems. In addition, alternative ways of arranging the subsystems into product *architecture* are studied. The interfaces between subsystems are identified and studied. Successful operation of the entire system relies on careful understanding of the interface between each subsystem. Phase 2 is where the form and features of the product begin to take shape, and for this reason it is often called *embodiment design.*

Selections are made for materials and manufacturing processes, and the configuration and dimensions of parts are established. Those parts whose function is critical to quality are identified and given special analysis to ensure design robustness.

Phase 3 , Detail Design, is the phase where the design is brought to the state of a complete engineering description of a tested and producible product. Missing information is added on the arrangement, form, dimensions, tolerances, surface properties, materials, and manufacturing of each part in the product. This result in a specification for each special-purpose part to be manufactured, and the decision whether it will be made in the factory of the corporation or outsourced to a supplier. At the same time the design engineers are wrapping up all of these details, the manufacturing engineers are finalizing a process plan for each part, as well as designing the tooling to make these parts.

Phase 4 , Testing and Refinement, is concerned with making and testing many preproduction versions of the product. The first (alpha) prototypes are usually made with *production-intent parts.* These are working models of the product made from parts with the same dimensions and using the same materials as the production version of the product but not necessarily made with the actual processes and tooling that will be used with the production version. This is done for speed in getting parts and to minimize the cost of product development.

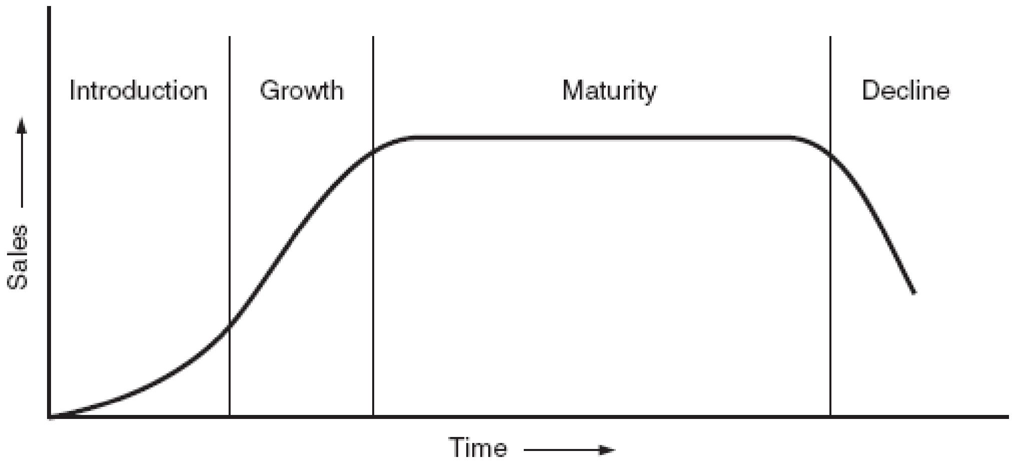
The purpose of the alpha test is to determine whether the product will actually work as designed and whether it will satisfy the most important customer needs. The beta tests are made on products made from parts made by the actual production processes and tooling. They are extensively tested inhouse and by selected customers in their own use environments. The purpose of these tests is to satisfy any doubts about the performance and reliability of the product, and to make the necessary engineering changes before the product is released to the general market.

PRODUCT AND PROCESS CYCLES

Every product goes through a cycle from birth, into an initial growth stage, into a relatively stable period, and finally into a declining state that eventually ends in the death of the product. Since there are challenges and uncertainties any time a new product is brought to market, it is useful to understand these cycles.

Stages of Development of a Product

In the introductory stage the product is new and consumer acceptance is low, so sales are low. In this early stage of the product life cycle the rate of product change is rapid as management tries to maximize performance or product uniqueness in an attempt to enhance customer acceptance. When the product has entered the growth stage, knowledge of the product and its capabilities has reached an increasing number of customers,



and sales growth accelerates. There may be an emphasis on custom tailoring the product by making accessories for slightly different customer needs. At the maturity stage the product is widely accepted and sales are stable and are growing at the same rate as the economy as a whole.

When the product reaches this stage, attempts should be made to rejuvenate it by the addition of new features or the development of still new applications. Products in the maturity stage usually experience considerable competition. Thus, there is great emphasis on reducing the cost of a mature product. At some point the product enters the decline stage. Sales decrease because a new and better product has entered the market to fulfill the same societal need.

During the product introduction phase, where the volume of production is modest, expensive to operate but flexible manufacturing processes are used and product cost is high. As we move into the period of product market growth, more automated, higher-volume manufacturing processes can be justified to reduce the unit cost.

In the product maturity stage, emphasis is on prolonging the life of the product by modest product improvement and significant reduction in unit cost. This might result in outsourcing to a lower-labor-cost location. If we look more closely at the product life cycle, we will see that the cycle is made up of many individual processes. In this case the cycle has been divided into the premarket and market phases.

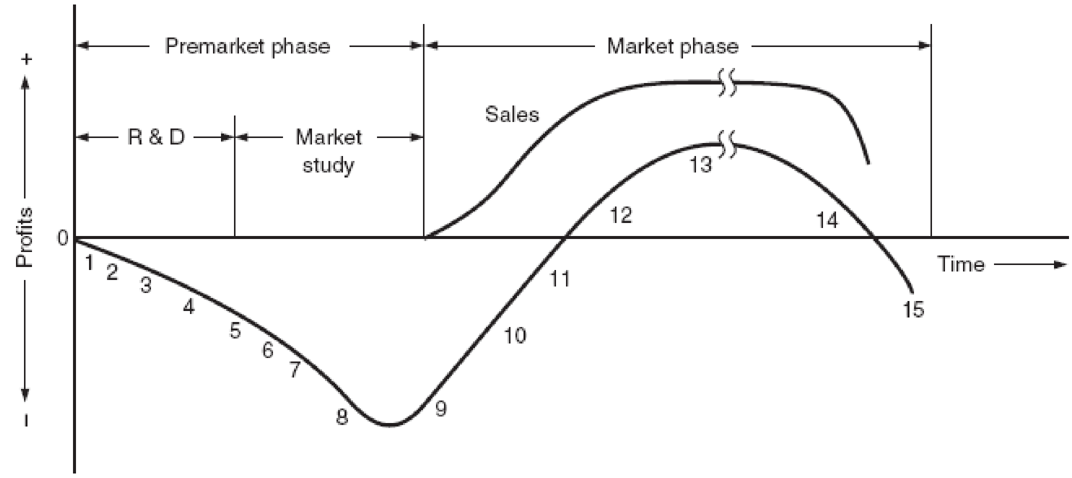
The former extends back to the product concept and includes the research and development and marketing studies needed to bring the product to the market phase. This is essentially the product development phases shown in Figure.

The investment (negative profits) needed to create the product is shown along with the profit. The numbers along the profit versus time curve correspond to the processes in the product life cycle. Note that if the product development process is terminated prior to entering the market, the company must absorb the PDP costs.

Technology Development and Insertion Cycle

The development of a new technology follows an S-shaped growth curve similar to that for the growth of sales of a product. In its early stage, progress in technology tends to be limited by the lack of ideas. A single good idea can make

Premarket phase	Market phasee
1. Idea generation	9. Product introduction
2. Idea evaluation	10. Market development
3. Feasibility analysis	11. Rapid growth
4. Technical R&D	12. Competitive market
5. Product (market) R&D	13. Maturity
6. Preliminary production	14. Decline
7. Market testing	15. Abandonment
8. Commercial production	

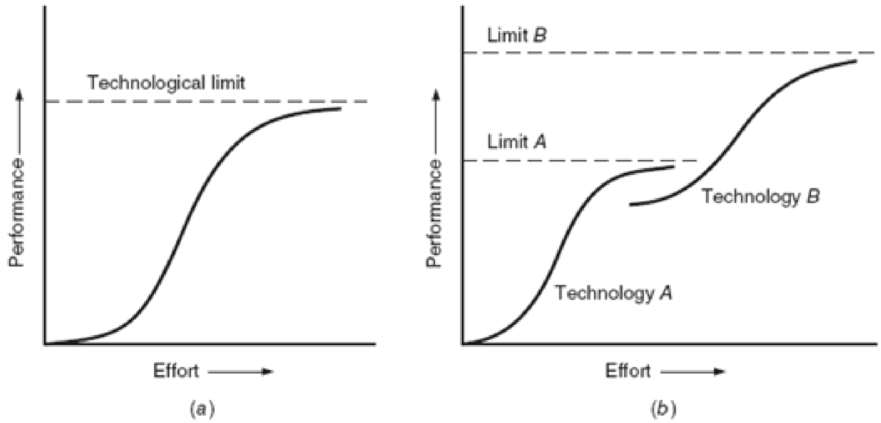


several other good ideas possible, and the rate of progress becomes exponential as indicated by a steep rise in performance that creates the lower steeply rising curve of the S.

During this period a single individual or a small group of individuals can have a pronounced effect on the direction of the technology. Gradually the growth becomes more nearly linear when the fundamental ideas are in place, and technical progress is concerned with filling in the gaps between the key ideas. This is the period when commercial exploitation flourishes. Specific designs, market applications, and manufacturing occur rapidly in a field that has not yet settled down. Smaller entrepreneurial firms can have a large impact and capture a dominant share of the market.

However, with time the technology begins to run dry, and improvements come with greater difficulty. Now the market tends to become stabilized, manufacturing methods become fixed in place, and more capital is expended to reduce the cost of manufacturing. The business becomes capital-intensive; the emphasis is on production know-how and financial expertise rather than scientific and technological expertise.

The maturing technology grows slowly, and it approaches a limit asymptotically. The limit may be set by a social consideration, such as the fact that the legal speed of automobiles is set by safety and fuel economy considerations, or it may be a true technological limit, such as the fact that the speed of sound defines an upper limit for the speed of a propeller-driven aircraft.



(a) Simplified technology development cycle. (b) Transferring from one technology growth curve (A) to another developing technology (B).

The success of a technology-based company lies in recognizing when the core technology on which the company's products are based is beginning to mature and, through an active R&D program, transferring to another technology growth curve that offers greater possibilities (To do so, the company must manage across a technological discontinuity (the gap between the two S-curves), and a new technology must replace the existing one). Past examples of technological discontinuity are the change from vacuum tubes to transistors and from the three- to the two-piece metal can.

Changing from one technology to another may be difficult because it requires different kinds of technical skills, as in the change from vacuum tubes to transistors. A word of caution. Technology usually begins to mature before profits top out, so there is often is a management reluctance to switch to a new technology, with its associated costs and risks, when business is doing so well. Farsighted companies are always on the lookout for the possibility for technology insertion because it can give them a big advantage over the competition.

Process Development Cycle

Most of the emphasis in this text is on developing new products or existing products. However, the development process shown in Fig. 2.1 can just as well be used to describe the development of a process rather than a product. Similarly, the design process described in Sec. 1.5 pertains to process design as well as product design. One should be aware that there may be differences in terminology when dealing with processes instead of products. For example in product development we talk about the *prototype* to refer to the early physical embodiment of the product, while in process design one is more likely to call this the *pilot plant* or *semi works* .

Process development is most important in the materials, chemicals, or food processing industries. In such businesses the product that is sold may be a coil of aluminum to be made into beverage cans or a silicon microchip containing hundreds of thousands of transistors and other circuit elements. The processes that produced this product create most of its value. When focusing on the development of a manufacturing process for a discrete product, as opposed to a continuous fl ow process like sheet steel or gasoline, it is convenient to identify three stages in the development of the manufacturing process. Production systems are generally classified as job shop, batch fl ow, assembly line, or continuous fl ow. Generally these classes are differentiated based on the number of parts that can be handled in a batch

1. *Uncoordinated development :* The process is composed of general-purpose equipment with a high degree of flexibility, similar to a batch process. Since the product is new and is developing, the process must be kept flexible.
2. *Segmental :* The manufacturing system is designed to achieve higher levels of efficiency in order to take advantage of increasing product standardization. This results in a high level of automation and process control. Some elements of the process are highly integrated; others are still loose and flexible.
3. *Systemic :* The product has reached such a high level of standardization that every process step can be described precisely, as on an assembly line. Now that there is a high degree of predictability in the product, a very specialized and integrated process can be developed.

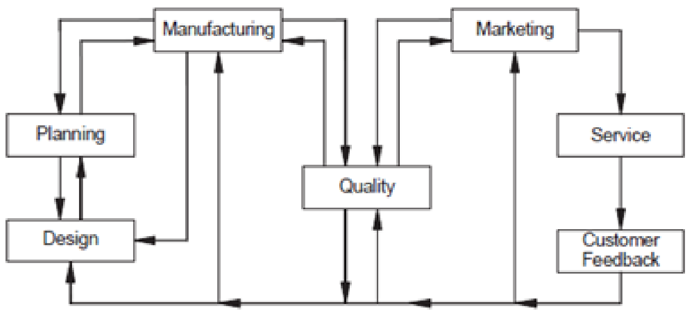
Process innovation is emphasized during the maturity stage of the product life cycle. In the earlier stages the major emphasis is on product development, and generally only enough process development is done to support the product. However, when the process development reaches the systemic stage, change is disruptive and costly. Thus, process innovations will be justified only if they offer large economic advantage. We also need to recognize that process development often is an enabler of new products. Typically, the role of process development is to reduce cost so that a product becomes more competitive in the market. However, revolutionary processes can lead to remarkable products. An outstanding example is the creation of micro electromechanical systems (MEMS) by adapting the fabrication methods from integrated circuits.

SEQUENTIAL ENGINEERING

The traditional product development process at the prototype development stage is sequential. It includes product design, development of manufacturing process and supporting quality and testing activities, all carried out one after another. This situation assumes that there is no interaction among the major departments involved in product manufacturing during the initial development process. Often the need for engineering changes is discovered during planning or manufacturing or assembly.

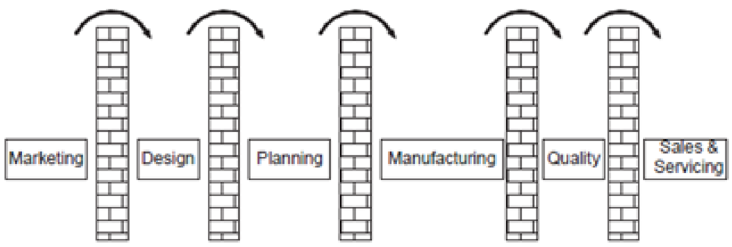
Design department in a typical sequential product development process finalizes the design without consulting the manufacturing, quality or purchase departments. Planning might feel it necessary to request design changes based on a number of reasons like the procurement or facility limitations. Changes in design may be called for when the manufacturing department is unable to meet design specifications or there are problems in assembly. These changes are however to be incorporated in design. The design documents are therefore sent back to the design department for incorporating the changes. The design/redesign path is shown in Figure. The design documents are passed on back and forth to incorporate design changes as illustrated. This will lead to inevitable conflicts, each department sticking to their own decisions and may often require intervention of senior management to resolve conflicts or differences in opinion. Design changes will involve both material and time wastages.

In such a situation, time taken to product development is usually more than what is anticipated and correspondingly the response to the market requirements will be slow compared to a competing company which can create an error free design at the first instance. In an age of reduced product life cycles as we witness today the time delay between market demand and introduction of product in the market has to be as short as possible. Sequential product development process, therefore, may not suit the present global scenario.



Design and Redesign Path

aEven after the prototype development stage is over, the need for design change may arise during service. Such changes are usually few in number, but are very costly. Thus in the traditional manufacturing, the design documents move sequentially through the various departments of the organization. The R & D group completes the design task and passes the data to planning, which in turn passes the information to manufacturing and so on. If any downstream department wants to introduce any change, the process has to backtrack and this often involves additional expenditure as well as inevitable delay in realizing the product.



Across the Wall Approach in Sequential Engineering

Sequential Engineering is often called “across the wall” method illustrates the insulated way each department may function in sequential approach. Each segment of the product development team (Design, Planning, Manufacturing etc.) completes its task in isolation and passes over the documents to the next segment. There is no interaction among the groups before the design is finalized. If a serious mistake in the product is detected during testing, the revision process has to start from design, resulting in materials wastage and loss of time. In the context of extensive outsourcing, there is also need for intensive consultation between vendors and manufacturers

CONCURRENT ENGINEERING

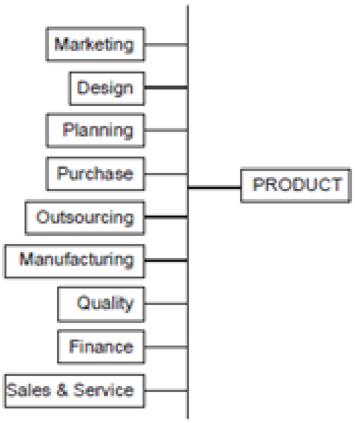
Concurrent engineering or Simultaneous Engineering is a methodology of restructuring the product development activity in a manufacturing organization using a cross functional team approach and is a technique adopted to improve the efficiency of product design and reduce the product development cycle time. This is also sometimes referred to as Parallel Engineering. Concurrent Engineering brings together a wide spectrum of people from several functional areas in the design and manufacture of a product. Representatives from R & D, engineering, manufacturing, materials management, quality assurance, marketing etc. develop the product as a team. Everyone interacts with each other from the start, and they perform their tasks in parallel.

The team reviews the design from the point of view of marketing, process, tool design and procurement, operation, facility and capacity planning, design for manufacturability, assembly, testing and maintenance, standardization, procurement of components and sub-assemblies, quality assurance etc as the design is evolved. Even the vendor development department is associated with the prototype development. Any possible bottleneck in the development process is thoroughly studied and rectified. All the departments get a chance to review the design and identify delays and difficulties.

The departments can start their own processes simultaneously. For example, the tool design, procurement of material and machinery and recruitment and training of manpower which contributes to considerable delay can be taken up simultaneously as the design development is in progress. Issues are debated thoroughly and conflicts are resolved amicably.

Concurrent Engineering (CE) gives marketing and other groups the opportunity to review the design during the modeling, prototyping and soft tooling phases of development. CAD systems especially 3D modelers can play an important role in early product development phases. In fact, they can become the core of the CE. They offer a visual check when design changes cost the least. Intensive teamwork between product development, production planning and manufacturing is essential for satisfactory implementation of concurrent engineering.

The teamwork also brings additional advantages ; the co-operation between various specialists and systematic application of special methods such as QFD (Quality Function Deployment), DFMA (Design for Manufacture and Assembly) and FMEA (Failure Mode and Effect Analysis) ensures quick optimization of design and early detection of possible faults in product and production planning. This additionally leads to reduction in lead time which reduces cost of production and guarantees better quality.



Concurrent Engineering

MATERIALS

Materials are the driving force behind the technological revolutions and are the key ingredients for manufacturing. Materials are everywhere around us, and we use them in one way or the other. The materials and the manufacturing process employed, could be better appreciated if one understands various types of materials and its properties.

Properties of Materials

Properties of materials include mechanical properties (such as strength, hardness, toughness), thermal properties (conductivity), optical properties (refractive index), electrical properties (resistance) etc. Here, however, we shall concentrate only on mechanical properties which are most important in manufacturing processes and also in everyday life and we use these terms quite often. To understand the mechanical properties, it is useful to first understand the behaviour of the material when subjected to a force which causes deformation; this could be understood with the 'stress-strain diagram'.

Malleability and Ductility

Both these properties relate to the plasticity of the material. Malleability refers to the ability of plastic deformation under compressive loads, while ductility refers to plastic deformation under tensile loads. A malleable material can be beaten into thin sheets and even thinner foils. A ductile material can be drawn into wires. A measure of ductility is "percentage elongation". Before the tensile test begins two punch marks are made on the stem of the tensile test piece. Distance between these marks is noted and is known as gauge length ($l0$). After the tensile test piece fractures in two pieces, the two pieces are retrieved and placed together as close to each other as possible

Brittleness

Brittleness can be thought of as opposite of ductility. It is a property which is possessed in great measure by glass and other ceramics. A piece of glass, if dropped on a hard surface shatters and is broken in many pieces. The real cause of brittleness is inability of the material to withstand shock loads. Of course, glass is an extreme case of brittle material.

Stiffness and Resilience

A material with high value of modulus of elasticity is said to be stiff and a material with low value of modulus of elasticity is said to be resilient. Consider a material undergoing tensile stress within the elastic range. If the material possesses a high value of Young's modulus (which is the modulus of elasticity corresponding to tensile stress), the material will not stretch much. It will behave as a "stiff " material. In this case, the slope of the line *OA* (Fig. 1.1) will be more. Resilience is a property which is totally opposite to stiffness. A beam made of stiff material will deflect to a lesser extent as compared to another made of resilient material under identical loading condition.

Toughness and Impact Strength

Toughness and impact strength are allied or similar properties (although these are some differences as mentioned later). They represent the ability of the material to absorb energy before actual failure/ fracture occurs. Refer to Fig. 1.1. If the scale of *y*-axis is changed and if force is plotted on this axis and, if actual elongation is plotted on *x*-axis instead of strain, we shall obtain a force-elongation curve instead of stress-strain curve. The shape of curve will remain the same; only scales of *x* and *y* axes will change. Now the area under this curve will represent energy required to fracture the material.

Hardness

Hardness is a very important property of materials. Hardness indicates wear-resistance and resistance against abrasion or scratching. A hard material also offers resistance to penetration by another body. In the olden days, a scale of hardness was established and diamond, which is the hardest known material was put on top of this scale. Glass and other materials were put lower down on this scale. The criterion used was a simple scratch test. If a material could scratch another material, then the former was considered harder than the latter material and was placed higher in the scale of hardness.

Fracture of Material

If a specimen is subjected to high stress beyond its strength, it fails and ultimately fractures in two or more parts. During the description of the tensile test, we have already come across fractures of ductile and brittle material. The ductile fracture occur after considerable plastic deformation

Fatigue Failure

It has been noticed that materials often fail or fracture at a stress level far below their strength, if the stress is either (*i*) alternating type or (*ii*) it is varying periodically. What is meant by alternating stress? An example will make this clear. Consider an axle fitted with two wheels. The axle bears the weight of the vehicle and at the same time it rotates along with wheels. Because of weight, the axle under goes a little deflection causing compressive stress in its top half and tensile stress in bottom half of the cross section. But since it is rotating, with every 180° rotation, the bottom half becomes the top half and vice versa. Thus the nature of stress at any point in the axle keep alternating between compression and tension due to its rotation.

Creep Failure

Failure of material can take place even under steady loads within the strength of the material. This happens if the subjected components remain under steady loads for a very longtime especially when they are subjected to high temperature conditions. Some common examples are stays in boilers, steam turbine blades, furnace parts etc. Such failures are termed creep-failures due to the fact the material continues to deform plastically under such conditions although at a very very slow rate. But over long periods of time, the effect of creep can become appreciable resulting in ultimate failure of the component.

Ferrous Material

Ferrous material refers to those materials whose main constituent is iron; while non-ferrous materials are those which do not contain iron in any appreciable quantity. Ferrous materials are usually stronger and harder and are used extensively in our daily lives. One very special property of ferrous materials is that, their properties can be significantly altered by heat treatment processes or by addition of small quantities of alloying elements. Ferrous materials are relatively cheap but suffer from a great disadvantage. They are subject to corrosion and rusting.

Iron and Steel

Most common engineering materials are ferrous materials such as mild steel and stainless steel which are alloys of iron. It is truly said that gold is metal for kings and iron is king of metals. Otto Von Bismark of Germany once said that “for development of a nation, lectures and meetings are not important, but what is important are blood and steel”. Incidentally, what is common in blood and steel is “iron’’. Though iron is important, but it is mostly used in the form of its alloy, namely steel. To a layman, words iron and steel convey the same meaning. But iron and steel are two different things. Iron is the name given to the metal, whose chemical symbol is Fe and refers to pure (or almost pure iron). Pure iron is relatively soft and less strong. Its melting point is about 1540°C. In industry, wrought iron is the material which is nearest to iron in purity; but is rarely used these days. Steel, on the other hand, is an alloy of iron and carbon; the percentage of carbon theoretically varies from 0 to 2%. However in actual practice, carbon rarely exceeds 1.25–1.3%. Carbon forms an inter-metallic compound called cementite (Fe3C), which is very hard, brittle and strong. The presence of cementite in steel makes steel much stronger and harder than pure iron.

CLASSIFICATION OF STEELS

Steel can be classified into (*i*) plain carbon steel, and (*ii*) alloy steel. Plain carbon steel is that steel in which the only alloying element present is carbon. In alloy steel, apart from carbon, other alloying elements like chromium, nickel, tungsten, molybdenum, and vanadium are also present and they make an appreciable difference in the properties of steel. Before we go further, readers must note that in steels, besides iron and carbon, four other elements are always present. These are S, P, Mn and Si. Removing these elements from steel is not a practical proposition. However, the effect of sulphur and phosphorus on the properties of steel is detrimental and their percentage is generally not allowed to exceed 0.05%. Similarly, the usual percentage of manganese and silicon in steel is kept below 0.8 and 0.3%, although their effect is not detrimental to the properties of steel. In fact, manganese counters the bad effect of sulphur. The presence of these four elements to the extent indicated does not put plain carbon steel into the category of alloy steel. However, if higher percentages of Mn and Si are intentionally added to steel in order to alter its properties, then the resulting steels come within the category of alloy steels.

Plain Carbon Steels

Since the properties of plain carbon steels are so dependent upon their carbon percentage, these steels are further classified into following categories on the basis of carbon percentage only:

(i) Low carbon or dead mild steel having carbon below 0.15%,
(ii) Mild steel having carbon between 0.15–0.3%,
(iii) Medium carbon steel having carbon between 0.3–0.7%, and
(iv) High carbon steels having carbon content above 0.7% (the higher practical limit of C% is 1.3%).

As the carbon percentage increases, the strength and hardness of plain carbon steel increases while ductility decreases. Reference is invited to Fig. 2.1 (see figure on next page), which shows the effect of increasing carbon percentage on certain mechanical properties of carbon steels.

Applications and Uses of Plain Carbon Steel

Dead mild steel. It has got very good weldability and ductility. Hence, it is used in welded and solid drawn tubes, thin sheets and wire rods, etc. It is also used for those parts which undergo shock loading but must have good wear-resistance. To increase its wear-resistance, the parts have to undergo case hardening process; which provides a hard surface, while the core remains soft and tough.

Mild steel. It is used very extensively for structural work. It retains very good weldability if carbon percentage is limited to 0.25%. Forgings, stampings, sheets and plates, bars, rods and tubes are made of mild steel.

Medium carbon steel. It has little weldability but is stronger and has better wearing property than mild steel. It is used for railway axles, rotors and discs, wire ropes, steel spokes, marine shafts, carbon shafts, general agricultural tools etc.

High carbon steels. It is used for hand tools like cold chisels, cold working dies, hammers, boiler maker's tools, wood working tools, hand taps and reamers, filers, razors, shear blades etc. High carbon steels can be hardened by the process of quenching and being hard can be used for cutting tools which are not used in hot condition. If they become hot (above 150°C), they begin to lose their hardness and become blunt.

Wrought Iron

It is the purest form of iron; although it may contain traces of carbon. It is usually made by ‘‘puddling process’’ and besides iron contains a small quantity of slag. It is very costly and its use has been almost totally replaced by cheaper steel. However, for some components like chain-links and chain-hooks wrought iron is still the preferred raw material. In old havelis/houses, one can still see iron railings and gates made of wrought iron.

Cast Iron

Cast irons contain more than 2% carbon, which is the theoretical limit for steels. However, in actual practice, carbon content of most cast irons is between 3 to 4 per cent. One characteristic of cast irons (except white cast iron) is that much of the carbon content is present in free form as graphite. It is this fact, which determines, largely, the properties of cast iron. Cast iron is generally produced in coke-fired cupola furnaces by melting a mixture of pig iron, scrap cast iron and a small percentage (usually not exceeding 5%) of small sized steel scrap. Melting point of cast iron is much lower than that of steel. Most of the castings produced in a cast iron foundry are of grey cast iron. These are cheap and widely used. There are many varieties of cast iron. These are listed below:

(i) Grey cast iron,
(ii) White cast iron,
(iii) Malleable cast iron,
(iv) Nodular cast iron, and
(v) Alloy cast iron.

As already mentioned, Grey cast iron is very widely used in the form of castings. In fact, it is so widely used that the term cast iron has come to mean grey cast iron. If a finger is rubbed on a freshly fractured surface of grey cast iron, the finger will get coated with grey colour due to the graphite present in the cast iron. Grey cast iron has good compressive strength, but is weak in tension. It is relatively soft but brittle. It is very easy to machine and the resulting surface finish is good. It is self lubricating due to presence of graphite and has good vibration damping characteristics. Compared to steel, it resists corrosion. Due to these properties, it is used extensively for making machine beds, slides, gear-housings, steam engine cylinders, manhole covers, drain pipes etc.

White cast iron and malleable cast iron. White cast iron has 2 to 2.5% carbon and most of it is in the form of cementite. If molten cast iron is cooled very quickly and its chemical composition lacks graphite-promoting elements like Si and Ni, then carbon remains in combined form as Fe3C. However, white cast iron does not have much use as such. It is very hard and shows white coloured fracture. Only crushing rolls are made of white cast iron. But it is used as raw material for production of malleable cast iron.

Malleable cast iron is manufactured by a complex and prolonged heat treatment of white cast iron castings. Grey cast iron is brittle and has no or very little elongation. Malleable cast iron castings loose some of grey iron's brittleness and become useful even for those applications where some ductility and toughness is required.

Nodular cast iron. This cast iron is also known under the name of spheroidal graphitic cast iron. If a little bit of magnesium (0.5%) is added to molten cast iron, the graphite, which is normally present in grey iron in the form of graphite flakes, changes its shape to small balls/spheres and remains distributed throughout the mass of cast iron. This change in the shape of graphite particles has a very big effect on the properties of resulting castings and their mechanical properties improve considerably. The strength increases, yield point improves and brittleness is reduced. Such castings can even replace some steel-components.

Alloy cast iron. The properties of cast iron can be improved by addition of certain alloying elements like nickel, chromium, molybdenum and vanadium, etc. Alloy cast irons have higher strength, heat-resistance and greater wear-resistance etc. Such enhanced properties increase the application and uses of cast irons. I.C. engine cylinders, cylinder liners, piston rings etc. are made of alloy cast irons.

Alloy Steels

Just as the properties of cast iron can be improved by adding some alloying elements to its composition, so can the properties of plain carbon steels be improved tremendously by addition of alloying elements. In fact, in the case of steels, the effect of alloying is much more marked. The main object of alloying in steels are:

(i) Alloy steels can be hardened by heat treatment processes to greater depth and with less distortion and less chance of cracking.
(ii) Alloying develops corrosion resisting property as in stainless steels.
(iii) Alloying develops the property of red hardness as in cutting tool.
(iv) Alloying develops the strength and toughness of steels as in high strength low alloy (HSLA) steels.
(v) Some alloy steel show a marked resistance to grain growth and oxidation at high temperatures etc.

Main alloying elements used are chromium, nickel, tungsten, molybdenum, vanadium, cobalt, manganese and silicon. Alloy steels are available in a great variety, each one has been developed for a specific purpose. We shall study them by grouping them in (*i*) stainless steels, (*ii*) tool steel and (*iii*) special steels.

Stainless steels. These steels are called stainless because they do not corrode or rust easily. Main alloying elements used are chromium and nickel. Stainless steels are further divided into the following three categories:

(i) **Ferritic stainless steel.** These steels contain a maximum of 0.15% carbon, 6–12% chromium, 0.5% nickel besides iron and usual amounts of manganese and silicon. These steels are stainless and relatively cheap.

They are also magnetic. These days, one and two rupee coins are made from such steels. These steel are essentially Iron-chromium alloys and cannot be hardened by heat treatment. Main usage for such steel is in manufacture of dairy equipment, food processing plants, chemical industry etc.

(ii) **Martensitic stainless steel.** These stainless steels have 12–18% chromium but contain higher carbon percentage (0.15–1.2%). These steels can be hardened by heat treatment, but their corrosion resistance is reduced. These steels are used for making surgical knives, hypodermic needles, bolt, nut, screws and blades etc.

(iii) **Austenitic stainless steels.** These are the most important and costliest among all stainless steels. In these steels, besides chromium, nickel is also added. Nickel is a very strong austenite stabiliser and therefore the microstructure of these steels is austenitic at room temperature. The most com mon amongst stainless steel is 18/8 steel. Its composition is 18% chromium, 8% nickel, 0.08–0.2% carbon, manganese 1.25% maximum and silicon 0.75% maximum. Such steels have extremely good corrosion resistance but they cannot be hardened by heat treatment. However, they are very susceptible to ‘‘strain-hardening’’. In fact, due to strain hardening, their machining becomes very difficult. It is used extensively for household utensils and in chemical plants and other places where high corrosion resistance is required.

Tool steels. The requirements in a tool steel are that it should be capable of becoming very hard and further, that it should be able to retain its hardness at high temperatures commonly developed during cutting of steel and other materials. This property is called ‘‘red hardness’’. Further tool steel should not be brittle and should have good strength. High speed steel (HSS) is the name given to a most common tool steel. Its name implies that it can cut steel at high cutting speeds. At high cutting speed, the temperature rise is higher but high speed steel tools can retain their hardness up to 600–625°C. The property of red hardness comes from addition of tungsten. A typical composition of H.S.S. is tungsten 18%, chromium 4%, vanadium 1%, carbon 0.75–1%, rest iron. Tungsten is a costly metal. It has been found that molybdenum can also impart ‘‘red hardness’’ to steel and actually half per cent of molybdenum can replace one per cent of tungsten. Molybdenum is far cheaper than tungsten. H.S.S. with tungsten are known as *T*-series and H.S.S. with molybdenum are known as *M*-series steels. A very useful H.S.S. has a composition of tungsten 6%, molybdenum 6%, chromium 4% and vanadium 2%, besides iron and carbon. Another version of H.S.S. is called super high speed steel. It is meant for heavy duty tools and has about 10–12% cobalt, 20–22% tungsten, 4% chromium, 2% vanadium, 0.8% carbon, rest iron. These days, tools are made of tungsten carbide and other materials, besides H.S.S.

Special Alloy Steels

(i) **Manganese steels.** All steels contain small amounts of manganese to mitigate the bad effects of sulphur. The true manganese alloy steels contain much larger amounts of Mn. They have work hardening properties. They are used for railway points and crossings, and with usage, they become more wear-resistant.

(ii) **Nickel steels.** Nickel can be added in steels up to 50%. Nickel makes the steel highly resistant to corrosion, non-magnetic, and having very low coefficients of thermal expansion. Such steels are used for turbine blades, internal combustion engine valves etc.

(iii) **Chromium steels.** Chromium makes steel corrosion resistant, and increases its UTS. and IZOD strength. Very often alloy steels are used with both chromium and nickel being added. Ni-Cr steel wires are often used in furnaces, toasters and heaters.

(iv) **Silicon steels.** A steel containing 0.05% carbon, about 0.3% Mn and 3.4% of silicon possesses extremely low magnetic hysteresis and is used widely for making laminations of electrical machines. Silico-manganese steels are also used frequently for making springs.

Heat Treatment of Carbon Steels

Object of heat treatment. Metals and alloys are heat treated to improve their mechanical properties, to relieve internal stresses or to improve their machinability. The properties of carbon steels can also be altered significantly by subjecting them to heat treatment processes. Heat treatment consists of three basic steps:

(i) Heat the metal/alloy to a predetermined temperature. This temperature will, ideally, depend upon the actual composition of carbon steel (*i.e.* carbon percentage),

(ii) Soaking or holding the metal/alloy at that temperature for some time, so that the temperature across the entire cross-section becomes uniform, and

(iii) Cooling the metal/alloy at a predetermined rate in a suitable medium like water, oil or air. The rate of cooling is the most important factor.

Kinds of Heat Treatments Given to Carbon Steels

Carbon steels are subjected to the following four basic heat-treatment processes:

(i) Annealing,
(ii) Normalising,
(iii) Hardening, and
(iv) Tempering.

NON-FERROUS METALS

Non-ferrous metals and alloys do not contain any significant quantity of iron. The most common nonferrous metals used in engineering applications are copper, aluminium, tin, lead and zinc. Nickel, magnesium and antimony are also used for alloying the aforesaid non-ferrous metals.

Properties and Uses of Non-Ferrous Metals

Copper. Copper is a corrosion resistant metal of an attractive reddish brown colour. It is an extremely good conductor of heat and electricity. It can also be drawn in wires, beaten into sheets and plates. Hence, it is extensively used in electrical industry for making armature coils, field coils, current carrying wires, household utensils etc. But its great usefulness lies in the fact that it alloys with zinc, tin and nickel to yield brass, bronze and cupro-nickels respectively which are widely used in engineering industry. Copper, as such, is used for many decorative items. Not much of copper is available in India. We import at least 50–60% of our requirement every year.

Aluminium. Aluminium metal is difficult to extract from its main ore called bauxite. However, bauxite is available in India very plentifully and we have a thriving aluminium industry. Aluminium is also very corrosion resistant (because an adherent oxide layer protects it from further oxidation). It is again a very good conductor of heat and electricity (although not as good as Cu). It is ductile and malleable and is much cheaper than copper. Hence, it has all but replaced copper wires for transmission of electricity. It is also used for household utensils including pressure cookers. However, since it can be converted into thin foils, it is now extensively used for beverage cans and in packaging industry. Its density is about a third of steel, hence it is also used for aircraft and helicopter frames and in transport vehicles. Sometime ago, in India, 1, 2, 5, 10 and 20 paisa coins were made of an aluminium-magnesium alloy. Aluminium forms a series of alloys with magnesium, which are harder and stronger than pure aluminium.

Tin. It has an attractive silvery white colour. It has very good resistance to acid corrosion. Before the advent of plastic tin coated steel sheets of thin gauge were used for manufacture of tin-containers for storage of ghee, mustard and other oils. Today tin is mostly used for alloying purposes. Tin and lead melted together give a series of soft-solders. Tin has a low melting point.

Lead. Lead is a heavy metal with dull grey appearance. It has good corrosion resistance and has got good malleability. In Europe, it was extensively used for roof protection. It was also used in plumbing. It can withstand sulphuric acid and previously this acid used to be stored in lead lined vessels. It has self lubricating properties. It was therefore used in lead-pencils. Sometimes, a small quantity of lead is added to steel and tin bronze to impart free cutting properties.

Zinc. Zinc possesses a bluish grey metallic appearance. It has high corrosion resistance. In fact, steel sheets are often covered by a thin coating of zinc. Such zinc coated sheet are known as galvanised iron sheets (G.I. sheets). The zinc coating provides protection to steel sheets from corrosion for many years. Zinc has a low melting point and high fluidity making it suitable for items to be produced by diecasting process. Zinc is incidentally much cheaper than either copper or tin; making brass, an alloy of copper and zinc much cheaper than copper or tin-bronze. Zinc is also used in torch light batteries. In the following table, colour, tensile strength, melting point–specific gravity and important properties of some non-ferrous metals are given.

Metal	*Tensile strength N/mm²*	*Colour*	*Specific Gravity*	*M.P. (°C)*	*Few important properties*
Copper	160	Reddish brown	8.9	1083	Good conductor, soft, ductile and malleable
Aluminium	60	White	2.7	660	Good conductor, very soft, ductile and malleable
Tin	13	Silvery white	7.3	232	Good appearance, acid resistance, soft
Lead	15	Dull grey	11.4	327	Very heavy, good corrosion resistance against H_2SO_4
Zinc	155	Bluish, white	7.1	419	Good corrosion resistance and fluidity when molten

ALLOYS OF COPPER

Brass

Brass is an alloy of copper and zinc. Commercially, two types of brasses are most important:

1. **Alpha brass.** It contains up to 36% zinc and remainder is copper.

2. **Alpha-Beta brass.** It contains from 36% to 46% Zn, remainder is copper.

Alpha and Beta are names given to different phases of brasses. Alpha-Beta brass contain both alpha and beta phases. The tensile strength and ductility of brass both increase with increasing Zn content up to 30% zinc. If zinc content increases beyond 30%, the tensile strength continues to increase up to 45% Zn, but there is a marked drop in ductility of brasses. β-phase is much harder and stronger but less ductile than α-phase. α-phase has excellent cold-formability and is used where the parts are wrought to shape. The mechanical properties of α-brasses also change with the amount of cold-work done on them. α-β brasses are fit for hot working. α-brasses can be sub-divided into two groups—

(i) red-brasses containing up to 20% Zn, and
(ii) yellow brasses containing over 20% Zn.

Red brasses are more expensive and are primarily used where their colour, greater corrosion resistance or workability are distinct advantages. They have good casting and machining properties and are also weldable. One well-known red-brass is "gilding-brass" or gilding metal with 5% Zn. It is used for decorative work.Yellow brasses are most ductile and are used for jobs requiring most severe cold forging operations. The cartridges are made from a 70% Cu, 30% Zn brass by a deep drawing process, hence this composition of yellow brass has come to be known as cartridge brass. Other famous compositions of brasses are: Admirability brass containing 29% Zn, 1% Tin, remaining copper. Muntz' metal contains 40–45% Zn, remainder is copper. Naval Brass contains 39% Zn, 1% Tin, remainder is copper. Admiralty brass, naval brass and muntz metal are all used for ships-fittings, condenser tubes, preheaters, heat exchangers etc.

Bronzes

Bronze is an alloy of copper and tin although commercial bronzes may contain other elements besides tin. In fact, alloys of copper with aluminium, silicon and beryllium, which may contain no tin are also known as bronzes. Tin bronzes are of a beautiful golden colour. As in brasses, both tensile strength and ductility of bronzes increase with increases in tin content. However, more that 10% tin is not used in bronze as it results in the formation of a brittle intermetallic compound, Cu3Sn. Addition of tin to copper up to 10% increases the strength, hardness and durability to a much greater extent than the addition of zinc to copper. The following varieties of tin bronzes are commonly used:

(i) **Phosphor-Bronze.** Addition of 0.5% phosphorous to tin bronze results in production of phosphorous bronze. Phosphorous increases fluidity of molten metal and fine castings can be made.

(ii) **Leaded-Bronze.** Addition of lead to tin bronze, results in production of leaded bronze. Lead is actually a source of weakness, but adds to machinability and has self lubricating properties. Usually, lead percentage does not exceed 2%.

(iii) **Gun-metal.** It contains 2% zinc, 10% tin and 88% copper. It is a very famous composition. This bronze is used for bearing bushes, glands, pumps, valves etc.

(iv) **Bell-metal.** It is a tin bronze but having a very high percentage of tin (20–25%). It gives a good tinkling sound on being struck with a hammer.

Bronzes having no tin. The following bronzes contain no tin and are commercially well-known:

(i) **Aluminium bronze.** Composition: 14% Aluminium, rest copper. It possesses good strength and good corrosion resistance. Colour: golden yellow. Often used for costume jewellery.

(ii) **Silicon bronze.** Composition: 1–4% Silicon, rest mainly copper. Possesses extremely good corrosion resistance. Can be cold worked and strain-hardened. Used for boiler fitting and marine fittings.

(iii) **Manganese bronze.** Composition: 40% zinc and 55–60% copper with 3–5% manganese. It is essentially a brass to which manganese has been added. It is used for ship's propellers.

(iv) **Beryllium bronze.** Beryllium is very costly. So is this alloy. It contains about 2% Be. It has very good mechanical properties and can be cold worked and age-hardened. It is mainly used for bellows, bourdon gauge tubes etc.

CUPRO-NICKELS

Cupro-nickels are alloys of copper and nickel. Copper and nickel, when melted together in any proportion are perfectly miscible and dissolve each other. When the alloy solidifies, the solubility continues forming a solid solution. Cupro-nickels are silvery white in colour and have extremely good corrosion-resistance. They are extensively used for marine fittings. They also possess good strength, hardness and ductility. Coins of rupee five are made of 75% copper and 25% nickel.

However, another alloy containing 45% Ni and 55% copper is called ‘‘constantan’’. It is used for manufacture of thermocouples, low temperature heaters and resistors.

Aluminium Alloys

Aluminium as such is a soft metal of relatively low strength. Most of the alloys of aluminium are made by alloying it with various percentages of magnesium; these are harder and stronger. These alloys known as L-M series alloys can be extruded and are used extensively for structural work. A famous alloy of Aluminium containing 4% copper, 0.5% magnesium, 0.5% manganese, a trace of iron and rest aluminium is called DURALUMIN. It has high strength and a low specific gravity. However, its corrosion resistance is much lower as compared to pure aluminium. Sometimes, duralumin is covered or clad by thin aluminium layer on all sides. Such material is called ALCLAD and is used in aircraft industry. If 5–15% silicon is alloyed with aluminium, we get alloys which are temperature resistant. Castings made of Al-Si alloys are used for manufacture of pistons of two wheelers on a large scale.

Alloys of Nickel

(i) **German silver.** It is a cupro nickel to which zinc has been added. A typical composition is 60% copper, 30% nickel and 10% zinc. Addition of zinc brings down the cost. Its colour is silvery with a slight pale tinge. It is very ductile and malleable and corrosion resistant. It is used for making electrical contacts, costume jewellery and high quality taps etc. Before the advent of stainless steel, it was also used for household utensils and coinage

(ii) **Monel metal.** Its composition is 68% nickel, 30% copper, 1% iron, remainder manganese etc.

(iii) **Nichrome.** Alloy of nickel and chromium, which is used as heat resistant electrical wire in furnaces, and electrical heating devices like geysers, electric iron etc.

(iv) **Inconel and incoloy.** Alloys principally containing, nickel, chromium and iron. Used in electrical industry.