21世纪高等教育系列教材(机械工程类)

机械工程专业英语

杜华 王敏 主编

Mechanical Engineering English Readings

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前　言

本书根据普通本科院校机械工程及其自动化专业人才培养方案的要求编写而成。

本教材在内容编排上主要是从涵盖专业词汇，内容易懂，引入新知识、新技术，扩大学生知识面的角度出发，文章全部摘自欧美文献原著，力求使读者在阅读中熟悉、掌握专业词汇，并开阔视野。本书可作为普通高等院校及大中专学校专业英语课程学时较少情况下的教学及参考用书，同时也适合生产实践工程人员使用。

全书主要包括机械基础、机械制造、计算机辅助设计与制造、计算机数控技术、先进制造技术、工程材料、热处理、焊接技术、模具制造等方面的内容。

尽管本书是英语类书籍，但重点在专业词汇的学习，淡化专业内容，力求简单易懂，以减少读者在阅读中的专业知识障碍，适当增加趣味性。为保持原著语言风格，编者对所选内容基本上是只作删减，不作改写。本书在编排传统的机械工程方面内容的同时，力求引入当前世界上机械工程领域中采用的新技术，如快速原型制造、纳米技术及应用、网络制造等，以突出“新”的理念。

本书由杜华、王敏主编，林洁琼参加了本书第1、第2单元的编写。

由于编者水平有限，书中难免有不足之处，希望广大读者批评指正。

编　者

2005年8月

CONTENTS

Unit 1

Engineering Materials

I. *Ferrous Materials*

We use a variety of metals, non-metals and their compounds in our daily life. For example, a typical automobile may contain the following materials (see Table1. 1):

Table 1. 1 Main materials a typical automobile may contain

Steel	1 530 kg	Cast iron	350 kg
Rubber	60 kg	Plastic	55 kg
Glass	52 kg	Aluminium	30 kg
Zinc	26 kg	Copper	16 kg
Lead	15 kg		

Wood, ceramics, etc. are in smaller quantities.

Based on their origin and composition these materials may be broadly classified as shown below in Figure 1. 1.

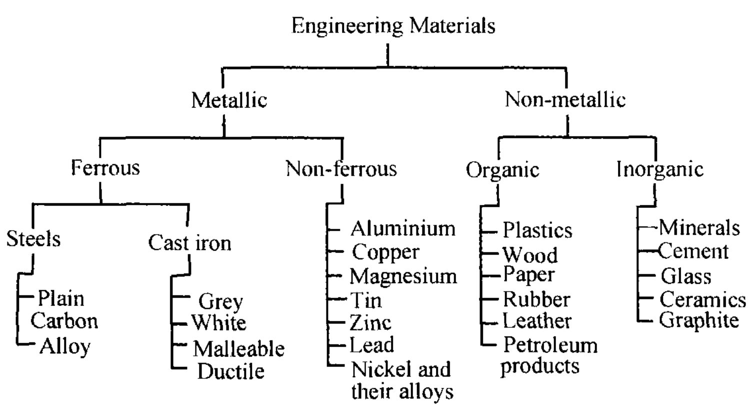

Figure 1. 1 Classification of engineering materials

Among these, ferrous materials are by far used most extensively because of their better and varied mechanical properties and lower costs.

1. Iron

The basic source of iron and steel is iron ore, which is an oxide of iron mixed with alumina, silica, phosphorous, manganese, sulphur and other materials. Major iron ores are haematite and magnetite which contain about 55% iron.

Pig iron, the principal base material for all steel furnaces, is the product of the blast furnace.

Pig iron contains carbon (about 4%), silicon (1%), manganese (1%) and smaller percentages of phosphorous and sulphur. Pig iron is hard and brittle. It lacks the great strength, ductility and resistance to shock that steel possesses.

Absolute pure iron is very difficult to obtain. In this state, it is a soft and highly plastic metal of a light grey colour having a specific weight of 7.86. The mechanical properties of commercial grade iron containing 0.1% to 0.2% impurities are:

Hardness, 60~80 BHN;

Tensile strength, 180~310 MPa;

Yield point, 200 MPa;

Reduction in area, 75%.

The only application that can be found for pure iron is in the making of magnets in view of its high permeability. Otherwise, the extensive use of iron is in the form of its large number of alloys. Iron can be alloyed with many elements. Alloys of iron and carbon are most widely used in engineering. They contain certain amounts of silicon, manganese, chromium, nickel and other elements.

Before proceeding to study the properties of ferrous alloys, a brief survey of the structure of materials would be beneficial to better understand the subject.

1) Plain Carbon Steels

As has been mentioned earlier, iron in its purest form is not used as an engineering material because it lacks tensile strength and hardness. But when alloyed with other elements, the properties can be controlled greatly. Out of the various alloying elements, carbon is the most important because it is found in all the alloys of iron.

The maximum amount of carbon that can be alloyed with iron is 6.67%. Alloys containing up to 2% carbon are termed steels and above 2% are called cast irons. Besides carbon, these alloys also contain small amounts of manganese, sulphur, phosphorous and silicon. These are generally considered as impurities and hence need to be controlled. However, in certain conditions some of these such as silicon are treated as alloying elements.

The properties of steel are influenced significantly by an increase in carbon content with a result that tensile strength is increased, greater hardness is obtained, ductility is decreased, and weldability is decreased.

A point however to be noted is that in all steels even when alloyed with other alloying elements, the maximum hardness that can be obtained after heat treatment processes is basically a function of the carbon content.

There are three classes of steels (plain carbon):

Low, up to 0.30% C;

Medium, 0.30%~0.60% C;

High, 0.60%~1.70% C.

(1) Low Carbon Steel

This is generally known as soft or mild steel. It is used where ductility and softness are important and high tensile strength is not required. They are tough but not resistant to wear. As they are soft, they can be very easily formed and later can be carburised to increase the hardness and wear resistance.

Low carbon steels are used for such operations as spinning, cold bending, riveting, swaging, etc. These are not responsive to normal heat treatment but for case hardening. They form the largest percentage of steel produced because of being the cheapest engineering material. Products such as screws, nails, nuts, bolts, washers, wire fences, light and heavy structural members, machine parts, forged parts can be made from low carbon steel. It is also used for tin plate and automobile body sheet. It is available in form of sheets, squares, rounds, plates, and wires.

(2) Medium Carbon Steel

They are less ductile but harder and have greater tensile strength than low carbon steels. They also have better machining qualities and are more responsive to heat treatment.

They are widely used in the industry. Medium carbon steels are used for making shafts, connecting rods, spindles, rail axles, gears, turbine bucket wheels, steering arms and other machine parts requiring medium strength and wear resisting surfaces.

(3) High Carbon Steel

They have higher tensile strength and are harder than other plain carbon steels. They also readily respond to heat treatment. They are used for making hand tools such as wrenches, chisels, punches, files, cutting tools such as drills, wood working tools, rail road wheels, rails, bars for reinforcing of concrete, etc.

2) Effect of Small Quantities of Other Elements

In addition to carbon the plain carbon steels contain small quantities of other elements more as impurities. They affect the properties in the following way.

Sulphur. Iron forms with sulphur, iron sulphide, FeS, which solidifies along the grain boundaries making the steel brittle and lowers its hot working properties. If an equal amount of manganese is present in the steel then manganese sulphide, MnS forms and the harmful effects of sulphur are reduced. It is generally recommended that manganese should at least be three times that of sulphur. However very small quantities (0.075% ~ 0.15%) that are generally present contribute to better machinability.

Phosphorous. Phosphorous in small amounts increases the strength and hardness of steels. Most of the steels contain a very small percentage of about 0.05% phosphorous.

Silicon. Silicon in very small amounts of the order of less than 0.2% do not have any effect. When it is between 0.2% and 0.4%, it raises the elastic limit and ultimate strength of the steel without greatly reducing the ductility. More than this percentage will reduce the ductility.

The main limitations of plain carbon steels are:

Low hardenability;

Loss of hardness during tempering;

Low strength at elevated temperature;

Lower resistance to corrosion and oxidation.

2. *Cast Irons*

The ferrous alloys which have carbon contents of more than 2% are called cast irons. Though cast irons can have any carbon percentage between 2 to 6.67, the practical limit is normally between 2% and 4%. These are important mainly because of their excellent casting qualities.

From the iron carbon equilibrium diagram (Figure 1.2), it can be observed cast irons have essentially cementite and ferrite. Because of the larger percentage of carbon, the amount of cementite is high resulting in very high hardness and brittleness qualities for cast iron.

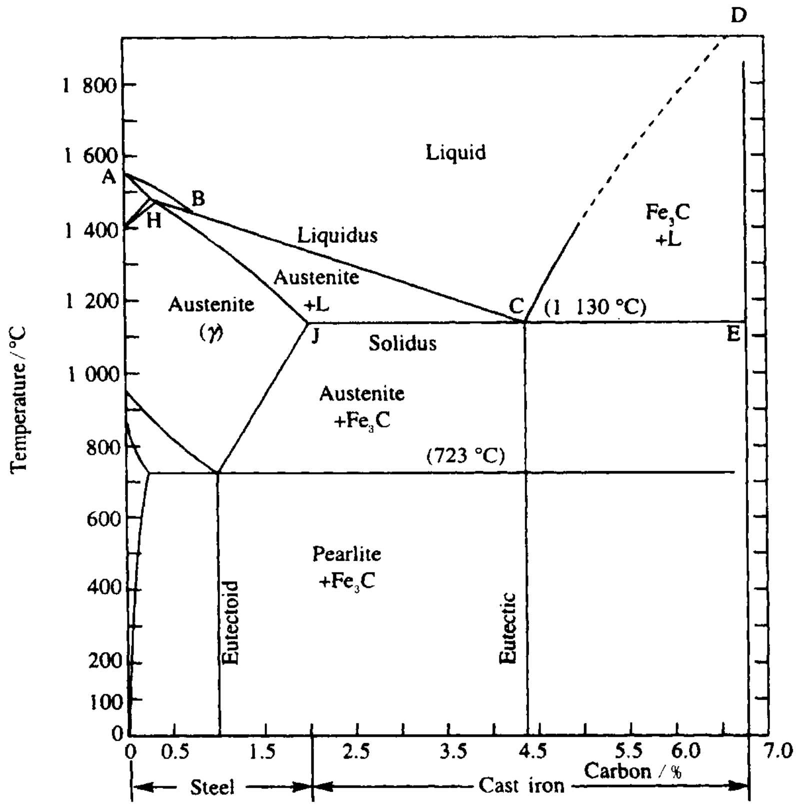

Figure 1.2 The iron carbon equilibrium diagram

When cast iron is slowly cooled, the cementite decomposes into iron and carbon in the form of graphite which is called graphitisation. Cast irons where a large percentage of cementite is decomposed by graphitisation are called grey cast irons. Cast iron in which graphitisation has not taken place, i. e. all the carbon is in the combined form, is called white cast iron. The graphitisation process requires time and, therefore, when liquid cast iron is cooled rapidly, white cast iron would result. White cast iron is comparable in properties to that of high carbon steels. However, it is highly brittle and as such is not used for structural parts. It is useful for parts where abrasive wear is present. Tensile strength varies between 170 and 345 MPa and is usually about 240 MPa. The hardness ranges from 350 to 500 BHN. In view of the very high hardness the machinability is poor and is commonly finished by grinding.

In the presence of graphitising elements such as nickel and silicon, iron carbide decomposes as follows:

$$Fe_3C \longrightarrow 3Fe + C$$

The decomposition is controlled by the graphitising agents as well as the cooling rate.

The dissociated carbon is in the form of graphite which is very soft and without any strength. Thus it reduces the hardness and increases the machinability of cast iron. The shape of graphite present in cast irons would greatly affect its strength. When it is in a flake like shape as in grey cast iron, the graphite breaks up the continuity of iron and greatly weakens it. But it also helps in absorbing vibrational energy, as a result of which grey cast iron is normally used for the beds of machine tools. Grey cast iron is easily machinable and is the cheapest form of cast iron. Because of its low melting temperature, higher fluidity and negligible shrinkage on cooling, it is extensively used in casting processes.

The other form of cast iron is known as malleable iron in which free carbon is present in the form of nodules in the matrix of cementite and ferrite. This is achieved by first chilling the casting so that all white cast iron is formed, followed by a controlled heat treatment process so that some of the cementite is transformed to ferrite and nodules of free carbon. This material is more ductile than grey cast iron. This form is suitable only for components with very small section thicknesses since all white cast iron is to form the starting point for malleable iron.

When graphite is present as small, round, and well distributed particles, its weakening effect is small and such cast irons would have higher ductility. This type of cast iron is called ductile or nodular iron or spheroidal graphite or simple SG iron. This form of graphite can be achieved by adding element almagnesium or cerium or a combination of the two elements to molten cast iron. Magnesium is added in quantities of 0.07% ~ 0.10% followed by the addition of ferro-silicon to promote graphitisation. During solidification, magnesium helps in the distribution of graphite throughout the metal.

Ductile iron has better strength to weight ratio, better machinability and higher impact value. Moreover, the ductile iron components are produced by casting process wherein better control of component shape can be achieved compared to drop forging. Thus many components such as crank shafts and connecting rods manufactured usually by drop forging are increasingly being replaced by ductile iron castings.

3. *Other Alloying Elements*

Steel is an alloy of iron. Normally, ferrous alloys containing only carbon as the alloying element are called plain carbon steels or simple steels while those containing besides carbon, some other alloying elements such as chromium are termed alloy steels. In fact, the definition given by American Iron and Steel Institute (AISI) is as follows:

"Steel is considered to be alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: manganese, 1.65%; silicon, 0.60%; copper, 0.60%; or in which a definite range or a definite minimum quantity of any of the following elements is specified or required within the limits of the recognised field of constructional alloy steels: aluminium, boron, chromium up to 3.99%, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium, or any other alloying element added to obtain a desired alloying effect."

The alloy steels are normally required when additional properties such as strength, ductility, toughness or corrosion resistance are desirable in large measures. The various ways in which special alloying elements are used to improve the properties of steels are:

To improve hardenability;

To improve mechanical properties at low or elevated temperatures;

To improve the corrosion and oxidation resistance;

To increase the machinability;

To increase the electrical and magnetic properties;

To increase resistance to softening on tempering;

To increase abrasion resistance;

To increase hardness of steels that cannot be quenched.

Since the microstructure essentially consists of ferrite and cementite, the mechanical properties can be controlled by changing either the properties of carbide and ferrite phases by the alloying elements or by controlled dispersion of carbide in the ferrite matrix. The carbide phase present in alloy steels is not pure iron carbide but a complex combination of iron and alloy carbides. Some of the alloying elements act as austenite stabilisers. The austenite stabilisers lowers the eutectoid temperature thereby expanding the temperature range in which austenite is stable.

The effect of alloying elements can also be described by means of the following empirical relationships which show the critical temperatures in the iron—carbon equilibrium diagrams. Ac_1 refers to the boundary between austenite and pearlite, while Ac_3 refers to the temperature separating austenite with austenite and cementite.

$$Ac_1 = 723 - 10.7\ Mn - 16.9\ Ni + 29.1\ Si + 16.9\ Cr + 290\ As + 6.38\ W$$

$$Ac_3 = 910 - 203\sqrt{C} - 15.2\ Ni + 44.7\ Si + 104\ V + 31.5\ Mo + 13.1\ W$$

Out of the various alloying elements, nickel, silicon and aluminium do not form any carbides whereas manganese, chromium, tungsten, molybdenum, vanadium, titanium and niobium are having increasing carbide stability in that order. When nitrogen is present, many of these carbide formers form carbonitrides or nitrides which are highly abrasion resistant. The following is a detailed account of the effect of individual alloying elements on the mechanical properties of alloy steels.

(1) Manganese

This is the most common alloying element in all steels. It decreases the critical temperatures appreciably and thus lets the steel oil harden. Also, it is a cheap way of increasing the hardenability of steels. It forms a carbide Mn_3C but its carbide forming tendency is the lowest of all alloying elements. It counteracts the brittleness caused by sulphur in steels. Equal amounts of manganese and sulphur in steel form manganese disulphide readily, which is evenly distributed in it. This greatly improves the hot working characteristics and also the lubrication in machining ensuring good surface finish. Manganese in amounts 2% ~ 10% imparts brittleness to steel. The particular composition of 11% ~ 14% manganese and 1% ~ 1.4% carbon has got a very high resistance to wear and abrasion even under high impact stresses. With such large manganese content the critical temperature is reduced and martensite could be obtained even with slow cooling during quenching. Very rapid quenching allows for retained austenite thus giving it high ductility and toughness. This is quite useful for service involving continuous impact loads but not suitable for abrasive loads.

(2) Chromium

It is a strong carbide former and forms complex series of carbide compounds of chromium and iron. It raises the critical temperature appreciably and thus resists tempering. It increases hardenability, wear resistance, corrosion and oxidation resistance. The primary use of chromium in steels, thus, is because of its high hardness and corrosion resistance.

(3) Nickel

Nickel is not a carbide former but strengthens and toughens the ferrite phase. It reduces the critical cooling rate required for quenching and therefore they can be very easily heat treated. It increases the tensile strength without appreciable decrease in elongation and decrease in area. In many ways its effect on properties is similar to manganese. In combination with chromium, it provides high elastic ratios, greater hardenability, higher impact and fatigue resistance.

(4) Tungsten

It is a very strong carbide former and forms abrasive resistant particles in tool steels. At larger percentages it improves hot hardness and hot strength and as such are useful in cutting and hot working tools. It is not softened by tempering. In tungsten steels much higher tempering temperatures may be employed with less loss in hardness with reduction in internal strains compared to plain carbon steels.

(5) Molybdenum

It greatly increases the hardenability. It is also a strong carbide former. It increases the hot hardness and hot strength when used in combination with chromium and vanadium. Since molybdenum is cheaper than tungsten, it is replacing tungsten to a great extent in tool steels. It raises the critical temperature for tempering and so does not soften even at a higher temperature. The typical amounts present are 0.15% ~ 0.50% molybdenum in general tool steels. The main problem with molybdenum is the promotion of skin decarburisation which is to be properly accounted for during heat treatment.

(6) Vanadium

It is a strong carbide former. It also increases the hardenability and has the secondary hardening effect upon tempering. Grain growth tendency at heat treating temperatures is minimised. Vanadium steels have a much finer structure than steels without vanadium. It increases hardness at elevated temperatures.

(7) Silicon

It slightly increases the hardenability. It sustains hardness during tempering. One of the important uses of silicon is as a deoxidiser in molten steel and for its ability to resist oxidation in steel. In large quantities above 2.5%, it increases the strength of ferrite phase without affecting its ductility. But at this percentage it develops poor machinability and is susceptible to decarburisation. Silicon increases the electrical resistivity of iron thus reducing eddy current effects with alternating current. Thus silicon steels are used extensively for electrical applications. Silicon steels can be easily magnetized in a direction parallel to their crystallographic cubic edge. By a careful combination of rolling and annealing, it is possible to align the grains in the desired direction, thus silicon steels are also used for magnetic applications.

(8) Aluminium

It is primarily used as a deoxidiser in steels. It is most effective in inhibiting grain growth. In those steels which are to be nitrided, aluminium provides an extremely high hardness of the nitrided case due to the formation of hard and stable aluminium nitride compound.

(9) Titanium

It has the highest carbide forming tendency of all the alloying elements. It has no effect on hardenability. It is a good deoxidiser and inhibits grain growth. Because of its strong carbide forming tendencies, medium carbon steels do not quench to harden.

(10) Niobium

Also called columbium, it reduces the hardenability and increases the ductility slightly which results in a marked increase in impact strength. It imparts a fine grain structure to steels and retards softening during tempering.

(11) Cobalt

It decreases the hardenability. Cobalt strengthens ferrite when dissolved in it and resists softening under elevated temperatures. It promotes skin decarburisation.

Ⅱ. *Non-Ferrous Materials*

Ferrous materials are extensively used in engineering industry because of their superior and range of mechanical properties and lower costs. Still non-ferrous materials are also used in various applications for their specific properties compared to ferrous alloys in spite of their generally high cost. Desired mechanical properties can be obtained in these alloys by work hardening, age hardening, etc. but not through normal heat treatment processes used for ferrous alloys. Some of the principal non-ferrous materials of interest are aluminium, copper, zinc, and magnesium.

1. Aluminium

Of all non-ferrous alloys, aluminium and its alloys are the most important because of their excellent properties. Some of the properties of pure aluminium for which it is used in engineering industry are:

(a) Excellent thermal conductivity (0.53 ℃ · cal/cm).

(b) Excellent electrical conductivity (376 600 ohm/cm).

(c) Low mass density (2.7 g/cm^3).

(d) Low melting point (658 ℃).

(e) Excellent corrosion resistance. Aluminium in fact has greater affinity towards oxygen. As a result, when aluminium is exposed to air, the outer surface readily gets oxidised forming aluminium oxide. This oxide skin has a good bond with the parent metal and thus protects it from further oxidation.

(f) That it is non-toxic.

(g) That it has got one of the highest reflectivities (85% ~ 95%) and very low emissivity (4% ~ 5%).

(h) That it is very soft and ductile as a result of which it has got very good manufacturing properties.

Some of the applications where pure aluminium is generally used are in electrical conductors, radiator fin material, air conditioning units, optical and light reflectors, foil and packaging material.

In spite of the above useful applications, pure aluminium is not widely used because of the following problems:

(a) It has got low tensile strength (65 MPa) and hardness (20 BHN).

(b) It is very difficult to weld or solder.

The mechanical properties of aluminium can be substantially improved by alloying. The principal alloying elements used are copper, manganese, silicon, nickel and zinc.

Aluminium and copper form the chemical compound $CuAl_2$. Above a temperature of 548 ℃ it is dissolved completely in liquid aluminium. When this is quenched and artificially aged (prolonged holding at 100 ~150 ℃) a hardened alloy is obtained. The $CuAl_2$ which is not aged do not have time to precipitate from the solid solution of aluminium and copper and thus is in an unstable position (super saturated at room temperature). The ageing process precipitates very fine particles of $CuAl_2$ which causes the strengthening of the alloy. This process is called solution hardening.

The other alloying elements used are magnesium up to 7%, manganese up to 1.5%, silicon up to 13%, nickel up to 2%, zinc up to 5% and iron up to 1.5%. Besides these, titanium, chromium and columbium may also be added in small percentages.

2. Copper

Similar to aluminium, pure copper also finds wide application because of its following properties:

(a) The electrical conductivity of pure copper is high (5.8×10^5 ohm/cm) in its purest form. Any small impurity brings down the conductivity drastically. For example, 0.1% phosphorous reduces the conductivity by 40%.

(b) It has a very high thermal conductivity (0.92 ℃ · cal/cm).

(c) It is a heavy metal (specific gravity 8.93).

(d) It can readily be joined together by brazing.

(e) It resists corrosion.

(f) It has got a pleasing colour.

Pure copper is used in manufacture of electrical wire, bus bars, transmission cables, refrigerator tubing and piping.

The mechanical properties of copper in its purest state are not very good. It is soft and relatively weak. It can be alloyed profitably to improve the mechanical properties. The main alloying elements used are zinc, tin, lead and phosphorous.

The alloys of copper and zinc are called brasses. With a zinc content up to 39%, copper forms a single phase (α-phase) structure. Such alloys have high ductility. The colour of the alloy remains red up to a zinc content of 20%, but beyond that it becomes yellow. A second structural component called β-phase appears between 39% and 46% of zinc. It is actually the inter-metallic compound CuZn which is responsible for the increased hardness. The strength of brass gets further increased when small amounts of manganese and nickel are added.

The alloys of copper with tin are called bronzes. The hardness and strength of bronze increase with the increase in tin content. The ductility is also reduced with the increase in tin percentage above 5. When aluminium is also added (4% ~ 11%) the resulting alloy is termed as aluminium bronze, which has a considerably higher corrosion resistance. Bronzes are comparatively costly compared to brasses due to the presence of tin which is an expensive metal.

3. Zinc

Zinc is principally used in engineering because of its low melting temperature (419.4 ℃) and higher corrosion resistance, which increases with the purity of zinc. The corrosion resistance is caused by the formation of a protective oxide coating on the surface. Principal applications of zinc are in galvanising to protect steel from corrosion, in printing industry and for die casting.

The disadvantages of zinc are the strong anisotropy exhibited under deformed conditions, lack of dimensional stability under ageing conditions, a reduction in impact strength at lower temperatures and the susceptibility to inter-granular corrosion. It cannot be used for service above a temperature of 95 ℃ because it will cause substantial reduction in tensile strength and hardness.

Its widespread use in die castings is because it requires lower pressure, which results in higher die life compared to other die-casting alloys. Further, it has very good machinability. The finish obtained by zinc die casting is often adequate to warrant any further processing, except for the removal of the flash present in the parting plane.

4. Magnesium

Because of their light weight and good mechanical strength, magnesium alloys are used in applications where the weight is important, for example, in aerospace industries and in applications involving very high speeds. For the same stiffness, magnesium alloys require only 37.2% of the weight of C25 steel, thus saving in weight. The two principal alloying elements used are aluminium and zinc. Magnesium alloys can be sand cast, permanent mould cast or die cast. The properties of magnesium as cast components are comparable with each of these processes. The die-casting alloys generally have high copper content so as to allow them to be made from the secondary metals to reduce the costs. They are used for making automobile wheels, crank cases, etc. Higher the content, higher is the mechanical strength of magnesium wrought alloys such as rolled and forged components. Magnesium alloys can be readily welded by most of the traditional welding processes. A very useful property of magnesium alloys is their high machinability. They only require about 15% of power for machining compared to low carbon steel.

Vocabulary

aluminium *n.*	[化]铝
adj.	铝的
cementite *n.*	[冶]渗碳体,碳化铁
chromium *n.*	铬
cobalt *n.*	[化]钴(符号为 Co),钴类颜料,由钴制的深蓝色
ferrous *adj.*	铁的,含铁的,[化]亚铁的
haematite *n.*	赤铁矿(美作:hematite)
magnesium *n.*	[化]镁
molybdenum *n.*	[化]钼
niobium *n.*	[化]铌
phosphorous *adj.*	磷的
sulphur *n.*	硫磺
titanium *n.*	[化]钛
tungsten *n.*	[化]钨
vanadium *n.*	[矿]钒,铅矿
zinc *n.*	锌
vt.	涂锌于
decarbonization *n.*	脱碳
zirconium *n.*	锆
wrench *n.*	扳钳,扳手
sulphited juice	亚硫酸处理汁
sulphide *n.*	[化]硫化物
malleable *adj.*	有延展性的,可锻的
emissivity *n.*	[物]发射率
deoxidization *n.*	[医][化]去氧,还原
decarburization *n.*	脱碳
crystallography *n.*	检晶仪
chisel *n.*	凿子
v.	砍凿

Unit 2

Engineering Properties and Their Measurements

Manufacturing of a component is normally influenced by the mechanical and thermal properties of the work material. Also, the mechanical properties are affected by the manufacturing process employed. Either way the knowledge of mechanical properties of engineering materials is important to a manufacturing engineer. In this unit, some of the mechanical properties which are influential in or are influenced by the manufacturing processes and their measurement are discussed.

Ⅰ. *Strength*

The resistance offered by a material on application of external force is called strength. Depending on the type of load applied, the strength could be tensile, compressive or shear. By application of load, the material is elastically deformed, which is called strain. It can be defined as:

$$\text{Strain}=\frac{\text{chance in dimension}}{\text{original dimension}}$$

The resistance offered by the material is also referred to as stress which can then be defined as:

$$\text{Stress}=\frac{\text{applied load}}{\text{area of cross section opposing the load}}$$

The deformation caused in a material is of two types, elastic and plastic. Elastic deformation is that part of the deformed material which when the applied load is removed, would spring back to its normal shape. Plastic deformation is on the other hand, permanently set in a material and cannot be regained.

Tensile strength is measured by a tensile test carried out on a universal testing machine. This involves the preparation of a test specimen as per standard shown in Figure 2. 1. The standard specimen is cylindrical in cross section with a diameter, d. The gauge length L is given by

$$L=5.65\sqrt{d}$$

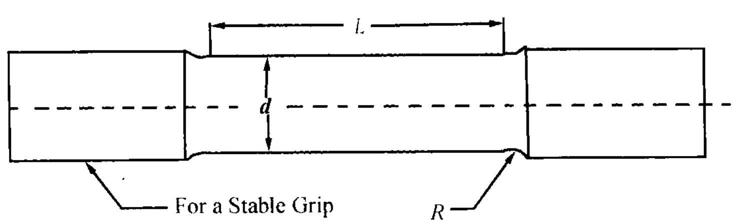

Figure 2. 1　Standard test specimen for tensile test

Then a uniformly increasing tensile load is applied on the specimen. As the load increases the specimen initially gets elastically elongated. On further elongation, the specimen starts necking at