Elements of Machine Design

An Online Continuing Education Course for Engineers

Course Number: M-3050

Credit: 3 Hours / 3 PDH / 3 CPD

Elements of Machine Design

Introduction

Machine Design is a field of endeavor that includes a wide range of topics that merit attention. This course begins by dealing with some of the fundamental issues such as engineering materials, drawings (including Geometric Dimensioning and Tolerancing), fasteners, couplings, belts and pulleys. It then provides more in depth design details on gears, bearings, shafts and how simple beam formula can be used to calculate gearbox shaft loads and deflections. It analyzes power flow through an automotive drive train from the engine, through the torque converter, transmission, drive shaft and to the wheels. It concludes with information on how to apply for an engineering patent and how a bill recently passed in Congress has changed an important aspect of the patent law.

Engineering Materials

Iron & Steel: One of the most important engineering materials used today is iron. Iron is the fourth most abundant element found in the earth's crust by weight following oxygen, silicon, and aluminum respectively and occurs as an ore in the form of iron oxide. Iron ore is loaded in a furnace with coke and limestone and blasted from the bottom with hot air. The coke and hot air combine to reduce the iron oxide to iron while the limestone removes impurities. This product called *pig iron* is further processed to make castings, pipe, and sheet stock that are used in the many industrial products that surround us today.

Most pig iron is put into huge furnaces with a small percentage of alloying elements to produce steel. Steel is the world's most important metal and is found in everything from bolts to bridges. The hardness and strength of steel can vary greatly depending on the kind and amount of alloying elements that are added to the pig iron. When an increasing amount of carbon is added to steel, its properties of hardness and strength increase. More important, it becomes increasingly responsive to heat treatment producing even higher hardness and strength properties. The carbon content of steel ranges from about .05% to 1.0%. This effect that carbon has in hardening steel ends approximately with a maximum content of about 1.0%. Amounts of carbon over 1.7% limit the ability of steel to be responsive to hot and cold treatment and revert it back to a pig iron type material.

Other important alloying elements of steel are manganese, phosphorus, sulfur, molybdenum, chromium, and nickel. Manganese is next to carbon in importance in steel additives. Manganese is usually present in quantities ranging from .5 to 2.0%. Manganese imparts strength and responsiveness to heat treatment in steel. Small quantities of phosphorus are present in all steel. Phosphorus increases the strength of steel and ductility at low temperatures. Sulfur is an important element in steel because it increases machinability. Molybdenum increases toughness and tends to resist softening at high temperatures. Chromium in the quantity of .5 to 1.5% increases response to heat treatment. Chromium in the quantity of 12 to 25%, in combination with up to 20% nickel, increase resistance to oxidation and corrosion in what is called *stainless steel*. Nickel, in the quantity of 1 to 4%, increases the strength and toughness of steel.

<u>Aluminum</u>: Another important material used today is aluminum. Aluminum is the third most abundant element found in the earth's crust behind oxygen and silicon. Although aluminum isn't as strong as iron and steel, it is used extensively in industry because it is lighter, easier cast, and has more corrosion resistance than iron and steel. Because of the strong chemical bond between aluminum and the oxygen in its ore, it cannot be processed in a furnace like iron. Aluminum is obtained from aluminum oxide using an electrolytic process. The oxide is placed in an electrolytic cell with cryolite. The resulting reaction reduces the oxygen in aluminum oxide to carbon monoxide and carbon dioxide leaving the aluminum to settle to the bottom where it is removed and sent to a holding furnace.

For sand casting, the primary alloying elements for aluminum are copper and silicon. A general purpose casting alloy contains 8% copper. Silicon alloys of 5% are used because of their excellent casting and resistance to corrosion properties. Aluminum wrought alloys are classified into different groups: those hardened and strengthened by cold working and those strengthened by heat treatment. Pure aluminum with no alloying elements is work hardenable and is an excellent conductor of electricity. Pure aluminum with 1.25% manganese added is similar but is stronger with a little less electrical conductivity. Both of these alloys are available in a wide range of products such as sheet, rod, tube, wire, and extruded shapes. Where high strength is required, it is necessary to use heat treatable aluminum alloys. One such alloy is 2024. It is a heat-treatable alloy containing primarily 4.4% copper. Its heat treatable hardness is among the highest of all aluminum alloys and is used in the aircraft industry. Another popular heat treatable aluminum alloy used for many industrial purposes is 6061. This alloy contains small quantities of copper, silicon, magnesium, and chrome.

<u>Magnesium</u>: Magnesium is the seventh most abundant element found in the earth's crust following oxygen, silicon, aluminum, iron, calcium, and sodium. Magnesium is the third most structural metal used today behind iron and aluminum. Magnesium is obtained from seawater using electrolysis methods. Magnesium is alloyed with aluminum, zinc, and manganese and can be heat treated. Magnesium is the lightest of the structural metals used today. It is used in the aircraft and missile field and for other industrial products where weight is of prime importance. Magnesium is available in castings, forgings, extrusions, and sheet. Magnesium is easily machined, can be riveted, welded, and has excellent corrosion resistant properties.

<u>Material Testing:</u> An important test in which many important strength characteristics of engineering materials can be determined is called the *tensile test*. The tensile test machine clamps one end of a round test bar and slowly applies a tensile load to the other end until the bar breaks. Figure 1 is an example of a tensile test plot for low carbon steel. The vertical axis is the stress applied to the test specimen in pounds per square inch (psi) and the horizontal axis is the resulting strain of the test specimen in inches per inch. The initial segment of the plot is a straight line representing the elastic region in which the test

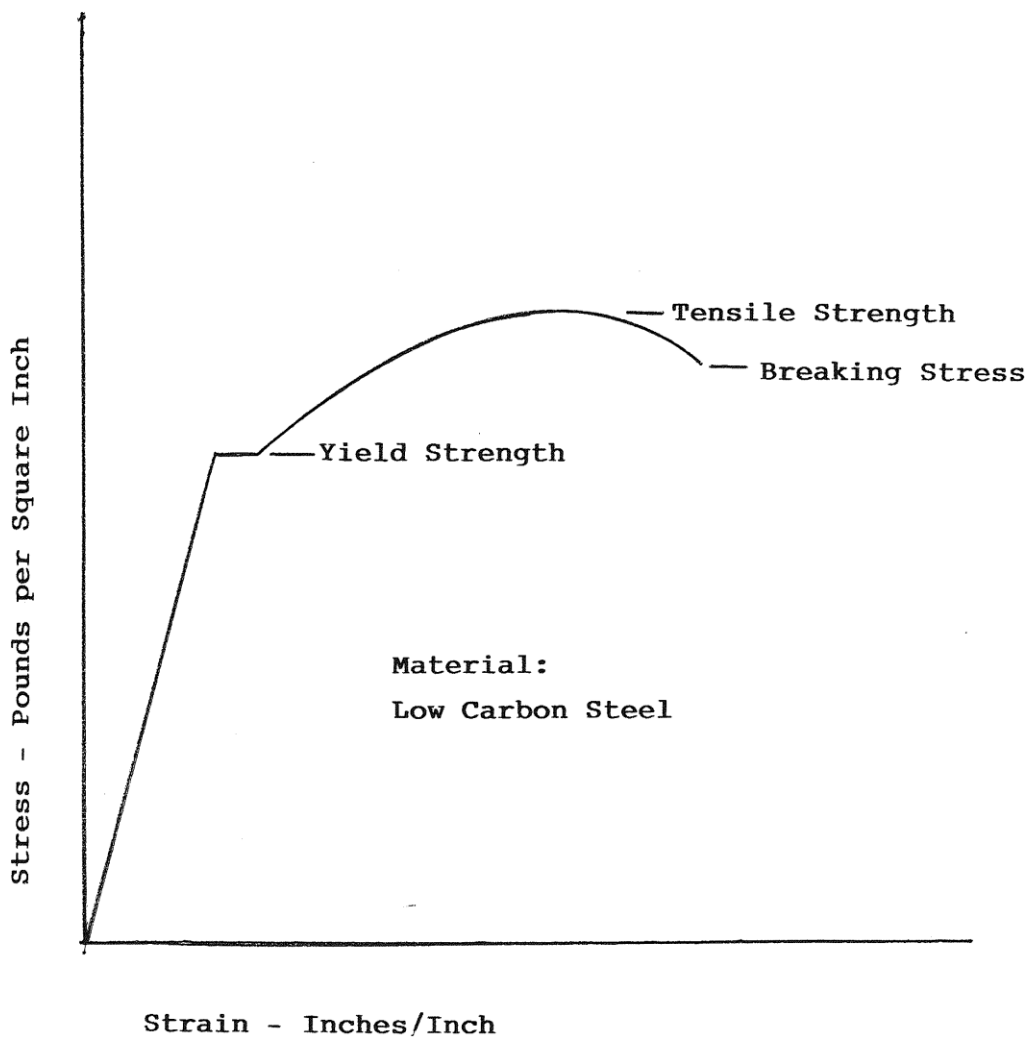
specimen will return to its original shape if the load is removed. The slope of the curve in this region is called the *modulus of elasticity* and is a measure of the stiffness of the material. In general, the point on the curve where the plot starts to deviate from a straight line is called the *elastic limit* and represents the *yield strength* of the material. Beyond the elastic limit, the test sample will not return to its original shape. It the load is increased further, the curve will deviate more and more from a straight line, reach a peak, and then start to descend until the test specimen ruptures. The *ultimate* or *tensile strength* is the stress that is being applied to the test specimen at the peak of the curve. The stress applied when the specimen breaks is called the *rupture stress*.

Material Hardness: A correlation exists between the hardness and the tensile strength of a material. Hardness is a very easy characteristic to test for and therefore has considerable use in industry. The Brinell machine is one tool that is widely used in industry to measure hardness. It is non-destructive and can be used for a wide variety of metals. It relies on the depth of penetration of a ball under load to determine the hardness of the test specimen. The following lists the yield strength, tensile strength, and hardness of some of the metals discussed above:

Metal	**Yield Strength**	**Tensile Strength**	**Hardness**
Magnesium Alloy	11,000 (psi)	21,000 (psi)	47 (BHN)
Magnesium Alloy	30,000	45,000	48
Aluminum Alloy	34,000	34,000	100
Aluminum Alloy	40,000	48,000	105
Wrought Iron	30,000	50,000	100
Cast Iron	24,000	39,000	200
Structural Steel	35,000	57,000	120
SAE 1300 Steel	40,000	70,000	150
SAE 4300 Steel	45,000	80,000	170

Figure 1

Stress-Strain Diagram



Engineering Drawing

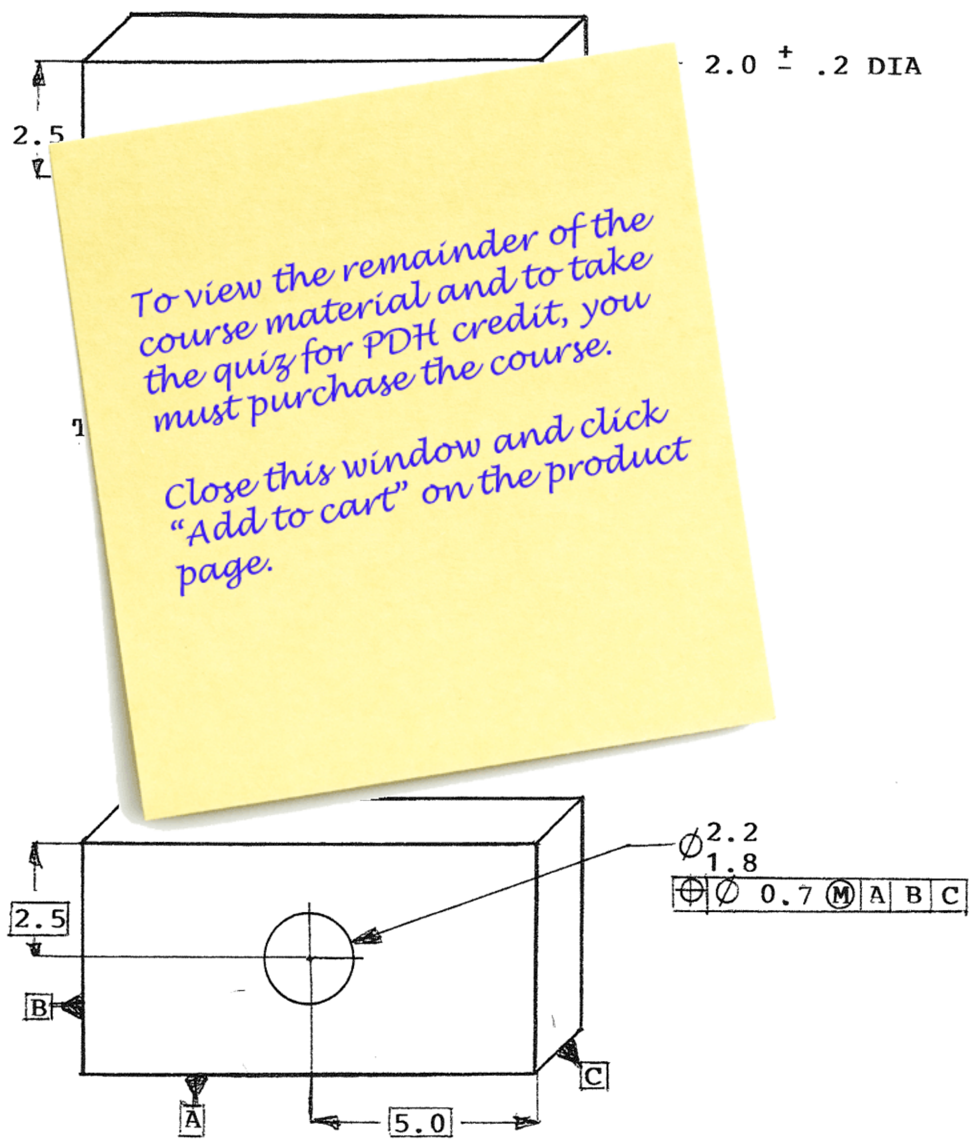
Geometric Dimensioning and Tolerancing describes a dimensioning system that is in use for preparing engineering drawings. It does not replace conventional dimensioning and tolerancing but supplements it by more precisely controlling requirements. It increases the tolerance zone for machining some features such as drilled holes and more precisely controls the fit between mating parts so that assemblies can be made without costly delays in production.

The sketch at the top of Figure 2 has a plate with a drilled hole. It is dimensioned using conventional dimensioning and tolerancing drawing practice. Assuming that the tolerance found in the drawing block for the 2.5 and 5.0 dimensions is plus or minus .5; the tolerance zone for the drilled hole is a square with sides equal to .5.

The lower sketch on Figure 2 is the same component with Geometric Dimensioning and Tolerancing. It contains the same information as the upper sketch along with a boxed in feature control frame that is applied to the hole. The crossed circle is the geometric characteristic symbol for position tolerance. The slashed circle indicates diameter. The .7 is the diameter of a circle that the center of the hole must fall within. It equals 1.4x.5 which is the distance from one corner of the .5x.5 square to the opposite corner established above using conventional tolerancing. The circled M is the material condition symbol meaning “maximum metal” (smallest hole). Other material condition symbols are L “least metal” or largest hole and R “regardless of feature size“. A, B, and C are reference datums applied to plate boundaries with A being the primary, B being the secondary, and C being the tertiary reference surface. The locational tolerance for larger hole centers is greater than for smaller holes. This system of dimensioning allows more area for the location of the hole center and more complete definition of the hole location with reference to all three datums insuring the successful assembly of the plate to its mating components.

Figure 2

Engineering Drawing



Geometric Dimensioning & Tolerancing