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Selection of Materials
Definition of Testing Methods

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Selecting materials for a particular application is an important part of the design process. Obviously the main concern is that the part won't fail in use and if that were the only criteria, the job of material selection would be easy.

There are only two ways a part can fail in an application. It either breaks, or it wears out. An automobile engine would last forever if gears, camshafts, valve guides, piston rings, cylinders and bearings did not wear out or if gear teeth and other parts did not break. So, why aren't all engines, machine tools, hydraulic parts, etc. made out of the strongest, most wear resistant material available? The reason is simple; a lot of parts have to be machined and materials have to be available and economical. This adds another dimension to the material selection process.

Material properties are used to evaluate metals. Understanding what those properties are is a very useful tool in determining if a selected metal will work in an application. Naturally the material selection process also involves an understanding on property requirements in an application. Knowledge of application requirements and material properties is extremely important if a designer wants to produce a part economically.

Test methods used to evaluate material properties are relatively simple. This section lists the type of test methods commonly used to determine strength and wear characteristics of a material.

Strengths

Tensile Strength:

The tensile test is one of the most commonly used means of evaluating strength of a metal. During this test, a specimen is pulled, or put in tension under a slowly increasing load until it breaks. Tensile strength is calculated from the load in pounds required to break the test bar divided by its cross sectional area in square inches. The resulting measurement is expressed in pounds per square inch or psi. Applied loads are expressed in pounds; stress is expressed in psi.

Tensile strength is the maximum load a part can withstand before breaking. A metal part most often becomes useless when it is permanently deformed but not yet broken. The point of this overload is called the proportional limit and this limit is often referred to as the yield strength.

Note: a standard test bar size is .505" in diameter. This makes the pounds per square inch calculation easy. .505" equals 0.200 square inches in cross section. Dividing the applied load by 0.200 is the same as multiplying it by 5 to get psi.

Yield Strength:

Metals are elastic as long as they return to their original shape when an applied load is released. Tensile strength is the force required to fracture a test specimen and yield strength is the force required to permanently deform the test bar. Yield strength is not as easy to determine as tensile strength but from a design standpoint, it is probably more important. Brittle materials such as gray iron do not have a yield point. In general, the more ductile the material is, the bigger the difference is between tensile and yield strength.

Steels may have significantly higher tensile strengths than ductile irons but the yield strength may be similar. Since parts are generally worthless when they become distorted, the yield strength should be considered to be a more important design criterion than tensile strength.

Strain and Modulus of Elasticity:

During tensile testing, the applied load causes the test bar to stretch. Before the test specimen is put in the test apparatus a gauge called an extensometer is clamped to the specimen. The extensometer has a dial indicator that measures the amount the test bar is being stretched over a given length, usually two inches. The amount it stretches divided by the given length is called strain and is expressed in inches per inch.

Modulus of elasticity (modulus means measure) is used to determine how much elastic distortion a part has under a given load. That load must be below the yield strength of the material meaning that the part is elastic and it is not permanently deformed. Metals having lower modulus values will have less elastic distortion than those with high modulus values.

Modulus of elasticity is expressed in pounds per square inch, or, psi. It is calculated by dividing the applied load by the cross section of the test bar and dividing that value by the strain. For example, suppose:

5,000 pounds is applied to a test bar measuring 0.505" in diameter. We can either calculate the deflection if we know the modulus of elasticity…or, we can use the stress strain curve to determine the modulus:

5,000 times 5 = 25,000 psi.
Assume the bar has stretched, or elongated, 0.00125"
The modulus would be 25,000 / 0.00125 = 20,000,000 psi.

Compressive Strength:

Compressive strength tests are similar to those used to measure tensile strength but instead of pulling the test bar until fracture, it is put in compression. Compressive strengths in most materials will not be much different than the tensile strength although there are a number of applications subjected to compressive loading. Concrete is very weak in tension but strong in compression. Tensile strength tests on a concrete specimen would not be very useful in determining the maximum permissible applied load on a bridge support. Compressive strength test would be more suitable.

Cast iron is also stronger in compression than in tension and compressive strength should be evaluated in applications undergoing compressive loads.

Torsion Strength:

Torsion strength is used to evaluate the maximum amount of twisting forces that can be applied in applications such as shafts and axles.

Torsion tests are performed by twisting one end of a test specimen while the other end is held fixed. Properties obtained in a torsion test are the breaking strength in psi, yield strength in psi and the amount of deformation in the fractured bar. Cast iron is usually higher in torsion strength than it is in tensile strength and torsional properties are useful in qualifying it for shafts and axles.

Fatigue Strength:

One of the most common causes of engineering failure is considered to be failure by fatigue. In tensile and compressive strength testing the load is applied very gradually until the test specimen fractures. Fatigue loads are cyclic, similar to bending a thin piece of wire back and forth until it breaks. Imagine trying to break the same wire by pulling on either end.

In fatigue testing, a crack begins at some point in the material. Once that occurs, the cross section is, in effect, reduced which increases the applied load in psi and the crack propagates rapidly without warning. Fatigue failures are always brittle; there is no "fatigue yield" strength.

Fatigue strength is the stress in pounds per square inch at which failure occurs in a definite number of cycles. Low cycle fatigue strength is the maximum stress a part can withstand over 2,000,000 cycles. High cycle fatigue involves 10,000,000 cycles. The fatigue strength can be significantly lower in high cycle fatigue than it is in low cycle fatigue. It is important to know which type of strength is required.

Hydraulic manifolds are usually tested in low cycle fatigue. Gears are always tested under hi cycle fatigue.

The most common type of fatigue test is the rotating beam fatigue test. A specimen is machined from a thin rod, usually around 0.250" in diameter. One end of the specimen is put it the test fixture with a specified load suspended from the other end. The bar is rotated until it breaks, or until the required number of cycles is met.
In fatigue testing, the load is constant. Remember that in tensile testing, the load is gradually increased until the specimen breaks. Determining the fatigue strength of a material requires a number of tests. The number of cycles to failure increases as the applied load decreases. The plot of the stress vs. number of cycles is called an S-N curve. Design engineers frequently request the S-N curve.

Endurance limit is the limiting stress that a metal can withstand an infinite number of cycles without failure. Fatigue strength is the stress a material can endure at a specific number of cycles. It is important to know the difference. If an engineer requests the endurance limit of a metal, they are asking for the strength that the part will never fail, regardless of the number of cycles. If they ask for fatigue strength, it should be stated as "the fatigue strength at 10,000,000 cycles".

Fatigue testing machines rotate at a speed of about 10,000-RPM, which is just over 14 million cycles per day. It takes about 7 days to develop an S-N curve, which makes the test relatively expensive, compared to tensile tests. By comparison, a simple tensile test will cost around $60. Fatigue tests cost about $2,000.

Other types of fatigue test that are commonly used for gears is a single point bending fatigue test. A test gear is machined and put in the test fixture. The load is repeatedly applied to a single tooth, and then relaxed over the required number of cycles.

The geometry of the part and the environment it is placed will have a huge affect on fatigue strengths and endurance limits. Lab tests can be used for comparison but usually a part is machined and tested in the application before it is approved for production. These types of tests can get very costly. An endurance test for a part on a Cummins diesel engine, for example, costs about $70,000.

Shear Strength:

A vertical load applied on a part similar to the way scissors cut through paper creates shear stress. The maximum amount of shear stress required to fracture the part is the shear strength of the material. Bolts, rivets, pinions, shear pins and keys are exposed to shear stresses and the shear strength of a material must be known to determine whether or not it will work in the application.

Shear strength is determined by one of two standard methods, the double shear test method and the single shear test method.

In the double shear method the test bar is laid horizontally on the test block that has a groove milled out of the center. The middle of the test bar is not supported. The load is applied down on the test specimen until it fractures.

The clearance between the groove and the applied load is very small, about .005" in order to minimize bending in the test bar. All edges are machined sharp.

Single shear test methods are similar to the double shear except that only one end of the test bar is supported.

Shear strength using the double shear method is calculated by dividing the load required to fracture the part by 2 x the test bar cross sectional area. The shear using the single shear method is calculated by dividing the load by the cross section of the test bar.

Impact Strength:

Toughness of a material is its ability to withstand a hard blow or sudden shock. The opposite of toughness is the brittleness of a material. The most common types of tests used to measure toughness are the Izod and Charpy impact tests; both are similar in principal.

Impact testing involves sharp blow to the test specimen. A pendulum swings from a predetermined distance against the test part that is held rigid in a clamp. In the Charpy test, the sample is held horizontally on either end. In the Izod test, the sample is held vertically on one end. Results of the test are reported as Impact Strength in foot-pounds.

Impact data cannot be used for design criteria and is only good for comparing the relative toughness of different metals. Impact data is useful in comparing the toughness of a metal at different temperatures and under different heat treat conditions. Low temperature toughness testing was forced on all parts of the metals industry during WWII because of the number of ships that cracked in half. (Don't forget about the Titanic)

Wear Resistance

Hardness:

Hardness is used to measure the wearability, strength and resistance to erosion of a material. Hardness is also a measure of how easy the material is to machine. It is easy to measure, usually does not require the part to be destroyed and is relatively inexpensive.

Several methods are used to measure hardness and the values obtained from each method can be converted back and forth. The best method to use depends on the material being tested.

Rockwell hardness test uses a small point that makes an indention on the surface of the test specimen. Brinell testing uses a much larger diameter ball. Brinell Hardness Testing is most commonly used for cast irons and Rockwell Hardness Testing is most commonly used for steels. If a Rockwell hardness test is used on cast irons, the reading may not be accurate if the indenter hits a graphite flake or nodule rather than the metal matrix.

There are a number of hardness tests and when properly used they serve a purpose in selecting the best material for an application. Hardness tests can also be very useful in measuring the consistency during production of a product.

Abrasion Resistance

One of the most common methods used to evaluate the wear resistance of a metal is the pin abrasion test. Wear involves two components and this test consists of a pin and a disk. The disk rotates with the pin pressed against it under a calculated load.

The exact nature of the test is outlined in ASTM D3702. The load starts at about 20 lbs. of force and increases by 10 lbs. every 5 minutes until the part fails (galling is evident) or the predetermined maximum load is reached.

After each cycle, he samples are weighed and measured and put back into the test stand. Usually, this type of test is used to compare a variety of metals, which are used as the disk against a constant metal used as the pin. Volume, or weight, loss in the disk can be compared against each sample.