When specifying seals for hydraulic, pneumatic, and fluid-handling systems, ensuring that seal materials suit the application is always a prime concern. Fluid incompatibility, temperature extremes, and many other factors can hasten a seal’s demise and quickly lead to leaks and downtime.

Fortunately, material tests provide a powerful tool to help evaluate and ultimately predict the relative performance of various engineered materials. But the amount of data they generate can be overwhelming. To interpret test reports, it is important to understand the test methods and verify that labs follow established protocols to ensure results are accurate and comparable from one material to another.

**PHYSICAL PROPERTIES**

Hardness, tensile strength, and elongation are physical property tests that form the starting point for evaluating materials. Test reports and material spec sheets usually list these results first. Hardness tests evaluate how far an indenter tool penetrates when pushed into the surface with a specified force. Reports commonly present data in either Shore A or IRHD units, depending on procedure and equipment, but results are generally similar and within about five points of one another. Other hardness methods, such as Shore M and IRHD-M, often provide more-repeatable results.
with round O-rings, but they are not comparable to results on flat specimens. That is because part geometry can have a considerable effect on outcomes. For instance, Shore M or IRHD-M data on flat samples are generally similar to those of Shore A and IRHD, while the same tests on otherwise identical small O-rings can differ by 20 points. There is no conversion factor from one method to the other, so engineers cannot legitimately compare Shore M or IRHD-M to Shore A or IRHD results.

In rubber-seal applications, hardness primarily predicts pressure resistance and compressive-load capacity. In a properly designed groove, an “average” 70-durometer material should resist about 1,500-psi (10.3-MPa) fluid pressure without damage. A harder, 90-durometer compound typically handles about 3,000 psi (20.7 MPa) in the same mating hardware. Some extremely hard materials — exceeding 90 durometer — are specifically designed for maximum pressure resistance. But in these cases, hardness does not reliably predict pressure rating.

Tensile strength is simply a sample’s maximum stress during a tensile test. With rubber materials it typically occurs just prior to failure (ultimate elongation). Because O-rings seldom stretch more than a few percent in applications, tensile strength is generally less critical than other properties. However, it does play a more-important role with other types of rubber components, including diaphragm and duckbill valves. Elongation helps determine how much components can stretch during installation.

When choosing between seal materials, it is almost always beneficial to reduce physical performance to gain improvements in other areas.

**COMPRESSION SET**

In traditional compressed-seal applications, the rate of “flattening out” is a critical indicator of how long a seal will last. In fact, flattening causes most end-of-life failures in static-seal
applications. Unfortunately, mathematical models have not yet linked compression-set values with actual service life, but users can draw general comparisons from applicable data.

Compression set testing (ASTM D395 Method B) involves a simple procedure. A sample of a known thickness is compressed 25% and held in place for a predetermined time at an elevated temperature. Technicians then measure the sample’s thickness after cooling to room temperature. “Compression set” is the percent of compression that has been permanently lost. A 0% compression set means that the sample completely returns to its original shape and has lost no thickness; 100% compression set means the sample has permanently deformed to the compressed thickness.

When comparing compression-set details, it is absolutely essential that sample sizes are identical. Resulting values are roughly inversely proportional to the original thickness for samples of identical composition. Geometry plays a role, too. Standard ½-in.-thick solid “buttons” of material exhibit slightly better compression set than 0.075-in.-thick discs stacked to the same height. Small O-rings (0.07-in. cross section) of the same material have even higher compression-set values.

With all other test variables equal, materials with lower compression set usually last longer in the field (assuming no other failure mechanisms). However, because no mathematical correlation exists, there is no way to quantify how much longer one material will last compared to another. Experience shows that seals often leak at approximately 80% compression set. However, this rough rule of thumb does not always apply.

HEAT AGING
A material’s ability to withstand elevated temperatures is another area of interest in evaluating rubber compounds — primarily how heat affects physical properties. To accelerate aging, tests usually run at or near a material’s upper operating-temperature limit. Historically, tests last 70 hr, but many recent specifications require 1,000 or even 2,000 hr to evaluate long-term effects.

Substantial changes in the sample’s physical properties indicate material degradation. Although most seal materials harden during heat aging, there are a few exceptions, particularly when temperatures exceed a material’s recommended limits. Therefore, both hardening and softening are of interest. Changes exceeding about 10 points Shore A may indicate significant damage. As a rubber hardens or softens, it typically affects tensile strength and elongation as well. Materials with tensile properties that change more than 25% require further testing.

FLUID IMMERSION
Whether exposure is deliberate or accidental, every seal comes in contact with liquids, gases, or solids that could cause chemical interactions. Few solids or gases react significantly with rubber, so testing primarily focuses on liquids. Exposing rubber to fluid causes three different, simultaneous interactions:

Swelling, the most well-known phenomenon.

Negative volume change, (shrinkage) caused by extracting liquid constituents from the rubber.

Chemical reaction and direct degradation of seal materials. Ultimately, minimizing all three interactions is critical to maximizing overall performance. Seals swell when they absorb fluid. This process usually reaches equilibrium within the first 24 to 48 hr. As a result, fluid immersion tests typically last 70 hr, although some specifications require 1,000 or 2,000-hr immersions. Whenever applications require fluid immersion, rubber specifications should include volume-swell limitations. If such limits are not stated, the following guidelines help interpret results:

• Fluid compatible: <20% volume change.
• Moderately compatible: 20 to 40% volume change.
• Fluid incompatible: >40% volume change.

Only specify moderately compatible materials in static environments, and avoid using them in safety-critical applications if more-suitable options exist.

Negative volume change (shrinkage) takes place because many rubber compounds contain liquid plasticizers that improve processing characteristics or low-temperature performance.

When immersed, the test fluid can dissolve plasticizers as they migrate out of the rubber compound. This causes the seal to shrink, usually within the first few days of exposure. Compounds that shrink in an application fluid often fail prematurely as the seal pulls away from mating surfaces.

Also consider changes in physical properties during fluid-immersion tests. For example, high-temperature steam seldom causes seal materials to swell but, nevertheless, can cause catastrophic damage. Steam can react with and oxidize rubber, often reducing tensile and elongation values by as much as 80%.

Other chemical reactions can significantly alter hardness or tensile properties, but there are no universally accepted limits for interpreting these results. In general, hardness changes of less than 10 points and tensile
strength/elongation changes smaller than 30% are considered acceptable. Hardness changes of 10 to 20 points are questionable, as are tensile and elongation losses of 30 to 50%. Larger changes generally indicate incompatibility. There are several exceptions to these rules of thumb, so consult a sealing expert if questions arise.

LOW TEMPERATURES

Sealing in cold environments is becoming increasingly critical. Aircraft flying at higher altitudes and oil drilling at higher latitudes may be the most visible, but practically every industry using rubber seals is on the lookout for improvements in low-temperature seal performance.

Low-temperature brittleness (ASTM D2137) measures a material’s crack resistance when extremely cold. A sample is cooled, typically to −40°C, struck with a specified force, and then examined for cracks and fractures. Materials that do not crack or break pass the test. This common method is useful for some mechanical components — for example, automotive steering boots that must withstand impact from rocks and road debris at low temperatures. However, it has little direct relevance to conventional seals. Materials that pass the test may not retain sufficient flexibility at −40°C to maintain a reliable seal. Conversely, some materials seal at temperatures well below the point at which they fail an impact brittleness test. For this reason, the test is a poor indicator of seal function at low temperatures.

A variation of this method bends or twists the sample at low temperatures. This tends to be less severe than D2137. A material that fails the impact-brittleness test may bend flat onto itself or around a mandrel without cracking at the same temperature. However, it still has little direct relevance to seal function.

Determining glass transition, $T_g$ (ASTM D3418) is a common method for evaluating thermoplastics. All polymers undergo a low-temperature phase change similar to freezing. Below this point, the material is glassy, brittle, and fractures easily.

There are, however, two fundamental problems with applying this method to rubber materials. First, the glass transition of most rubbers takes place gradually over a range of several degrees. Second, there is no widely accepted correlation between glass transition and loss of seal function. Tests usually report the midpoint of the glass transition process, but published values can be the onset (warmest temperature) or final (coldest temperature) transition point. The specific point in the transition range where sealability is lost varies dramatically among rubber materials.

The temperature retraction method (ASTM D1329) is currently the most reliable test for low-temperature sealing performance. A rubber seal is stretched 50%, clamped in position, and frozen. The clamps are then released and temperature slowly increased. The temperature at which the material regains enough resilience to recover 10% of the original stretch is the TR-10 (temperature retraction, 10%) point. This test directly evaluates when a material stops being rubbery and starts behaving more like a soft plastic. As a result, it accurately predicts low-temperature behavior. In general, rubber seal materials function reliably down to their TR-10 point in dynamic applications. In static applications, rubber materials typically maintain a seal 15°F below their TR-10 temperature.

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