Compression set testing is defined as the measure of a material's elasticity after prolonged action of compression (Figure 1), either under ambient conditions, or while being exposed to elevated temperatures. The results are used to relate the elastomer's compression set result to its propensity to leak in service. The higher the compression set, the higher the risk of a leak.

An elastomer's compression set performance is dictated by two factors: the elastomer (polymer type, crosslink type and quantity, filler type and process aids) and test procedure.

Under compression the elastomer is subject to both thermal and chemical attack. The rate of thermal attack is dependent on the temperature of the test oven. Chemical attack can occur in a variety of ways, with crosslinks forming or breaking or through degradation of the polymer chain.

As temperatures are increased, or test times extended, the degree of thermal or chemical attack increases, thus reducing the ability of the rubber to recover to its original shape (see Figure 2 on page 13).

Therefore, the compression set test can be used as a measure of the cure of the elastomer. By testing at elevated temperatures, the degree of compression becomes a measure of the strength of crosslinking within the elastomer.

Compression test methods
There are two compression test standards commonly included on product data-sheets: ASTM D395 and ISO 815.

ASTM D395
Compression test ASTM D395 defines two different methods (A and B).

Method A is not often used and relates to compression under a constant load.

Method B is the test procedure normally quoted on material data-sheets. Here, a sample is typically compressed by 25% to 75% of its original height, and heated for a number of hours. The temperature and duration of the test are dictated either by test standards (such as ASTM) or customer-specific requirements. The fixture is then removed from the oven – the test pieces removed whilst hot and allowed to cool uncompressed over a 30-minute period before they are remeasured.

The compression set result is a measure of how much the seal has not recovered. Therefore, a result of 100% means that the seal has not recovered at all, while 0% means that the seal has returned to its original dimensions. (Note: For standard ASTM testing, only 25% squeeze is used. For the ISO method, however, the actual degree of compression can vary depending on the hardness of the material. Therefore, tests on the same material can give different results).

ISO 815
ISO 815 Method A is equivalent to the ASTM Method B, but also includes two other alternatives – Methods B and C.

For ISO 815 Method B, the same set-up and heating regime is followed as D395 Method B, however, once the test is complete, the fixture is removed from the oven and allowed to cool to room temperature before the test samples are removed and measured.

This method essentially ‘freezes’ the rubber into shape, and could also be described as ‘cold set’. Therefore, the results from this type of testing are higher (worse) than for the ASTM Method B, and for some families of rubber significantly so, for example, those whose glass transition $T_g$ is closer to room temperature.

ISO 815 Method C follows the same procedure as Method B, however, the test fixture is disassembled whilst hot, and the samples are then allowed to recover in the oven for 30 minutes at the test temperature before being removed from the oven and measured. This compression set test method should give the best results of each of the different procedures.
FFKM comparison

A comparison of the results of tests using the three different methods for perfluoroelastomer (FFKM) is shown below in Table 1.

FFKMs, in general, suffer from poor compression set, and so the Method B (‘cold set’) result is not unexpected. Recent developments in FFKMs have shown that 38% compression set is now achievable with Method B, bringing perfluoroelastomer in line with a typical FKM material.

Limitations

There are important limitations to the compression set test methods that should be borne in mind when comparing compression test results for the same, and different, elastomers.

Compression test methods do not take into account variables of temperature and pressure experienced by the seal in use.

Compression set testing is conducted at a high temperature to accelerate the effects of seal compression. This short-term compression set testing is best regarded as a quality control tool rather than offering any lifetime service predictions for the seal.

Unfortunately many engineers are relying on the test results more and more for the long-term prediction of performance. However, these short-term compression set results will have little bearing on how a material would actually perform in service.

Comparative guide

Given these limits, it is clear that compression set tests can be used only as a means of comparing compression set performance between elastomers. The question is then: Which test method is best for the comparison?

Each of the different test methods has its merits. To obtain the best sealing solution, the engineer should look at the results of all three tests. ISO Method B more closely represents most types of applications. However, Method C, within the ISO procedure, would be more indicative of the effects of polymer degradation.

Therefore, to obtain the optimal material, all of the three different test methods should be used; and ideally over a range of times and temperatures that bear some relation to the application.

As Table 2a and Table 2b show, taken as a purely comparative selection tool the holistic view of compression set performance can provide valuable insights into elastomer selection.

Referring to Table 2a, if the results for method B are large, these materials may not be suited to temperature-cycling applications. Those with lower results for Method C would be better suited to long-term performance at elevated temperatures.

For example, where the choice is between a FKM or tetrafluoroethylene/propylene (TFE/P), TFE/P may perform well over a long period at 200°C, but it may not be the best grade if it is cycled between low and high temperatures – in these instances, FKM materials may be better.

The most interesting point to note in Table 2b, is the testing of nitrile versus HNBR. Using the normal ASTM test, or the ISO B method, they appear to be comparable. However, ISO Method C reveals evidence of thermal degradation for the nitrile – an important consideration where both materials are being considered for higher temperature applications.

Conclusion

Rarely is compression set the ultimate criteria in seal selection. Chemical and temperature resistance are more important.

It is widely acknowledged that compression set test methods (and results) often bear no relation to the actual sealing application.
Translating compression results into in-life-service predictions is, therefore, a risky business.

Finding 2. Two sections of the same O-ring – the section on the left displays compression set after being compressed at a high temperature for a period of time.

Compress set becomes important when refining a shortlist of candidate elastomers. By undertaking all three ISO compression tests, engineers should be in a better position to select the best elastomer from the shortlist.

(Darryl Turland, materials technologist, Precision Polymer Engineering Ltd, a unit of IDEX Corp, can be contacted at the address given below.)

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Editor's comment:
I am very pleased to be able to publish this feature. It very ably illustrates something that has been a bit of a hobby horse of mine for many years - in fact, since I first tested some very new FFKM back in the 1970s. The results show that if compression set is to be used for anything other than material manufacturing QC, the general industry method only gives anything near a usable figure for NBR. For higher-duty materials the application requirements should be considered carefully. There are, of course, those who contend that compression set is unreliable and stress relaxation should be used. But, how can CSR be used to measure performance in real equipment, or on seals returned from service. I look forward to further developments of this work.

PATENTS

Retractable seal for ball valve

Applicant: Process Pigging Systems LLC, USA
This invention relates, in general, to a ball valve and, in particular, to a ball valve that has a retractable main ball seal (600/602) and a clean-in-place spindle seal that enables cleaning to be carried out within a pipeline. By opening the spindle seal, the spindle seal cavity may be cleaned without disassembly by enabling fluid to flow around and within the ball-valve cavity. Similarly, by retracting the main ball seal (600/602), the valve cavity may be cleaned without disassembly. Opening a spindle seal causes the fluid to drain naturally.

Sandwich seal

Applicant: Neo-Plastic Dr. Doetsch DIESPECK GmbH, Germany
These three patents describe a seal that is manufactured by injection moulding a hard plastic substrate and then covering it with a softer plastic material to form a seal. The manufacturing process and production of a number of seal designs are described. An application – as a bearing seal – is covered in some detail, with conventional ball races, linear ball races and machine slide-ways illustrated.

Inventors: H. Freiherr von und zu Franckenstein and P. Freiherr von Twickel
Publication date: 5 August 2010

Container closure assembly with pressure seal

Applicant: Beeson and Sons Ltd, UK
A screw-top container and cap arrangement for carbonated drinks bottles are detailed. The design provides an effective seal without the need for a seal liner in the cap, and also without the need for a strong axial sealing force between the container neck and the cap. Furthermore, it is tolerant of high axial forces applied to the cap when it is in the closed and sealing position on the neck (for example, this takes into account the potential weight of 'superimposed' containers when the containers are stacked). The cap includes what is described as an olive sealing plug that provides a seal on the inside diameter of the bottle neck, with a skirt on the outside diameter creating the sealing force.

Patent number: WO/2010/086609
Inventor: R.M. King
Publication date: 5 August 2010

Pipe joint

Applicant: Kubota Corp, Japan
An annular seal member is provided to seal a tube joint between a tube opening and an inserted tube-end. A valve portion of the seal member has a first valve, extending from a heel portion; a second valve, extending further towards the inserted tube-end; and a reduced portion, provided at the boundary between the first and the second valve. The first valve abuts the inner periphery of the tube opening while the second valve abuts the outer periphery of the inserted tube-end. In an 'un-installed' state the second valve tapers from the first valve towards the centre of the tube-end. The inner diameter of the second valve is smaller than the outer diameter of the inserted tube-end.