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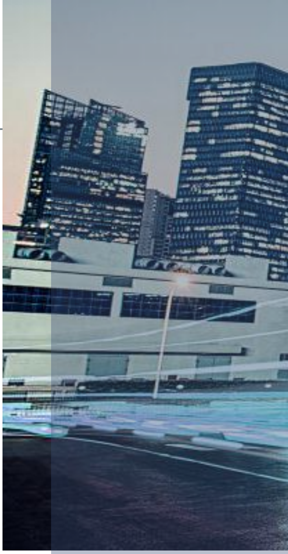

O-rings: the system-critical sealing solution with high performance

Richard Katona

Engineering technology in the mobility sector moves forward fast. But there is one small component that, although it has evolved, has remained as important today as it was when Niels A. Christensen filed US Patent Number 2,180,795 on 2 October 1937. Christensen had invented the O-ring – at the time primarily as a means of preventing fluid from leaking as pistons went through the process of reciprocating motion – solving a challenge that would revolutionize sealing solutions in the mobility sector.

Seventy-five years later, the experts of today have a particular challenge of their own – how to deal with the sealing challenges associated with the transition from the internal combustion engine (ICE) to electrification. Today, we are seeing a split of approximately 80/20 in favour of the ICE, but projections out to 2028 put that figure at closer to 55/45, with usage behaviour changing at the same time.

New applications present new challenges

Further predictions suggest there will be a shift towards ride sharing and ride-on-demand services, instead of vehicle ownership. This means components will have to be more durable, more resistant to new aggressive media, and more robust to deliver what is required of them in higher mileage electrified applications. Here, we take a look at the electric parking brake (EPB) as an example – a critical function within electrification that must operate to the highest safety standards at all times, particularly as the levels of autonomous driving increase.

Within the EPB, the O-ring has to provide a shaft seal under special conditions, as it is pressed against a rotating spindle and must be able to withstand more than 300,000 actuations over the lifetime of the application. In terms of functional requirements, the brake itself is actuated by rotating the spindle in the centre by +/-420° at a max. speed of 50 rpm, and temperatures range from -40°C at their lowest to a maximum of 120°C. Given these conditions, and a required seal pressure range of between -0.6 and 120.0 bar, the challenge is to create a seal with specialized reinforcement, improved abrasion resistance, optimized hardness and improved processability.

How does this translate to material requirements?

In short, the material will need to be easily processable, but still have a hardness and abrasion resistance that meets expectations, which makes the problem quite demanding. The material itself must be finely tuned to meet the required hardness, for example using special fillers to optimize the abrasion resistance, and then tested

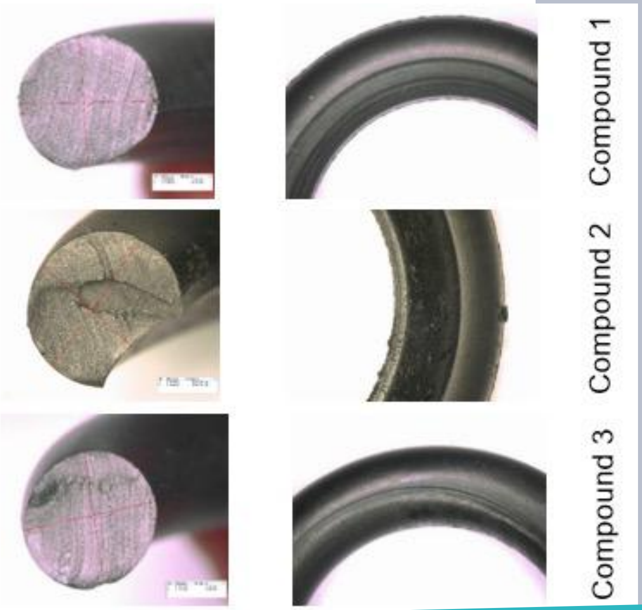

Figure 1: Comparison of different compounds in application environment

extensively in an application relevant environment to provide a thorough evaluation ahead of field testing.

Today, it is possible to replicate a real-world application using specialist equipment under laboratory conditions, which allows the behaviour of parts to be observed, to collect the associated data and to analyze this with a view to optimization. This reduces development time and costs. In the image below, a comparison of different compounds in an application relevant environment can be seen, where compound 1 has outperformed its rivals under the set parameters of the test.

It is now also possible to make further enhanced tests to determine the best possible combination of compound and surface treatment for specific

applications. These testing capabilities mean scaling up of a new technology can be achieved faster and with unprecedented levels of accuracy, closing the gap further between the lab and serial production.

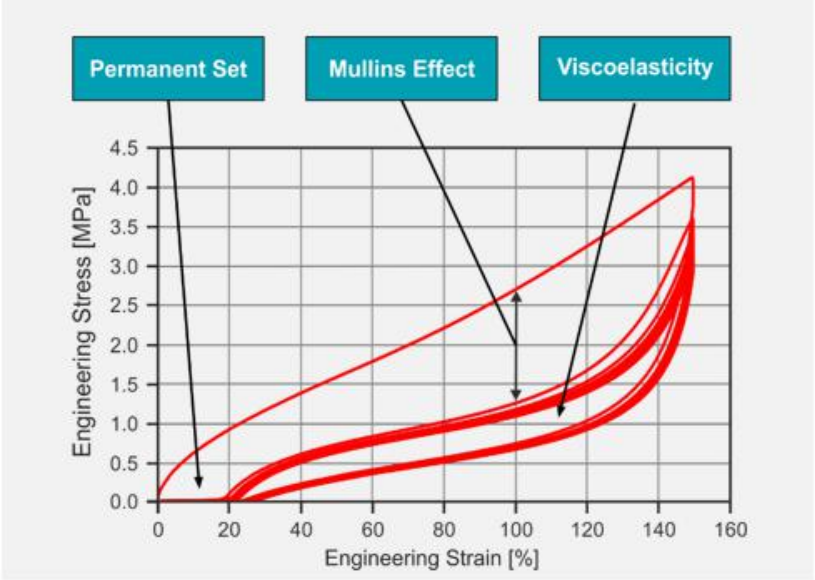

Figure 2: Uniaxial tensile test of a rubber material

Simulation is a critical part of the O-ring development process

O-rings for future mobility applications must deliver high performance, high reliability, and durability. Therefore, the importance of structural mechanical analysis, virtual molding, testing and modelling using advanced simulation techniques cannot be underestimated.

For rubber materials there is a typical uniaxial tensile strength test. The training curve below shows a relatively complicated stress strain behaviour. The Mullins effect is observed, in addition to stress softening after the first stress loading. If cyclic loading is required it is important to look at the hysteresis curve as well as the permanent set. All these different effects must be considered to get a very accurate simulation model to feed into O-ring designs and therefore to optimize them.

The accuracy of material models depends on the optimization of the testing process. It is important to take optical strain measurements to calculate the strain at a local scale in a contact-free method. Video images of the whole tensile test are then created and a speckle pattern applied on top of the surface to follow the displacement of these different points. From the change of the distance distribution between the different points the strain is accurately calculated.

Structural Mechanical Analysis

To optimize the structure of an O-ring, the design must be the starting point - which is the inner diameter and the cross section. A model is made and the mounting within the housing is simulated to calculate elements such as contact pressure distribution. The typical design parameters of the O-ring are then analyzed, and the parameters of compression and groove filling can be calculated.

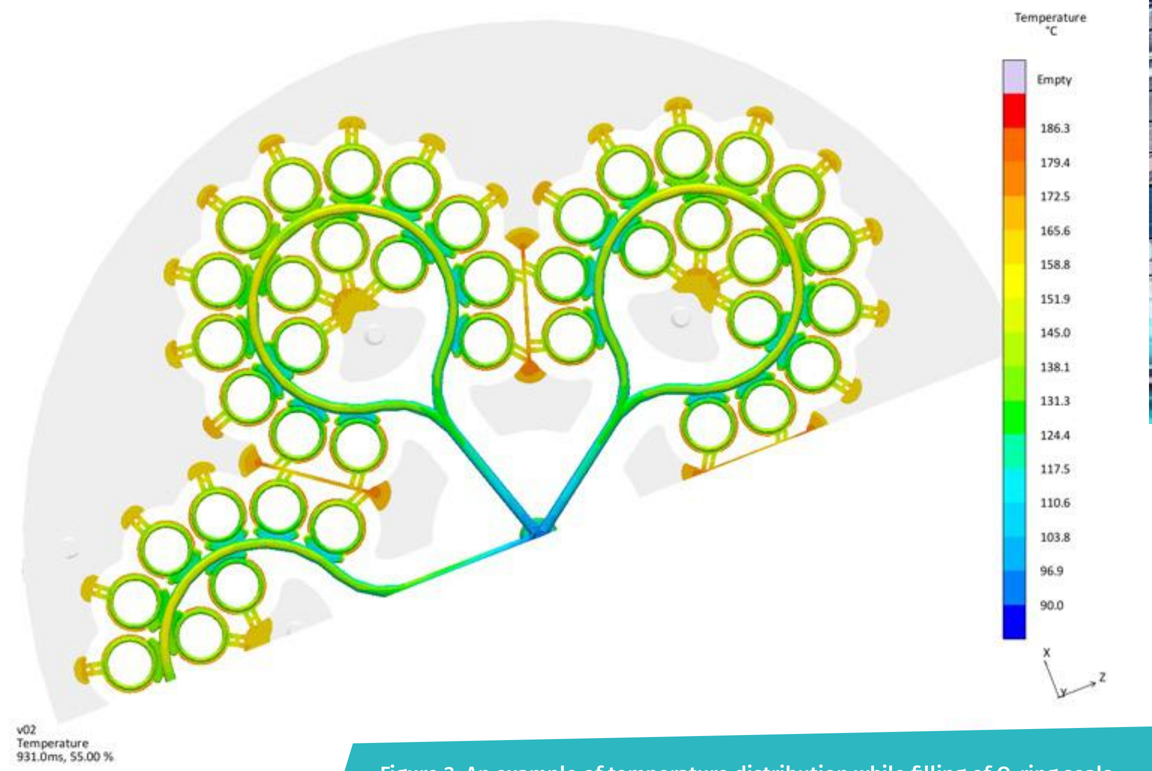

Figure 3: An example of temperature distribution while filling of O-ring seals

The next step is design tolerances – geometrical and temperature range. Typically, calculations are made of a nominal material at room temperature conditions, followed by two further simulations – one at the lowest temperature in the functional range, and one at the highest temperature. This allows the complete design space of the system to provide detailed information about its functionality. Normal stress and contact pressures are also important to measure as they will guarantee seal tightness.

Virtual molding delivers next level quality

The process of virtual molding optimizes molds through an understanding of the forming process itself to calculate temperature distributions and to improve them in the mold, making sure the cavities are evenly filled.

First, a 3D model of the mold is made, the cavities are measured and a simulation of the material being injected into these meshed cavities is run to observe material flow, injection pressures, etc. The virtual molding of O-ring seals is seen in the image below. Here it is possible to observe the flow of the material in the channels. By simulating this process, step filling can be avoided, leading to a much faster development process. In addition, it is also possible to calculate the curing degree, which is critical to understand as it defines the functionality and performance of the O-ring.

Conclusion

On the surface, a small rubber ring may appear straightforward in terms of design and development, but there is far more involved than simply injecting rubber into a mold. The level of detail required to ensure critical seals perform as they should is very high. When those seals are critical to the safety of passengers, there can be no corners cut anywhere in the process. Working closely with a specialist supplier of O-rings can mean the difference between a good seal and an excellent one. As the parameters of what these seals must deal with are expanding further and further, the excellent seal is sure to become the required standard.

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