Thermoset Shaft Seals – A new Generation of Radial Shaft Seals

Cornelius Fehrenbacher, Simon Kayser, Simon Haaf

Radial shaft seals used in corrosive media need usually a stainless steel support part. To achieve sufficiently good adhesion between the support part and the elastomer, a complex pre-treatment process is required.
With radial shaft seals using a thermoset support part, the high corrosion protection requirements of some customers can be met. In addition, a weight saving is achieved and the process time is significantly reduced by eliminating the time-consuming pretreatment process of the stainless steel support part. But there are challenges in using a thermoset support part.
The design of a thermoset support part is discussed and the investigations are described.

1 Introduction

Radial shaft seals are used in large numbers in the automotive industry as well as in other areas. Radial shaft seals are used for sealing in gearboxes or engines. The task is to keep the medium in the space to be sealed and to prevent the ingress of foreign substances from outside, such as water or dirt.

The use of radial shaft seals in corrosive environments requires some attention. On the one hand, the right material must be selected for the seal. On the other hand, an increasingly longer resistance to any kind of corrosion is required. The requirement of a corrosion resistance of more than 15 years is no longer a rarity today.

For this reason, the use of a stainless steel support parts has been indispensable up to now. The use of stainless steel and the associated higher process costs increase the cost of the product significantly. From an economic point of view, it therefore makes sense to consider alternatives to the use of stainless steel support parts.

2 Problem

The production of radial shaft seals using the injection molding process often requires the use of cams on the bottom side of the radial shaft seal to hold the steel part in position during the vulcanization process. As standard, the support parts of radial shaft seals are made of steel. These are coated with a binder to ensure good adhesion with the elastomer material and thus contribute to the functionality of radial shaft seals. At these areas on the support parts, the steel part is uncovered or merely covered with a thin rubber skin, which also mostly has low adhesion properties due to the low material thickness.

The uncovered areas or those covered with a thin rubber skin in the area of the cams on the steel part are directly exposed to the environment and are not adequately protected against corrosive attack. There is a risk of corrosive decomposition and thus weakening of the function of the steel part.

If the radial shaft seal is exposed to corrosive media on the bottom side, a corrosion-resistant steel part, usually stainless steel must be selected in this case.

In order to be able to use a stainless steel support part, a complex surface treatment of the steel part is necessary to ensure a sufficient bond between the elastomer and the steel part. Despite or because of the complex surface treatment, it is always possible to have rejects in which the elastomer-metal bond is insufficient.

3 Thermoset Lip Seal

A possible alternative to the steel part is the use of plastics as a support part. Plastics are corrosion-resistant and also have good stability as a support part. However, the use of thermoplastics is not possible. Thermoplastics consist of long molecular chains. When subjected to external stress, the molecular chains slide off each other or unbundle, resulting in creep. Creep is a time- and temperature-dependent viscoelastic or plastic deformation. The higher the ambient temperature, the greater the creep.

In thermosets, on the other hand, the polymers crosslink to form a close-meshed lattice. Once they have fully cured, they can no longer change their shape and disintegrate when the decomposition temperature is exceeded. Creep, as occurs with thermoplastics, does not take place.

Figure 1 shows the lattice structure of thermosets, thermoplastics and elastomers.

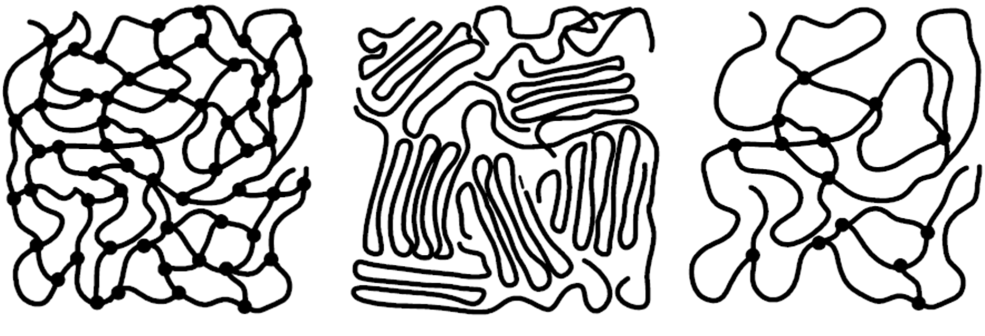

Figure 1: Comparison of the lattice structure of thermoset, thermoplastic and elastomer [1]

3.1 Structure of Thermosets

Thermosets are plastics that can no longer be deformed after they have cured. They are hard, glass-like polymer materials that are firmly cross-linked in three dimensions via main chemical valence bonds. Thermosets do not have a softening range. The material retains its strength even at high temperatures and has high heat resistance. Thermosets are characterized by their hardness and rigidity. The low coefficient of expansion brings high dimensional stability. In contrast to thermoplastics, there is no creep behavior under temperature and pressure loads. This is a key criterion for the application in a radial shaft seal.

Compared to stainless steel, thermosets are much more brittle, which poses a number of challenges when processing them as support parts in elastomer injection molding to not damage the parts.

Thermosets made from synthetic resins are among the first industrially produced plastics. Their oldest representative is Bakelite, which was discovered in 1909. Originally, they could only be produced in compression molds from their precursors (e.g. phenoplastics from phenolic resins) and were therefore also named as compression molding compounds, in contrast to thermoplastics, which were named as injection molding compounds. It has only been possible to produce thermosets by injection molding since the mid-1960s. Nowadays, thermosets are processed by numerous methods. The focus is always on the high thermomechanical strength and the low specific part weight compared to metal.

3.2 Pre-processing of the Support parts

In addition to corrosion protection, thermoset offers another advantage instead of stainless steel. It is very complex to achieve a good rubber-metal adhesion with a stainless steel part. The steel parts loaded with drawing oil must be pretreated in several individual process steps. Only then can a suitable binder/bonding system be applied.

For thermoset components, the pretreatment process is not necessary and is eliminated completely. Just as for the stainless steel component, a binder is also required for the thermoset component. This binder must ensure a stable bond between the substrate and the elastomer used. Depending on the requirements of the application, it is possible to use a single-layer or multilayer bonding system.

Exceptions are elastomer materials that function with a binder based on phenolic resin. For these elastomers, direct adhesion is possible.

In the first step, a wide variety of binders were tested on adhesion test specimens. As a test specimen, a rubber button is pressed between two discs treated with adhesive. These are torn in the tensile testing machine and evaluated via the determined separating force and the optical crack pattern. In the case of test specimens with poor adhesion, detachment can be seen in the interface area. This can occur either between the thermoset and the adhesive, in the adhesive itself, or between the adhesive and the elastomer. With good adhesion, the test specimen tears completely in the elastomer matrix.

4 Designing a Thermoset Support Part for Radial Shaft Seals

A number of points must be taken into account in designing of plastic components. The design of a support part made by steel cannot be copied without further action.

4.1 Design Guidelines for Thermoset Components

Support parts made of steel are manufactured in a forming process. The production of a support part made of plastic, on the other hand, is carried out by means of injection molding. Therefore, individual shaping is possible.

Thermosets are brittle materials, so tensile stress should be avoided. The permissible compressive stress, on the other hand, is significantly greater. This must be taken into account when designing the overlaps. Comparable overlaps between the housing and the outer diameter of the support part as with the steel part can lead to rupture of the thermoset support part during assembly. Similarly, special attention must be paid in the design to the pinch-off points where the rubber is stopped in the vulcanization process. Here, as well, the overlap due to the surface area load on the thermoset support part caused by the pinch-off must be taken into account. If the surface area load is too large, there is a risk of cracks in the thermoset component at these points and thus of the component breaking.

It is therefore advisable to provide stiffening ribs at heavily stressed zones in the component in order to reduce the load in these zones and thus minimize the risk of overstressing the component.

In addition, it is not possible to design thermoset components with wall thicknesses lower than 1 mm. A minimum cross-section of 2 mm in the component is recommended. Furthermore, sharp transitions should be avoided and radii of at least 1 mm, preferably 1,5 mm, should be provided. [2], [3]

4.2 Design of the Thermoset Support Part

The design of the support part was computer-aided using FEA.

In the first step, the thermoset support part was designed based on the existing geometry of the steel part (C-profile). The basic design guidelines for thermoset components were taken into account [1]. In particular, a cross-section of the support part smaller than 1 mm, as is the case with standard radial shaft seals, is not feasible. Subsequently, in the radial shaft seal, the stainless steel support part was replaced by the thermoset one.

Based on this new geometry of the radial shaft seal, the vulcanization mold was designed according to current standards. When the vulcanization mold is closed, the support part will be in contact with the cams in the mold to hold it in position. In addition, pinch-off edges are located in the vulcanization mold to stop the rubber flow at this point.

In the next step, the force distribution in the thermoset component was determined using FEA and the critical points was identified. Based on these results and the comparison with the permissible characteristic values for the stressing of the component, the component was optimized in several iteration loops.

The stresses that occurred were reduced by design changes to the thermoset component and by changes to the pinch-off edges in the vulcanization mold.

In any optimization, the flow behavior in the injection mold must be considered during the production of the thermoset component in order to obtain a homogeneous filling. The rubber flow in the vulcanization mold during the manufacture of the radial shaft seal must also be taken into account in order to prevent flow defects and air inclusions etc.

Figure 2 shows the optimized thermoset support part.

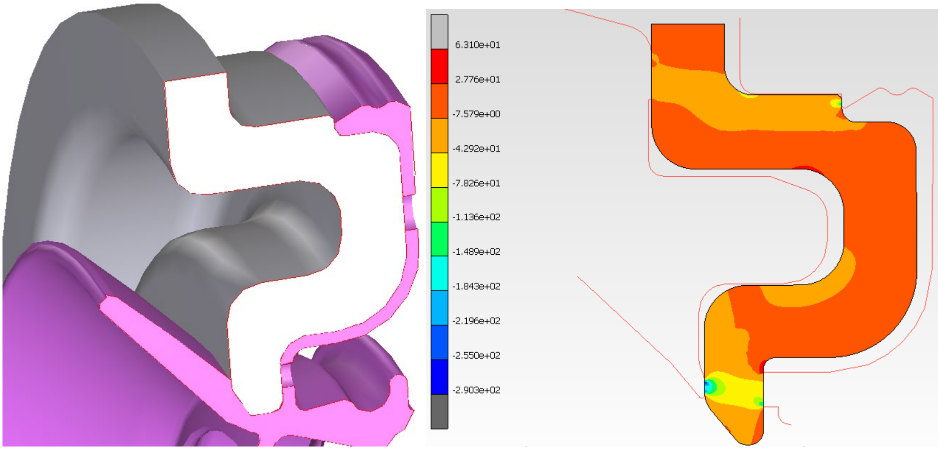

Figure 2: 3D Model (left) and FEA result (right) of an optimized thermoset support part [4]

5 Production of Thermoset Support Parts

The production of a thermoset radial shaft seal takes place in four to five manufacturing steps.

5.1 Step 1: Production of Thermoset Support part in Injection Molding Process

In the thermoset injection molding process, the raw material is injected into a corresponding mold via an injection unit with a special screw that generates as little shear heat as possible, where it then crosslinks under temperature and pressure. In contrast to thermoplastic injection molding, the mold is heated to the appropriate crosslinking temperature of the material, similar to elastomer injection molding. Sprues must then be removed mechanically from the part.

5.2 Step 2: Postcuring of the Thermoset Support Part

The thermoset part acquires its final material properties only after a subsequent postcuring process. This is carried out over several hours according to a temperature curve that must be maintained exactly. This curing process has a significant influence on the brittleness of the material.

5.3 Step 3: Surface Treatment

Depending on the type of elastomer used for the oil seal, the thermoset support part must be coated with a primer.

5.4 Step 4: Elastomer Injection Molding

In the elastomer injection molding process, the thermoset support part is placed in an elastomer injection mold and overmolded with elastomer, which then crosslinks under temperature and pressure. During crosslinking of the elastomer, a chemical bonding is also formed between the thermoset support part and the elastomer. The challenge here compared to the use of metal support parts is mainly the mold design in the areas where the elastomer needs to be stopped. The brittle behavior of the thermoset leads to cracks and breakouts if this is not taken into account accordingly.

5.5 Step 5: Postcuring of the Elastomer

In most cases (depending on the material used), the elastomer acquires its final properties after a postcuring process lasting several hours at a corresponding temperature.

6 Tests with the Thermoset Radial Shaft Seals

6.1 Vulcanization

The greatest stresses in the component occur at the pinch-off edges. After all optimization measures, these were within the permissible range. The height of the pinch-off edges was therefore selected analogously to the pinch-off for support parts made of (stainless) steel. When the radial shaft seals were analyzed after manufacture, cracks were visible in the thermoset support part. These cracks, starting from the pinch-off edges, go deep into the component in some cases. As a result, the support part could break when the radial shaft seal is installed in a bore due to the necessary overlap.

To avoid cracks in the area of the pinch-off edges in the thermoset component, the penetration depth of the pinch-off edge was reduced to a minimum.

Despite the reduction of the penetration depth, the rubber flow could still be stopped during the vulcanization of the radial shaft seal. Cracks in the thermoset component could also be avoided.

6.2 Adhesion Test

After producing initial sample parts with a functioning binder, Adhesion evaluation is carried out on the part using a pair of pliers. The pliers are used to pull on the soft component and tear it off. The crack surface is evaluated optically, according to the same principle as for the adhesion test specimens. Figure 3 shows the results of the adhesion test. On the left side a radial shaft seal with good adhesion between the elastomer and the thermoset. The right picture shows the blank thermoset surface with a poor adhesion after the pincer test.

Figure 3: Adhesion test result: good adhesion (left) and poor adhesion (right) [4]

6.3 Durability Tests on the Test Rig

The suitability of the thermoset support parts for radial shaft seals was tested in endurance tests. Three radial shaft seals each were tested with the stainless steel support part and the thermoset support part. High-temperature endurance tests were carried out for 240 h and 1000 h, respectively.

None of the radial shaft seals examined showed any leakage during the test period. In the subsequent analysis of the seals, neither oil carbon formation at the sealing edges nor increased wear could be detected. The wear of all radial shaft seals is comparable. No differences can be seen on the radial shaft seals with the different support parts.

In addition, sufficient holding force of the radial shaft seals in the bore was present after the endurance tests. No creep could be detected.

6.3.1 Storage Tests

Radial shaft seals were aged in a test medium. The sample components made of a fluoroelastomer were aged at 150°C in current gear oil. After a test period of 1000 hours, the components were removed and tested for adhesion. Intermediate tests were carried out after 168 hours and 500 hours. Over the complete test period, no deterioration in adhesion between the thermoset and elastomer was detected.

Figure 4 shows the result of the adhesion test at the end of the test period.

Figure 4: Adhesion test after 1000 h storage in gear oil at 150° [4]

6.4 Influence of Temperature on the Thermoset Support Parts

The radial shaft seals are exposed to large temperature fluctuations during operation. At any temperature, the radial shaft seal must fulfill its function. In addition to reliable sealing to the rotating shaft, the secure seating of the seal in the housing must be ensured. Particular attention must be paid to this when using partially rubberized radial shaft seals. In the case of steel support parts, thermal expansion can be easily covered by the choice of tolerances. With thermoplastics, creep of the material at high temperatures has been observed. Thermosets, on the other hand, do not tend to creep. Nevertheless, it should be checked, especially since the overlaps between the support part of the radial shaft seal and the housing bore are smaller than for stainless steel support parts.

For this purpose, a temperature cycling test was carried out over 168 hours (7 days).

The radial shaft seals were measured on the outside diameter and test rings were made to match the individual radial shaft seals in order to realize a minimum, nominal and maximum overlap.

The radial shaft seals were pressed into the test rings at room temperature using a servo press with force-displacement monitoring, and the press-in forces were documented.

The test specimens were then stored in a climatic chamber for 24 hours each at 150°C and -40°C. At the end of the test cycle, the radial shaft seals were pressed out at 150°C to obtain the holding force at high temperature.

In all test specimens, there is sufficient holding force of the radial shaft seal in the bore.

7 Summary

Radial shaft seals with a steel support part cannot be used in corrosive environments. Therefore, corrosion-resistant materials must be used. Nowadays, radial shaft seals with a stainless steel support part are usually used in this case.

These are comparatively expensive, firstly because of the higher material price and secondly because of the process involved.

It has been shown that radial shaft seals with a thermoset support part are an alternative. In addition to a cost saving in manufacturing costs (material and process costs), a weight saving of around 30% could be achieved.

Other areas of application can be radial shaft seals with a large diameter. The production of support parts with very large diameters (> 150 mm) is not economically feasible with a conventional stamping and deep-drawing process, since the material loss due to the large bore diameter is greater than the material input. At this point, radial shaft seals with a thermoset support part can be an economical alternative. In these cases, the support parts are not produced by injection molding, as is the case with smaller diameters, but by compression molding.

8 References

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9 Authors

KACO GmbH + Co. KG

Industriestraße 19, 74912 Kirchardt, Germany

Dr.-Ing. Cornelius Fehrenbacher, ORCID 0000-0002-8297-0603, cornelius.fehrenbacher@kaco.de

Simon Kayser, Dipl.-Ing. (BA), simon.kayser@kaco.de

Simon Haaf, B. Eng., simon.haaf@kaco.de