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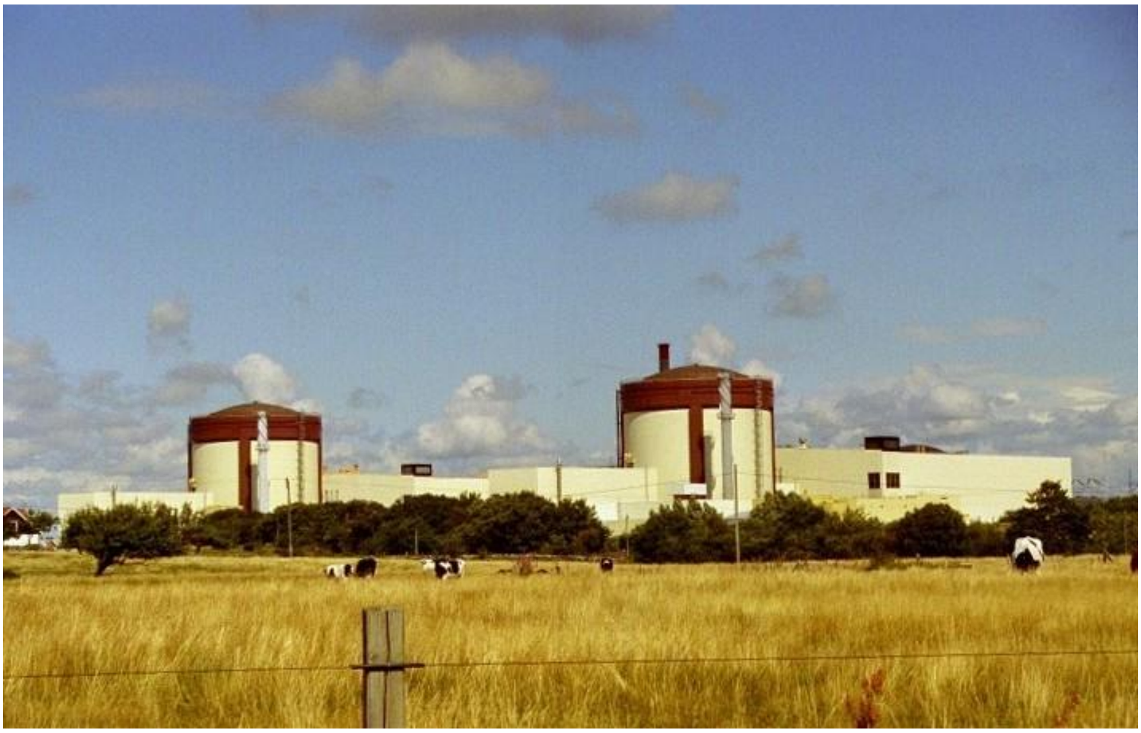

Setting up safety margins for O-rings 2022

Anna Bondeson, David Kiefer

RISE Report : P114242.AP01DP01.A02

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Abstract

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A set of three different EPDM materials are compared using compression set, leak testing and stress relaxation under compression. The top-level material, nuclear grade 1 EPDM shows the highest performance and longest lifetime, followed by industrial EPDM material grade 2. Instead, a commercial grade 3 shows unsatisfactory performance and lifetime for use in NPPs. Grade 2 is expected to represent the average for O-rings used in NPPs as not always nuclear grade 1 may be used. The report provides evidence for the importance of choosing appropriate EPDM material and setting safety margins accordingly.

Key words: O-rings, EPDM, compression set, stress relaxation, aging

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Content

1 Background and aim

This task aimed to attain usage lifetimes for rubber O-rings which are present in critical functional capacities in Nuclear Powerplants (NPPs). SAMPO 2019 focused upon verification of COMRADE results and was successful in doing so. SAMPO Task 1.3 focused on utilising model materials to attain material failure, further verifying methods, and better representing average power plant material.

Rubber O-rings can be found in some critical components such as pumps and pipe connections. If these pipes were to fail, a so-called 'loss of coolant accident' (LOCA) could occur. This could obviously be disastrous to the Powerplant and surroundings.

2 Project plan

The project plan is summarised below:

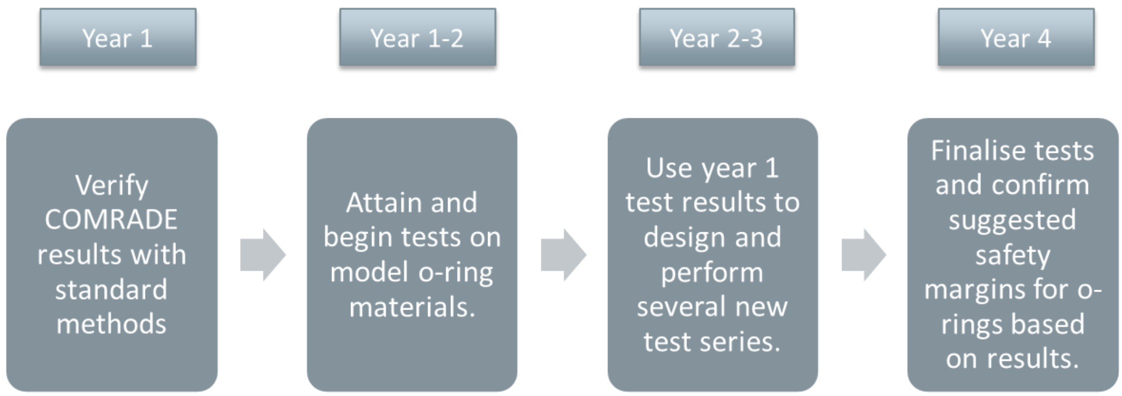

Figure 1. Plan for SAMPO Task 1.3

3 Methods

Materials

Ethylene Propylene Diene Monomer (EPDM) was supplied by James Walker Ltd. Three grades were used during this project listed in Table 1. Grade 1 has previously been used in COMRADE and SAMPO 2019, and grade 2 is a bespoke material fabricated from James Walker for SAMPO. Grade 3 EPDM is an off-the-shelf consumer grade EPDM.

Table 1. EPDM grades investigated in project

Grade	**Type**	**Number**
1	Nuclear	LR9444
2	Industrial	LR9678
3	Consumer, stabilized	NA

Compression set

Compression set test was performed on standard test specimen of cylindrical shape with a diameter 13 ± 0.1 mm and a thickness 5,6 ± 0,2 mmm according to ISO 815-1. The standard test specimens were cut from the rubber sheets with a standard cutting mould. Three test specimens were placed between the plates of one compression device with the spacers with a height of 1.4 mm. The bolts were tightened so that the percentage of the compression was 75% of the original thickness. In total, three assembled compression devices were papered for EPDM and nitrile sample, respectively.

The compression was performed in air.

The compression set was calculated as:

$$\frac{h_0 - h_1}{h_0 - h_s} \times 100\% \qquad (1)$$

where h_0, h_1 and h_s is the initial thickness of test specimen, the thickness of the test specimen after recovery, and height of the spacer, respectively.

Leak test rigs had O-rings compressed to approximately 20 % and calculated as above.

Stress-relaxation

Testing was performed in duplicate for each temperature (90, 120, 140 °C for grade 1 and 2; 70, 80, 90 °C for grade 3). The samples were compressed initially to 75 % and the force was measured continuously until 50 % of initial force was reached or until the experiment was terminated for time reasons.

4 Results and discussion

Compression set and leak test

The initial work focused on the overall verification of the data attained in the prior project COMRADE, i.e. the method used in COMRADE (measurement on O-rings), and the standardised method for measuring compression set (cylindrical cut-outs from a sheet). This experimentation showed that the data is reliable in both circumstances. Further on the compression set of a model material provided by James Walker (JW), at a level which has been described by JW as 6/10 (denoted grade 2 material), where the material (grade 1) measured previously is considered at top levels, 9-10/10. The purpose of this was two-fold. Firstly, we wanted to assure that a material could reach failure, unlike the prior COMRADE project, where the top-level material was used, and failure was rare – thus casting into doubt at time whether the experiment was at fault, or if the material was simply very high quality. Secondly, it is unknown whether power plants will at all times use top level material, so experimentation upon a more realistic, yet still proficient material, was deemed wise.

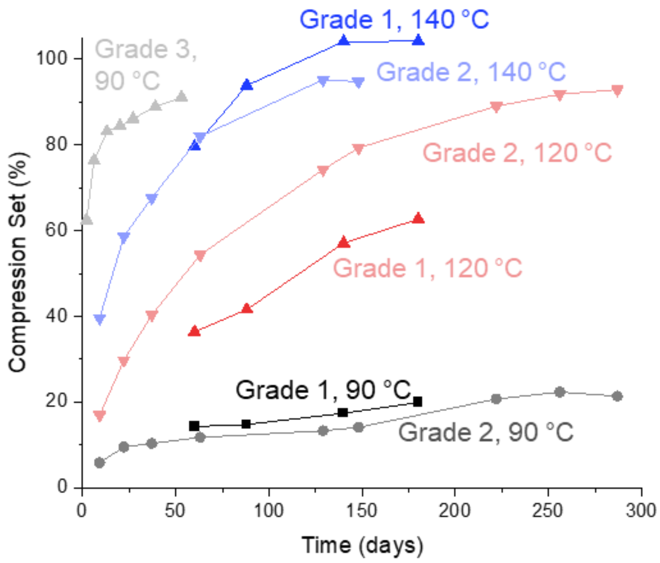

Figure 2. Comparison of compression set of EPDM grades 1 and 2 at 90 120 and 140 °C, as well as grade one at 90 °C. An activation energy of ~100 and ~103 kJ/mol was estimated by time-temperature superposion for grade 1 and 2, respectively.

Compression set of grade 1 EPDM material previously measured in the COMRADE project and compression set of grade 2 material are depicted in Figure 2. At 120 °C one can observe the grade 2 material performing worse than the top-level grade 1 material, with, as far as the data goes, ~60 vs. ~85 % respectively. Therefore, it is expected that grade 2 material will likely reach failure even during leak testing despite similar activation energies. The activation energy for grade 1 material is likely underestimated as only aging at 140 °C has reached the end-of-life criteria of 80 % compression set.

Experimentation moved on to compression set within leak test rigs, having verified compression in this manor is appropriate. During a symposium summarising 2019 data for stakeholders, it was brought to our attention that the 'old' test rigs may not be deemed satisfactory enough for duplicating the environment that O-rings find themselves in inside a power plant. Thus, the rigs were redesigned as per Figure 3, where one can see a groove has been cut out for the ring to sit within, compared to the ‘old’ test rig with much more empty space in the centre.

Figure 3. O-ring test rigs. Left: old test rig from COMRADE. Right: new test rig re-designed for SAMPO.

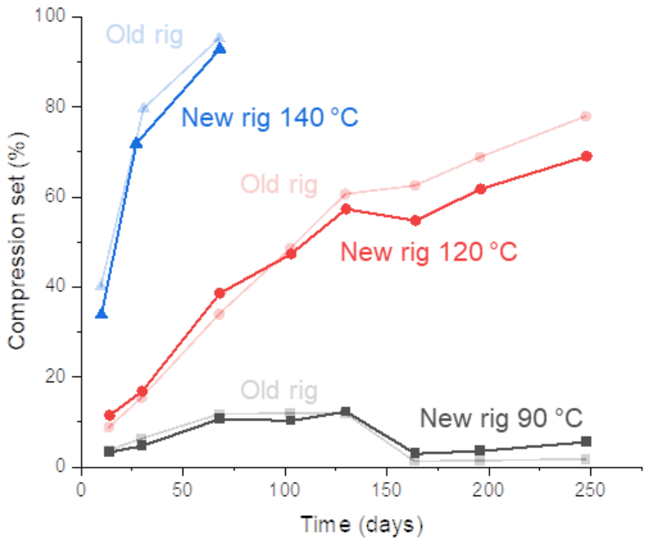

Figure 4. Compression set of grade 2 EPDM O-rings with ‘old’ and ‘new’ redesigned test rigs at 90, 120 and 140 °C.

Compression set measurements have been performed for EPDM material within both leak test rig designs, and the data can be found in Figure 4. The data follows the expected trend, with raising temperature, a higher compression set is attained. Leak testing has been performed at several time points, no leaks were detected except for the ‘old’ rig, at 140 °C. For the first of the two time points a leak was detected under low pressure (~5 Bar) and once the operating pressure for the test was attained (~60 Bar), the leak was no longer detected. It could be deduced that the higher pressure allowed the O-ring to attain a tighter seal within the test rig. For the last point at 140 °C, the rig was leaking continuously and could not hold any higher pressure. No leak was detected for series at 120 and 90 °C.

Both grade 1 and 2 materials are high quality EPDM grades which is clearly visible in the previous results. Since it cannot be excluded that besides special high quality grade also lower quality material may be used for O-rings in nuclear power plants a third grade of lower quality EPDM was added to the analysis. Since it was not known how quickly and at what temperatures this grade would show changes in its compression set a first set of data at 50, 90 and 120 °C was collected. No significant compression set at 50 °C was recorded while at 120 °C measurements turned out to be likely difficult due to diffusion limited oxidation. However, the series at 90 °C showed an expected trend of continuously rising compression set with aging time (Figure 5a). A second series at 70, 80, and 90 C° was recorded (Figure 5b). Aging of grade 1 affects the compression set of grade 3 much more significantly than the other grades as can be seen in Figure 2 when comparing the data for 90 °C. The sample reaches failure, i.e. compression set of 80 % after only about 15 days. Instead, both grade 2 and 3 do not reach failure within the experimental time.

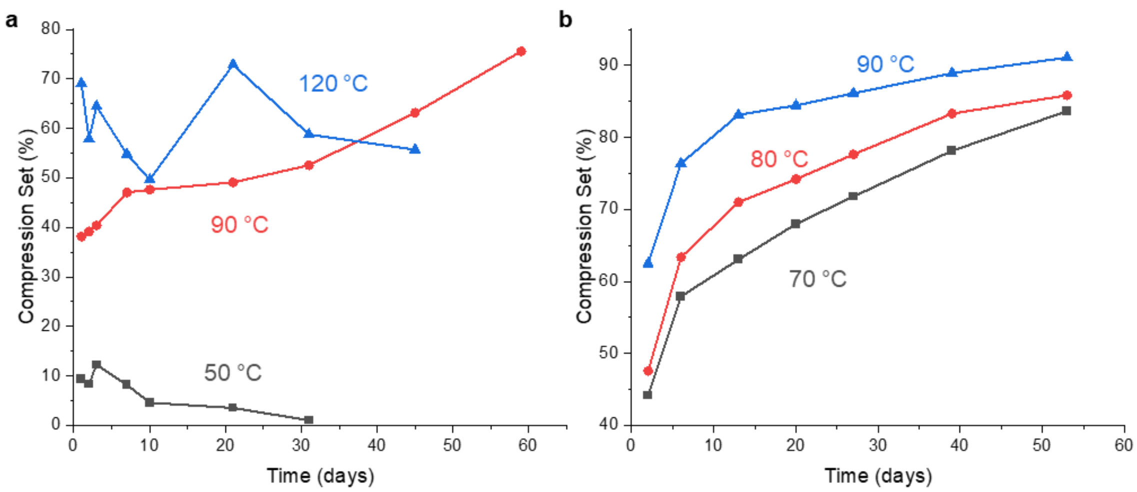

Figure 5. (a) Pre-evaluation of compression set of grade 3 material after aging at 50, 90, and 120 °C. (b) Compression set of grade 3 material after aging at 70, 80, and 90 °C. We estimate an activation energy E_a of ~75 kJ/mol.

Stress-strain characteristic in compression (stress relaxation)

Stress relaxation was conducted to determine failure (F_{50}, 50% compression) for all EPDM material grades (Figure 6 and Table 2). For grade 1 and 2 samples were aged under compression at 90, 120 and 140 °C. As expected, aging at 140 °C resulted in the fastest decay of the compression force and both samples reached failure after 45 and 17 days for grade 1 and grade 2, respectively. Instead, at 120 °C grade 2 reached failure after 112 days. Grade 1 did not reach failure within the experimental time. Instead, the time to failure was extrapolated to about 193 days. Neither grade 1 nor grade 2 reached failure within the experimental time.

The stress relaxation of grade 3 was measured at 80, 90 and 100 °C. To compare this grade with the other two grades the expected time to failure at 120 and 140 °C was extrapolated to 0.3 and 0.1 days, respectively, using activation energy. Thus grade 3 shows significantly faster degradation also during stress relaxation as compared with grade 2 and 3.

Table 2. Time for F_{50}, failure, at 50% compression from two sample average. ([a]Material was aged at this temperature but did not reach F_{50} within the time of the experiment. [b] Calculated value. [c] One cylindrical sample and one O-ring were used for analysis.)

Temperature	**Grade 1**	**Grade 2**	**Grade 3**
	Time to F_{50} [days]		
80 °C	-	-	9,9
90 °C	-[a]	-[a]	3.7
100 °C	-	-	1.6
120 °C	193[a][b]	112	0.3[b]
140 °C	45[c]	19	0.1[b]

Overall, the industrial EPDM rubber (grade 2) performs somewhat below that of the nuclear EPDM rubber (grade 1). Both grades should be suitable to be used in NPP's with grade 2 requiring somewhat higher exchange intervals. Instead, a commercial EPDM rubber (grade 3) should not be used due to its low performance. The current exchange intervals for O-rings in NPP's are not known to the authors. However, based on exchange intervals of other components they are likely to be within the range of 3-8 years. Depending on the environment and temperature EPDM O-rings of similar quality to grade 1 and 2 the exchange intervals may be adjusted depending on what EPDM O-rings are being used. Safety margins for grade 1 may be somewhat larger than for grade 2 O-rings.

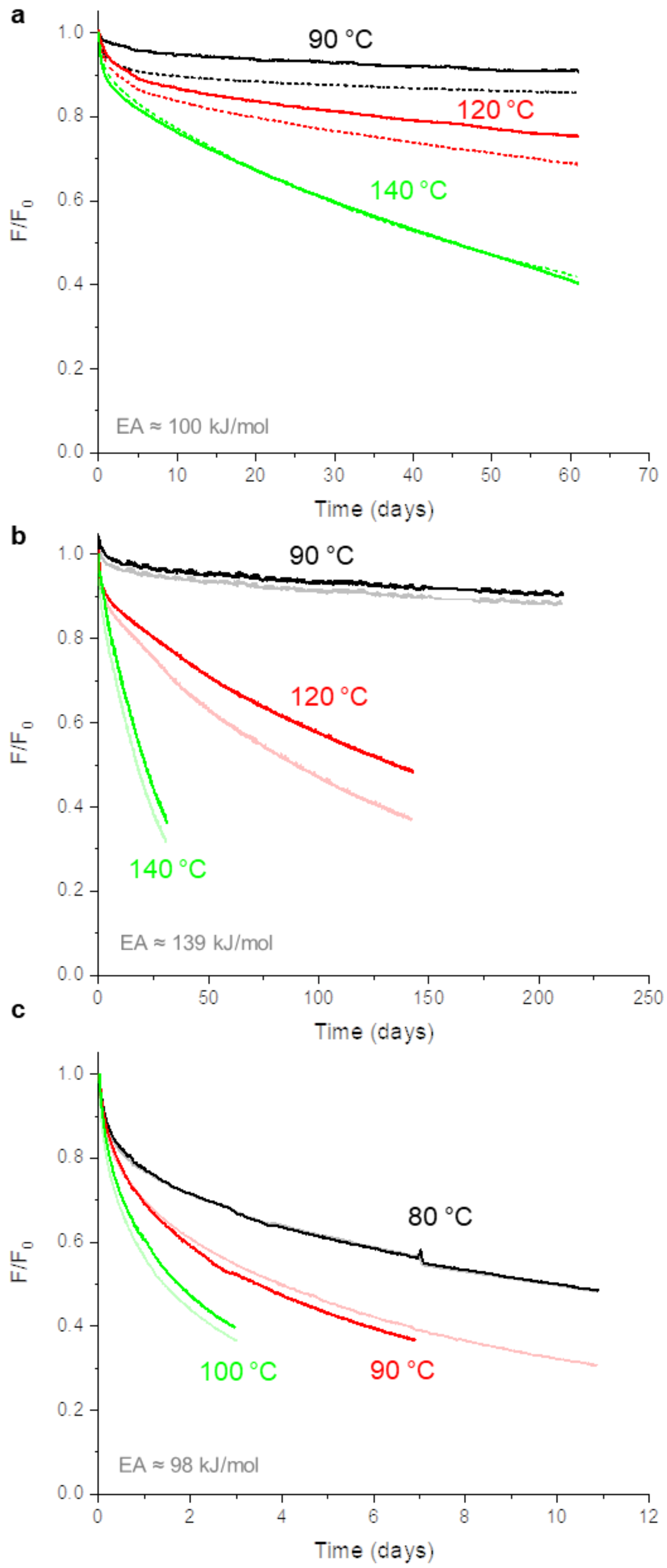

Figure 6. Stress relaxation of (a) grade 1, (b) grade 2 and (c) grade 3 EPDM material. For grade 1: Bold and dashed lines correspond to cylindrical test pieces and O-rings, respectively. For grade 2 and 3 tests were performed twice with cylindrical test pieces. Note, that the estimated activation energies for grade 1 and 2 may be somewhat erroneous since not all curves reached failure.

5 Conclusions

Three different EPDM grades for O-rings were tested using compression set and stress relaxation. As expected, the top-level grade 1 for nuclear applications performed best overall, followed by grade 2 for industrial applications. Instead, the commercial grade 3 performed significantly lower. Leak test performed showed that both grades 1 and 2 do not leak unless aged at high temperature (140°) for a long duration. Grade 2 is likely to represent the average of O-rings used in NPPs and despite a somewhat lower performance may be sufficient with suitable service intervals. Overall, it is shown that three different EPDM grades have significantly different lifetimes and thus care should be taken when choosing EPDM components for safety critical infrastructure like NPPs.

6 References

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