BIOSCIENCE AND MATERIALS
CHEMISTRY AND MATERIALS

WP1 SAMPO Task 1.3
Setting up safety margins for O-rings 2020

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RISE Report : 9P03241-02

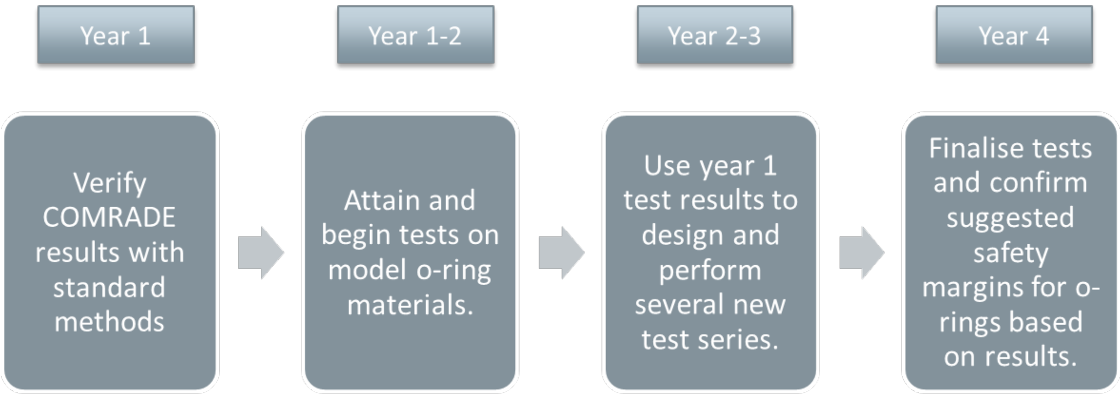
Background and aim

This task primarily aims 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 2020 focuses 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.

Project plan

The project plan can be best summarised as followed:



Testing is predominantly on schedule. Due to the ongoing SARS-CoV-2 pandemic some experiments have less data points than planned. However all experiments are ongoing, yet valuable insight can still be attained from the data gathered so far.

Experimental

Materials

Ethylene Propylene Diene Monomer (EPDM) was supplied by James Walker Ltd. Two grades are present and defined here as ‘top-level’, which is the same material as used in COMRADE and SAMPO 2019, and ‘bad’ which is a bespoke material fabricated from James Walker for SAMPO.

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). The samples were compressed initially to 75 % and the force was measured continuously until 50 % of initial force was reached (test of samples in 90 °C was discontinued before reaching 50 %).

Results and discussion

Compression set and leak test

Previous work in 2019 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. In Task 1.3 2020, work has been undertaken on compression set of a model material provided by James Walker (JW), at a level which has been described by JW as 6/10 (denoted 'bad' material), where the material measured in SAMPO 2019 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 just simply that good. 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 1 depicts a result from 2019 (120 °C EPDM) compared with 2020 results upon this model 'bad' material. For the comparable 120 °C one can observe the 'bad' performing worse than the top-level material, with, as far as the data goes, ~60 vs. ~85 % respectively. This is a good sign, and the data follows the trend that we would expect.

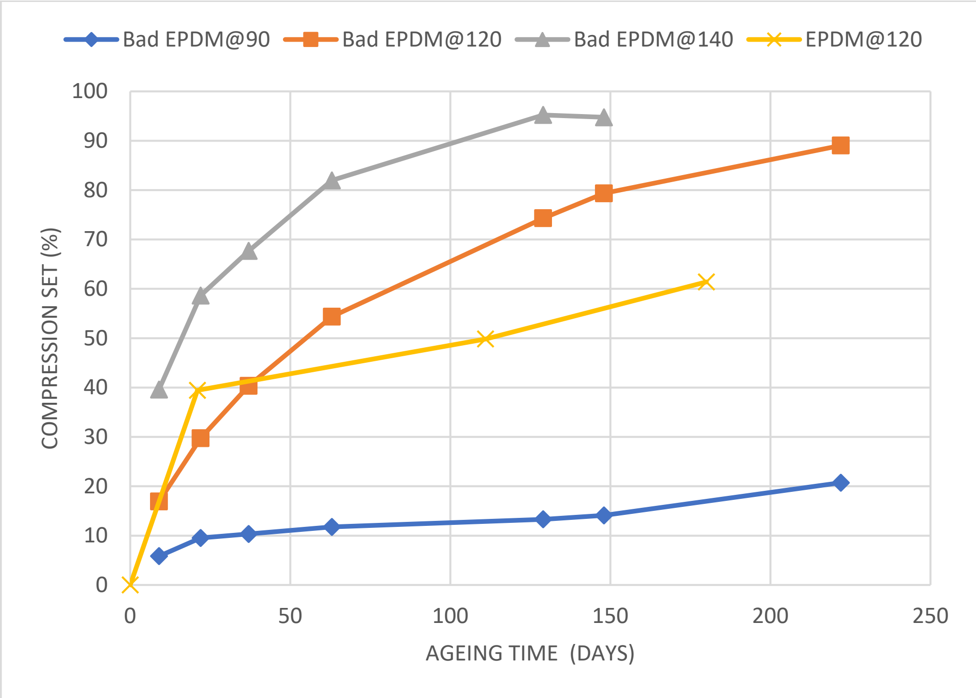


Figure 1. Data of compression set for model 'bad' material, and one set of data of top-level material at 120 °C for comparison.

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

Compression set is underway for EPDM material within both leak test rig designs, and the data can be found in figure 3. The data follows the expected trend, with raising temperature, a higher compression set is attained. The testing will continue to attain more data points. Note that leak testing has been performed at the 2 latter time points as per figure 3, no leaks were detected except for the 'old' rig, at 140 °C. For the first of the two time points he 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, the rig was leaking continuously and could not hold any higher pressure.

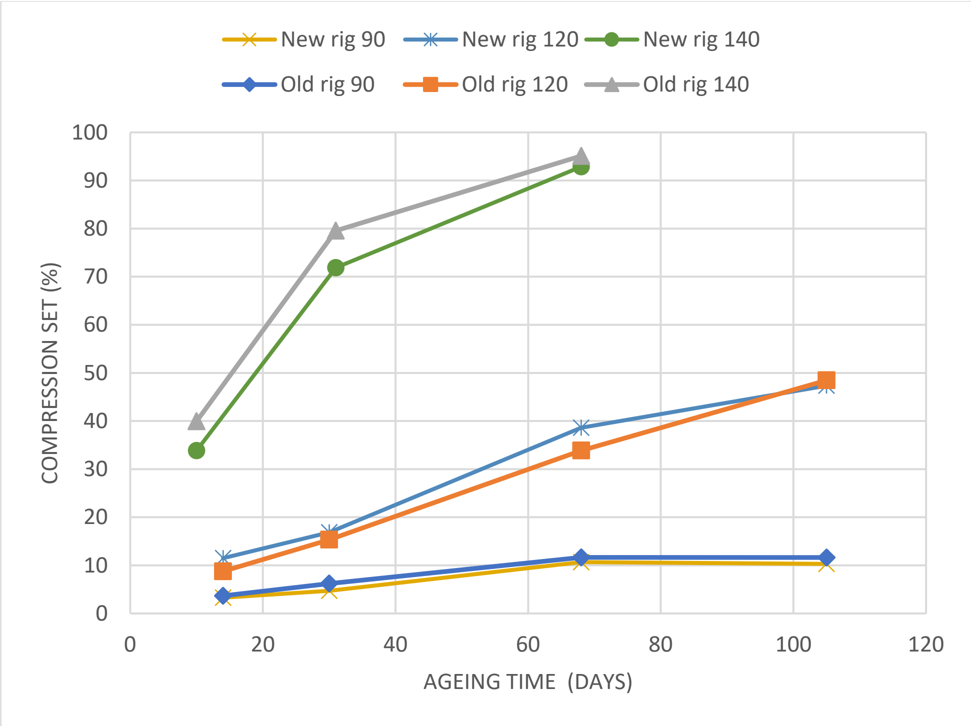


Figure 3. Compression set of model 'bad' EPDM material within test rigs, both 'old' and redesigned.

Stress-relaxation

Stress relaxation was conducted to determine failure (F_{50}, 50% compression) for the model 'bad' material, EPDM. The values of which can be found in table 1.

Temperature	Sample no	Time to F_{50} [days]
120 °C	1	89
	2	134
140 °C	1	19
	2	23

Table 1. EPDM material: time for F_{50}, failure, at 50% compression.

The values follow an expected trend that at higher temperature the material fails sooner. It should be noted that the EPDM being run at 90 °C has reached only ~90% compression as of 150 days (Figure 4). Top-level EPDM rubber, as determined in COMRADE, gave for 140 °C an F_{50} of 49 days. Whereas, for 120 °C, compression reached 75 % after 58 days.

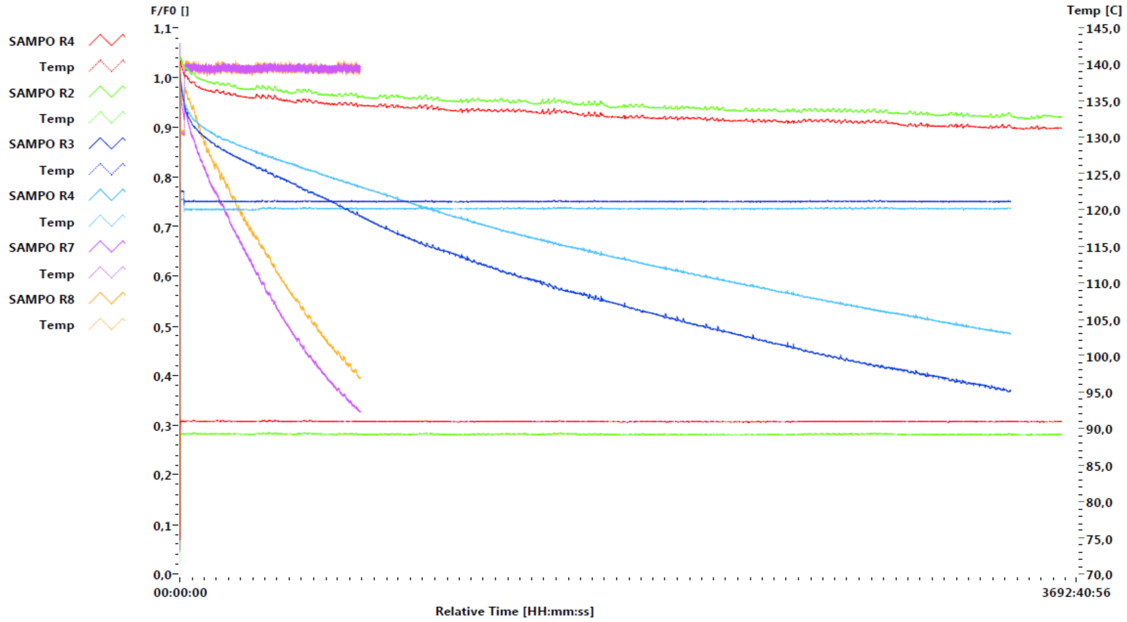


Figure 4. Stress-relaxation data for EPDM model 'bad' material. Red and green: measurements at 90 °C. Light blue and dark blue: measurements at 120 °C. Orange and purple: measurements at 140 °C.

Conclusions

1. Expected trends are present for all data – higher temperature leads to greater/faster failure.
2. Model 'bad' material performs worse, as expected, than the top-level material from SAMPO 2019 and COMRADE before.
3. The model 'bad' material is important as it better represents the average material in use at a power plant. Additionally, allowing for shorter test times whilst working with similar degradation mechanisms.
4. The new rig seems to hold against leakage longer than the old rig.
5. Perhaps more experimentation should be performed on commercial grade material, which JW denotes as being a 2-3/10 level material. Stress-relaxation particularly would be useful to determine key aging points in the material. This could lead to the use of a material that allows for shorter testing time, which ties in with WP2 requirements.

References

[1] Conference Polymers in nuclear applications 2019, November 27-28, Fortum head office, Keilalahdentie 2-4 (CD-building), Espoo, Finland.

[2] Sipilä K, Vaari Jukka, Jansson A, Bondeson A. Condition monitoring, thermal and radiation degradation of polymers inside NPP containments (COMRADE), Report for COMRADE project.