RESEARCH REPORT

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Synergistic effects of radiation and heat on EPDM and CSM rubber

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Summary

Two common rubber materials that are used in Finnish nuclear power plants, EPDM and CSM, were exposed to different amounts of heat and gamma radiation in order to study their synergistic effects to material degradation. The harshest ageing conditions were characteristic to simulated DBA conditions without the element of hot steam.

It was noted that elongation at break is more sensitive to detect material degradation than tensile strength or hardness. Based on the elongation at break results and OIT measurements, EPDM seemed to be susceptible to synergistic effects of gamma radiation and heat. Increase in temperature seemed to hinder the degradation under the simultaneous exposure to gamma radiation when the absorbed dose was 228 kGy. This was somewhat opposite what was expected and previously reported in the literature. It seems that different ingredients used in the EPDM compounds may have an effect to their behaviour under simultaneous exposure to gamma radiation and heat.

For the CSM samples studied the effect was opposite. Increase in temperature also increased the degradation under simultaneous gamma radiation. The overall trend was that CSM was more susceptible to degradation than EPDM in the ageing environments. It was confirmed that OIT measurements for CSM are impractical.

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Preface

This study was made as part of the project “Condition Monitoring, Thermal and Radiation Degradation of Polymers inside NPP Containments (COMRADE)” executed within the SAFIR 2018 research program. The purpose of this study was to clarify the effects of radiation, heat and their synergies to the degradation of two common polymer based materials that are used in Nordic nuclear power plants. Finnish State Nuclear Waste Management Fund (VYR) and VTT Technical Research Centre of Finland Ltd are acknowledged for funding this work.

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Contents

1. Introduction

The Finnish radiation safety authority (STUK) obligates nuclear power plant (NPP) operators to manage different ageing mechanism on materials used inside NPP containments that have safety relevance. The ageing management guidelines are stated in the YVL guidelines provided by STUK (YVL A.8 304). Qualification and validation of components before their use is an essential part of ageing management. For polymer materials qualification is usually performed according to the regulator instructions. These instructions include YVL E7 (cables), YVL 4.1 & 4.2 (paint coatings), YVL E.9 (pump sealants) and YVL B.5 (greases and lubricants) to name few examples. These YVL guidelines provide general guidelines that should be followed during qualification. In order to have more detailed description on the qualification process, proper standards should be followed which provide detailed information on accelerated ageing parameters etc. Such standards include STUK-YTO TR-210 for paint coatings and IEEE 383 for safety class E1 cables.

During a qualification, objective proof is created that will ensure that the qualified component or material will endure in its designed use. Thus qualification process should simulate or correspond to the real service environment of the component in order to achieve proper validation. One stage in qualification process of a polymer component is the accelerated ageing which should yield in similar degradation in the material that it will experience in its designed use. Typical accelerated ageing procedure simulates the realistic conditions where first the polymer experiences the ageing in the normal conditions for the designed life time e.g. ageing at elevated temperature that would correspond 40 or 60 years of normal service life at defined service temperature. After the accelerated thermal ageing polymer is irradiated with a total absorbed dose that corresponds the dose that is absorbed during normal service life and followed by a design basis accident (DBA) testing (exposure to high temperature, steam etc.). However, it is not always possible to combine DBA testing and irradiation which will cause that irradiation and thermal ageing components of the DBA test are conducted sequentially. The component performance can be monitored as “online” during the sequential ageing programme or after the accelerated ageing treatments and exposure to simulated DBA conditions, a pre-defined material property of the polymer is tested and evaluated whether it fulfils the defined acceptance criteria.

For polymers it is known that heat can induce changes in polymer structure (melting and rearranging of crystalline regions) and applying simultaneous exposure to ionizing radiation can effect to the bonds between and within the polymer chains. Simultaneous exposure to heat and ionizing radiation is known to increase crosslinking of such polymers that have sufficient amount of amorphous structure and a low glass transition temperature. Competing reaction with crosslinking is chain scission and it is related to oxidation. Oxygen molecules that are diffused into the polymer matrix react with different radicals formed by the ionizing radiation forming peroxide radicals. These peroxide radicals react with polymer chains containing hydrogen atoms causing more unstable structures and hydro peroxides which will decay with time and cause additional degradation [Makuuchi et al. 2011]. On the other hand, when exposure only to elevated temperatures is considered, accelerated oxidation in air atmosphere is observed. Additional complicating effects to polymer degradation are caused by the additional ingredients, such as plasticiser, fillers, antioxidants etc. that are typically used in commercial polymer blends.

In this work two commonly used rubber types in Finnish NPPs, EPDM (ethylene propylene diene) and CSM (chlorosulphonated polyethylene) are aged at different ageing environments and their degradation and any synergistic effects induced by heat and gamma radiation are studied. Previously Ito [Ito, 2007] has been conducted some work with different EPDM compounds and reported synergistic effects of heat and gamma radiation on the degradation. Also Lay [Lay, 2013] observed that the ageing mechanism of EPDM seems to change as thermal ageing time is increased and absorbed dose is 250 kGy or more. CSM has been previously studied by Gillen et al. [Gillen et al. 2006] and Spång [Spång 1997].

2. Goal

In this study the synergistic effects of ionizing radiation and heat are studied on two commonly used Nordic NPP materials EPDM (ethylene propylene diene) rubber and Liplalon cable jacketing manufactured from CSM (chlorosulphonated polyethylene) rubber.

3. Methods

The studied materials included peroxide cured EPDM rubber manufactured by James Walker and CSM cable jacket material (tradename Hypalon, cable tradename Lipalon) provided from storage of the Finnish nuclear power company TVO. The EDPM samples were stamped out of two millimetre sheet delivered by the manufacturer and CSM samples were prepared from the jacket of the cable delivered by TVO. An example of each of the samples is shown in Figure 1.

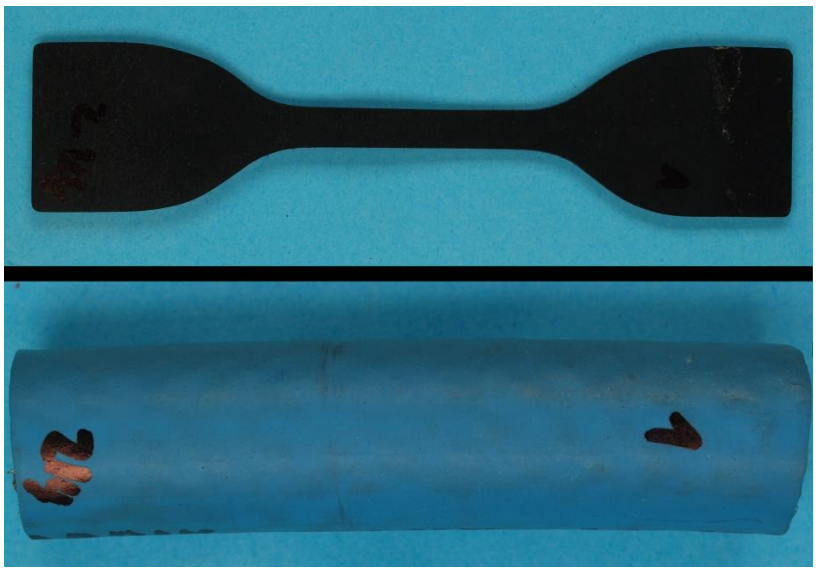

Figure 1: EPDM tensile specimen (above) and Lipalon cable sample (below).

The samples (as shown in Figure 1) were aged according to Table 1. Generally samples were either irradiation aged, thermally aged or irradiated simultaneously at elevated temperature. One set of EPDM samples were first irradiated and then thermally aged. The used dose rate, the highest absorbed dose and temperature are typical to what would be present during a loss of coolant accident (LOCA), even though it must be stated that dose rate and temperature do vary during real accident situation. Only the effect of steam is excluded in this experimental work which would be an additional stressor in DBA. It could be also stated that if there is not any significant dose rate effect existing for this particular material, the obtained 23,3 kGy absorbed dose would correspond a situation where component is exposed to constant dose rate of 0,044 Gy/h for 60 years' time.

The irradiation treatments were conducted at ROZA irradiation facility in ÚJV Řež, Czech Republic. The heat treatments were conducted at SP laboratory located in Borås, Sweden. The irradiation chamber was well-type where the gamma ray source (^{60}Co) was located in the middle of the well and the samples were lowered around it. The simultaneous exposure to elevated temperature was

obtained by placing part of the samples into specially build thermoboxes. During the irradiation treatments, a constant dose rate of 0,39 kGy/h was applied. The mean absorbed dose values described in Table 1 cover the actual absorbed dose values approximately with 95% probability. The shorter treatment times presented in Table 1 (6 h vs. 5,5 h and 58 h vs. 55,5 h) between thermal and combined ageing are very close to unity while the longest treatment times differ with 17 hours (ca. 3%) from each other's. This is mostly due to the difference between the real and the predicted irradiation treatment times, since the predicted irradiation times were used in calculation of thermal ageing treatment times. In addition, an electric blackout that occurred during the irradiation treatments which caused the heating to stop and temperature decrease to room temperature for approximately 48 hours. It did not have an effect to the irradiation treatment.

The three week accelerated thermal ageing conducted at 125,8°C can be shifted to correspond ageing at room temperature (25°C) by calculating the activation energy for thermal ageing from experimental data. However, in this particular case the degradation data was incomplete for the specific calculation of the activation energy. The corresponding ageing time at room temperature can be roughly estimated by the "rule of thumb" of accelerated ageing which states that an increase of 10°C in temperature accelerates the ageing by factor of 2. Thus 100°C increases in temperature would correspond then 2^{10}*525 h = 61,4 years i.e. the three week thermal ageing conducted at 125,8°C would roughly correspond the degradation that is induced at 25°C during 60 years of service.

Table 1. Ageing environments for the studied samples. Ageing condition number 16 comprehends from sequential thermal and irradiation ageing treatments.

Ageing condition No#	Temperature/°C	Mean absorbed dose/kGy	Total net treatment time/h
1	28,6±1,0	2,3±0,3	6
2	28,6±1,0	23,3±2,4	55,5
3	28,6±1,0	228±23	508
4	75,0±1,0	0	5,5
5	75,0±1,0	0	55,5
6	75,0±1,0	0	508
7	77,3±1,0	2,3±0,3	6
8	76,5±0,6	23,3±2,4	58,5
9	76,5±0,8	228±23	525
10	125±1,0	0	5,5
11	125±1,0	0	55,5
12	125±1,0	0	508
13	125,5±2,0	2,3	6
14	126,1±1,5	23,3±2,4	58,5
15	125,7±1,3	228±23	525
16	125±1,0	228±23	525+508

Tensile testing was conducted according to ISO 37 standard. From each ageing condition five samples were tested and the tensile stress and absolute elongation at break values were extracted from the stress-strain curves. Shore-A hardness were measured from the tensile testing samples according to ISO 7619-1 standard. Oxidation induction time (OIT) was measured by using

differential scanning calorimeter. The OIT measurement procedure comprehend from three stages where in the first one sample was heated in nitrogen environment up to 225°C and this temperature was held constant during the whole measurement. At the second stage the nitrogen atmosphere was replaced with oxygen and during the third stage exothermic transitions characteristic to different decomposition reactions induced by oxidation were measured.

4. Results and discussion

4.1 Visual inspection

Samples were photographed and visually inspected after the ageing treatments. In case EPDM samples no major changes in colour compared to reference samples were observed. In case of Lipalon samples there is clearly change in cable jacket colour after the exposure to the harsher ageing environments. Irradiation ageing did not result in significant changes in the colour of the jacketing material as can be seen in Figure 2. Increasing temperature and exposure time had an effect on the colour of the jacketing material, as can be seen from Figure 3. The increasing exposure to heat resulted in the colour change, first into greenish and then to blackish.

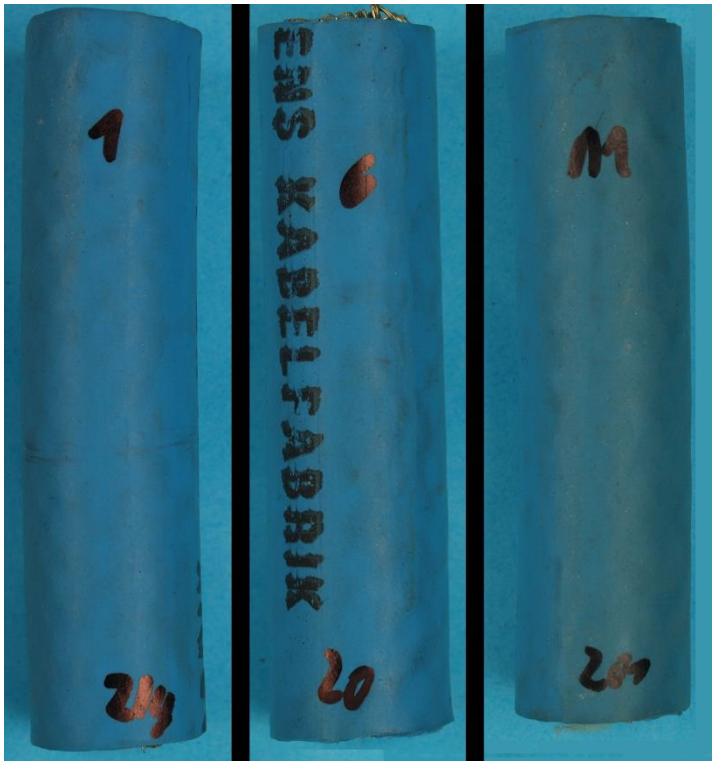

Figure 2: Lipalon cables after irradiation ageing at 28,6°C. From left to right: total absorbed dose 2,3 kGy, 23,3 kGy and 228 kGy, respectively. The used dose rate during all irradiations was 0,39 kGy/h

Figure 3: Lipalon cables after combined irradiation and thermal ageing from left to right: 58,5 hours at 125°C, 525 hours at 75°C and 525 hours at 125°C. The used dose rate during all irradiations was 0,39 kGy/h.

The cross sections of aged and unaged Lipalon tensile specimen are shown in Figure 4 and Figure 5, respectively. The colour change on the aged samples is evident. The whole cross section is oxidized and the amount of oxidation is decreasing as moved towards to the insulator as the change in colour indicates. The darker area is approximately 1 mm thick and presumably degraded more than the inner parts of the cable insulator.

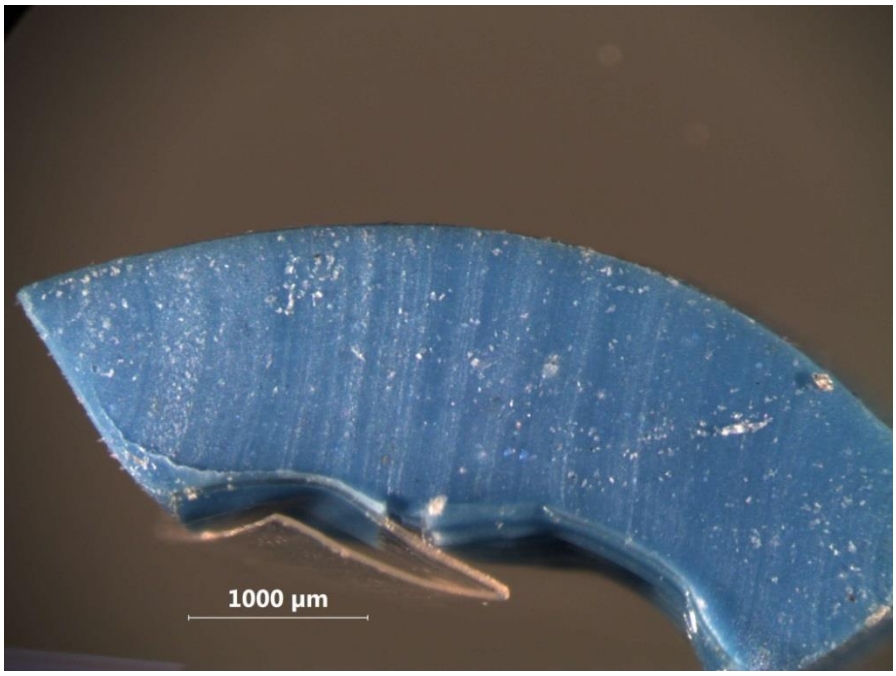

Figure 4: Cross section of unaged Lipalon tensile specimen.

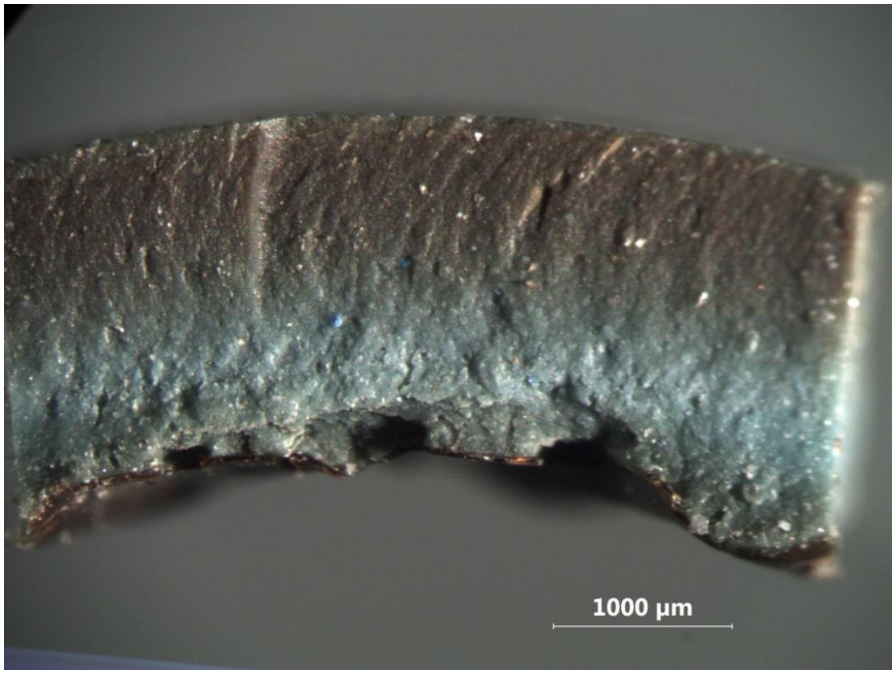

Figure 5: Cross section of Lipalon tensile specimen after 525 hours of combined irradiation and thermal ageing at 125,7°C.

4.2 Tensile testing

4.2.1 EPDM

The tensile test results for EPDM samples are shown in Table 2. The degradation can be observed from the tensile strength and elongation at break values which were obtained from the stress-strain curves. The measured tensile strength values show very small variation as the absorbed dose increases, as can be seen in Figure 6. As the absorbed dose increases to 228 kGy at near room temperature, a small decrease (12%) in tensile strength value can be seen. Other data points are considered to be within the scatter band from the reference value indicating that high temperature could be beneficial for this EPDM compound when retaining mechanical strength is considered. Generally the ultimate tensile strength is an indicator for cross-linking and chain scission [Šarac et al. 2016]. Increasing ultimate tensile strength is related to cross-linking and decreasing value to chain scission. From the tensile strength results no significant changes in degradation mechanism occur. Only at 28,6°C chain scission might be interpreted to be increased by a very small value. When tensile strength values obtained with irradiation aged samples are compared to the ones aged at the thermal environment (shown in Figure 7), thermal ageing at 125°C yields in equivalently small increase (12%) in tensile strength as in irradiation ageing. This would be then interpreted to be due to the small increase in crosslinking. Such increase is not observed in the environment where irradiation and thermal ageing are conducted simultaneously, as can be seen from Figure 6.

*Table 2. Tensile test results for EPDM. Results marked with * are obtained from sequential ageing treatments.*

Ageing temperature/°C	Absorbed dose/kGy	Ageing time/h	Elongation at break/%	Tensile strength/MPa
N/A	0	0	182	13,0
28,6±1,0	2,3±0,3	6	162	12,2
28,6±1,0	23,3±2,4	55,5	174	13,4
28,6±1,0	228±23	508	126	11,5
75,0±1,0	0	5,5	180	12,8
75,0±1,0	0	55,5	176	12,6
75,0±1,0	0	508	175	13,1
77,3±1,0	2,3±0,3	6	173	12,8
76,5±0,6	23,3±2,4	55,5	165	12,1
76,5±0,8	228±23	508	138	12,7
125±1,0	0	5,5	177	13,3
125±1,0	0	55,5	177	13,1
125±1,0	0	508	178	14,6
125,5±2,0	2,3	6	185	13,6
126,1±1,5	23,3±2,4	58,5	188	14,1
125,7±1,3	228±23	525	154	13,1
125±1,0	228±23	525+508	117*	12,3*

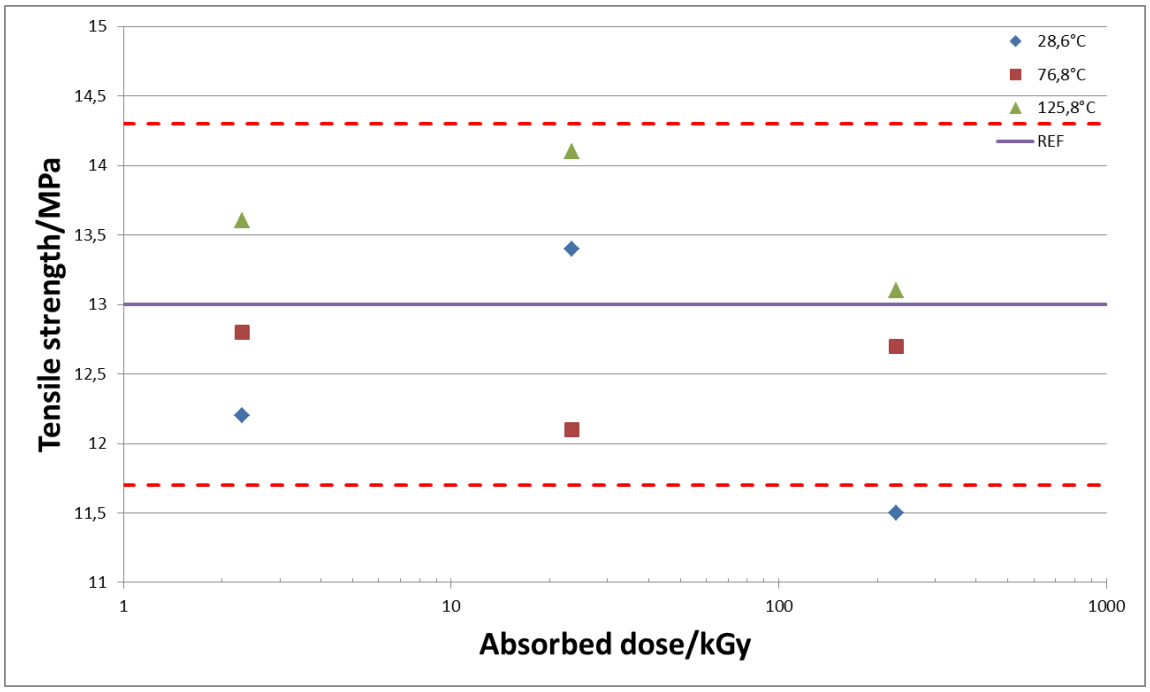

Figure 6: Tensile stress at break values as function of absorbed dose for EPDM samples. Results obtained experimentally at 28,6°C are marked as blue diamonds, 76,8°C red squares and 125,8°C green triangles. The red dashed lines describe the 10% scatter band from the reference result.

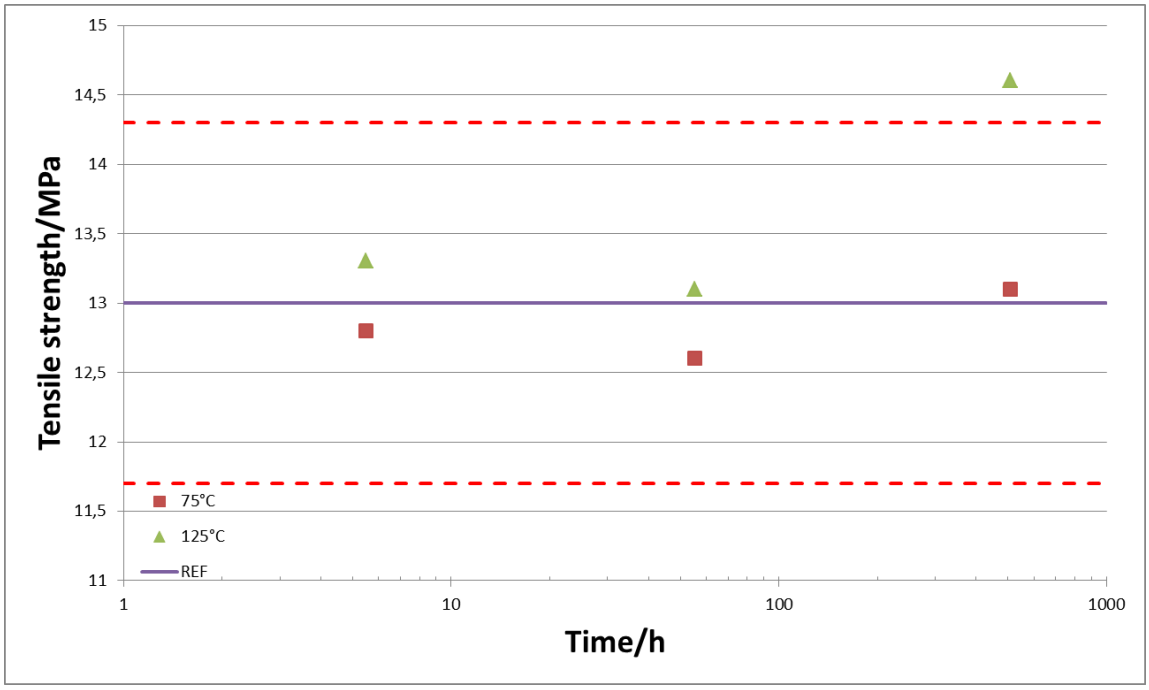

Figure 7: Tensile strength values as function of thermal ageing time at ageing temperatures of 75°C and 125°C. The red dashed lines describe the 10% scatter band from the reference result.

The elongations at break results obtained at three different temperatures as function of absorbed dose are plotted in Figure 8. From this figure it can be observed that during combined thermal and radiation ageing, increasing temperature yields in decrease in amount of degradation. When the sequential ageing (irradiation up to 228 kGy and following heat treatment at 125°C for 508 hours) results are compared to the simultaneous ageing data, there is small synergistic effects from heat and gamma radiation on the ageing of this EPDM compound. When the irradiation is conducted at 125,8°C and after the absorbed dose is 228 kGy, the elongation at break value is decreased ca. 15% from the reference value. For comparison, the corresponding percentage in the case of sequentially aged sample is ca. 36%. When the results obtained from the lower ageing temperature of 76,8°C and near room temperature are considered (absorbed dose 228 kGy), the decrease in elongation at break values are 24% and 31%, respectively. When the thermal ageing only data was compared to the reference data, no changes in elongation at break values were seen, even not at the longest ageing times and highest temperature. Thus it seems that during a DBA temperature has inhibiting effect on degradation for this EPDM grade.

Previously Placek et al. [Placek et al. 2008] have been reported that simultaneous radiation and thermal ageing is more severe than the corresponding sequential ageing to EPDM seals. The results obtained in this work predict quite opposite. The difference is considered mainly to be due to the differences in the used EPDM compounds. When the elongation at break values are compared the James Walker EPDM compound had reference value of 182% while the compound used in [Placek et al. 2008] had ca. 550%. This indicates that the compounds most likely have considerably different additional ingredients blended within them. Also the ageing procedures used in these two studies differ from each other which make the comparison of the results further difficult.

Another interesting observation is that the combined thermal and radiation degradation follows power law as plotted for each temperature. The R^2 values indicate that the plotted power law functions for each temperature show good or excellent correlation with the fitted function.

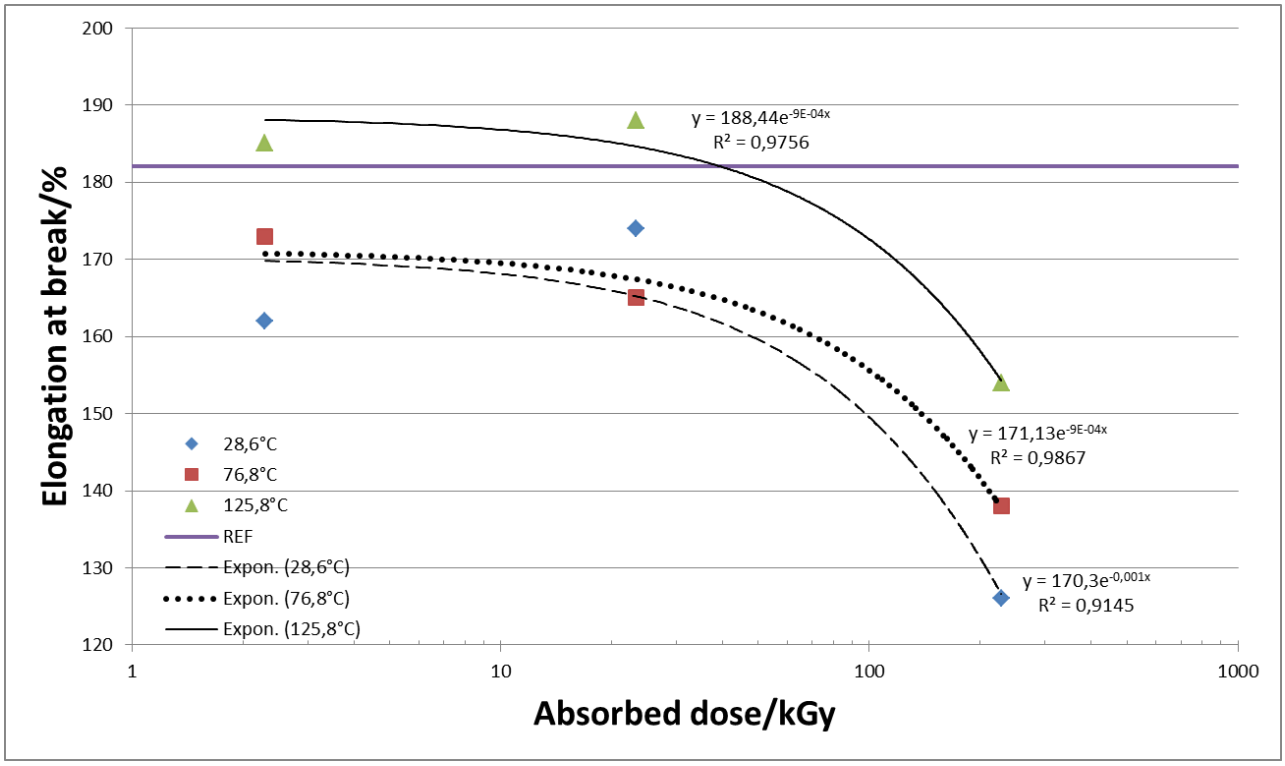

Figure 8: Elongation at break as function of absorbed dose for EPDM. Results obtained experimentally at 28,6°C are marked as blue diamonds, 76,8°C red squares and 125,8°C green triangles. Purple line indicates results obtained with reference samples. The fitted exponent functions are plotted as dashed, dotted and solid curves at temperatures of 28,6°C, 76,8°C and 125,8°C, respectively.

4.2.2 CSM

The tensile test results for CSM (Lipalon) samples are shown in Table 3. Results showed more scatter than in the case of EPDM samples. Despite the scatter, a clear trend towards decreasing tensile strength and elongation at break values as irradiation dose is increased can be observed. When only thermally aged data is considered, no clear indication of decrease in tensile strength values can be observed, as can be seen in Figure 9. There is some variance in the measured values but they can be concluded to be within the scatter band.

The development of tensile strength as function of absorbed dose at three different temperatures is shown in Figure 10. If the scatter is considered to be ±1 MPa, only in the case of samples aged at 125,8°C the tensile strength is clearly decreased from the reference value, approximately 47%.

Table 3. Tensile test results for Lipalon.

Ageing temperature/°C	Absorbed dose/kGy	Ageing time/h	Elongation at break/%	Tensile stress/MPa
N/A	0	0	102	4,5
28,6±1,0	2,3±0,3	6	87	4,1
28,6±1,0	23,3±2,4	55,5	73	3,6
28,6±1,0	228±23	508	58	5,4
75,0±1,0	0	5,5	96	4,5
75,0±1,0	0	55,5	123	4,3
75,0±1,0	0	508	104	5,4
77,3±1,0	2,3±0,3	6	89	3,5
76,5±0,6	23,3±2,4	55,5	77	4,5
76,5±0,8	228±23	508	47	5,0
125±1,0	0	5,5	107	3,7
125±1,0	0	55,5	90	5,2
125±1,0	0	508	30	4,0
125,5±2,0	2,3	6	86	3,7
126,1±1,5	23,3±2,4	58,5	75	4,1
125,7±1,3	228±23	525	19	2,4

The elongation at break values as function of absorbed doses at different ageing temperatures are shown in Figure 11. The trend observed from Figure 11 is that increasing absorbed dose and temperature increases degradation. Already the smallest absorbed dose seemed to have a small decreasing effect on the elongation at break. According to Pinel [Pinel, 1991] radiation induced degradation is mostly due to crosslinking which causes scission of the covalent bonds between hydrogen and chlorine atoms. At absorbed dose of 228 kGy, the effect of temperature to the amount of degradation can be clearly observed.

When the samples are thermally aged at 76,8°C no clear decrease in elongation at break is observed. The effects of thermal ageing can be seen when ageing time and temperature is sufficiently high, as can be seen from the thermal ageing data obtained at 125°C illustrated in Figure 12. However, the combined radiation and thermal ageing seem to be only slightly detrimental to the studied samples than the bare thermal ageing, as can be observed from Figure 11 and Figure 12. Thermal ageing conduced seemed to cause more degrdation than bare radiation ageing. Comparison of the data also indicates that CSM is a bit more prone to thermally induced than irradiation induced degradation in these simulated DBA conditions.

The ageing in combined thermal and radiation environment seems to obey power law. Excellent fit is obtained for the data aged at 125,8°C. The quality of the obtained fit decreases with temperature. An excellent fit for a power law function is also obtained from thermal ageing data obtained at 125°C as can be seen from Figure 12.

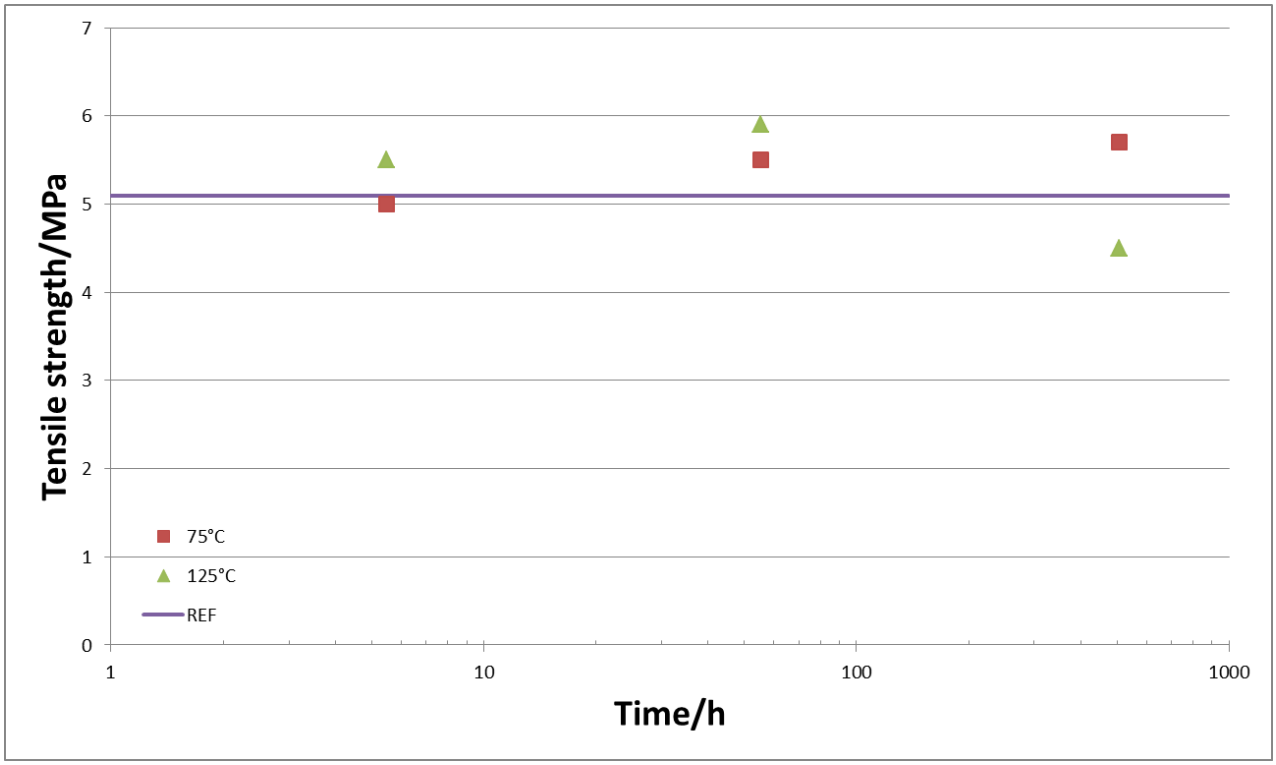

Figure 9: Tensile strength of Lipalon cable jacket samples as function of ageing time at ageing temperatures of 75°C and 125°C.

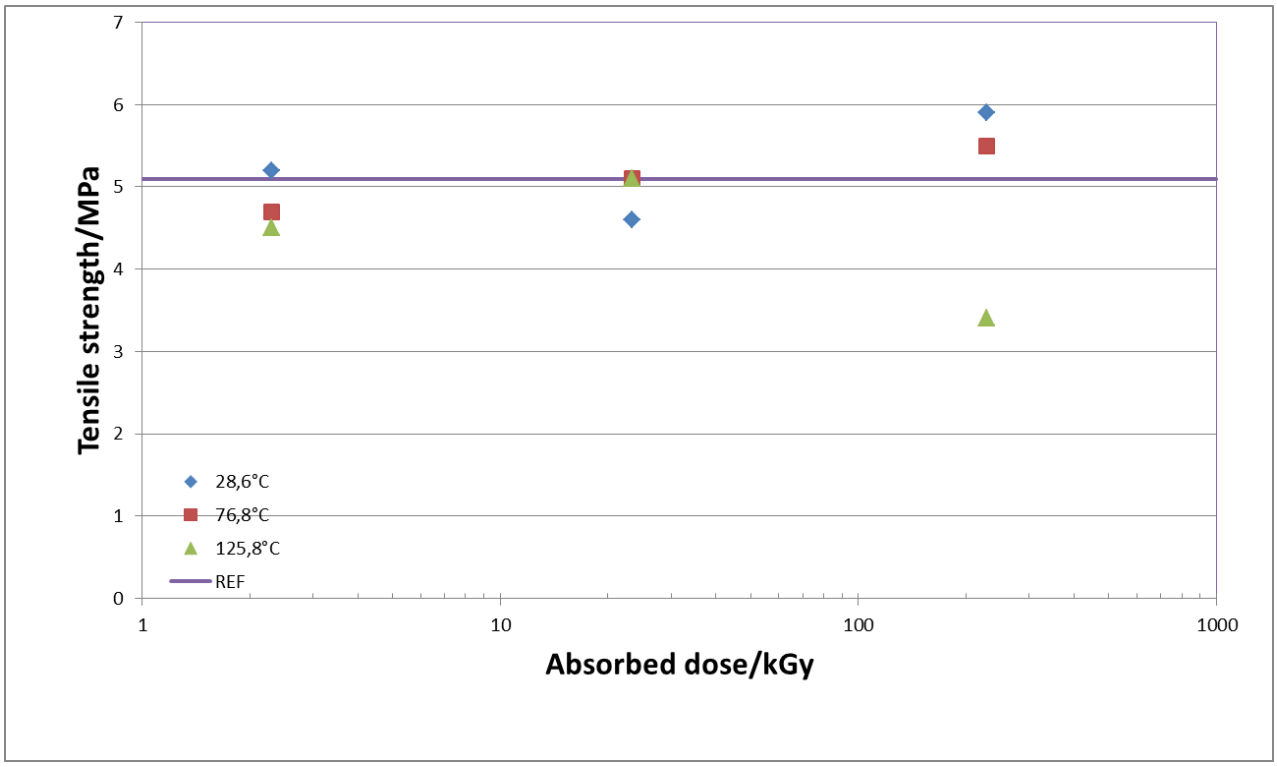

Figure 10: Tensile stress at break values as function of absorbed dose for Lipalon samples. Results obtained experimentally at 28,6°C are marked as blue diamonds, 76,8°C red squares and 125,8°C green triangles.

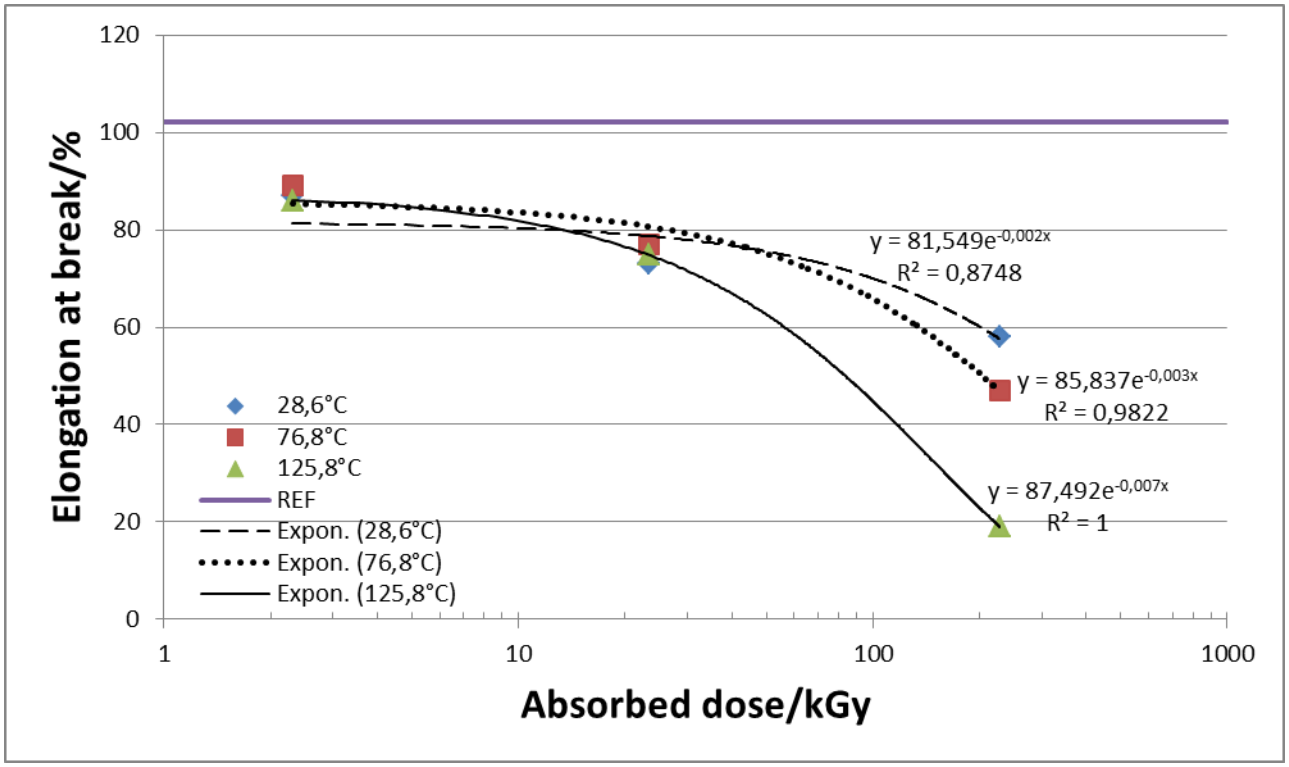

Figure 11: Elongation at break as function of absorbed dose for Lipalon. Results obtained experimentally at 28,6°C are marked as blue diamonds, 76,8°C red squares and 125,8°C green triangles. Purple line indicates results obtained with reference samples. The fitted exponent functions are plotted as dashed, dotted and solid curves at temperatures of 28,6°C, 76,8°C and 125,8°C, respectively.

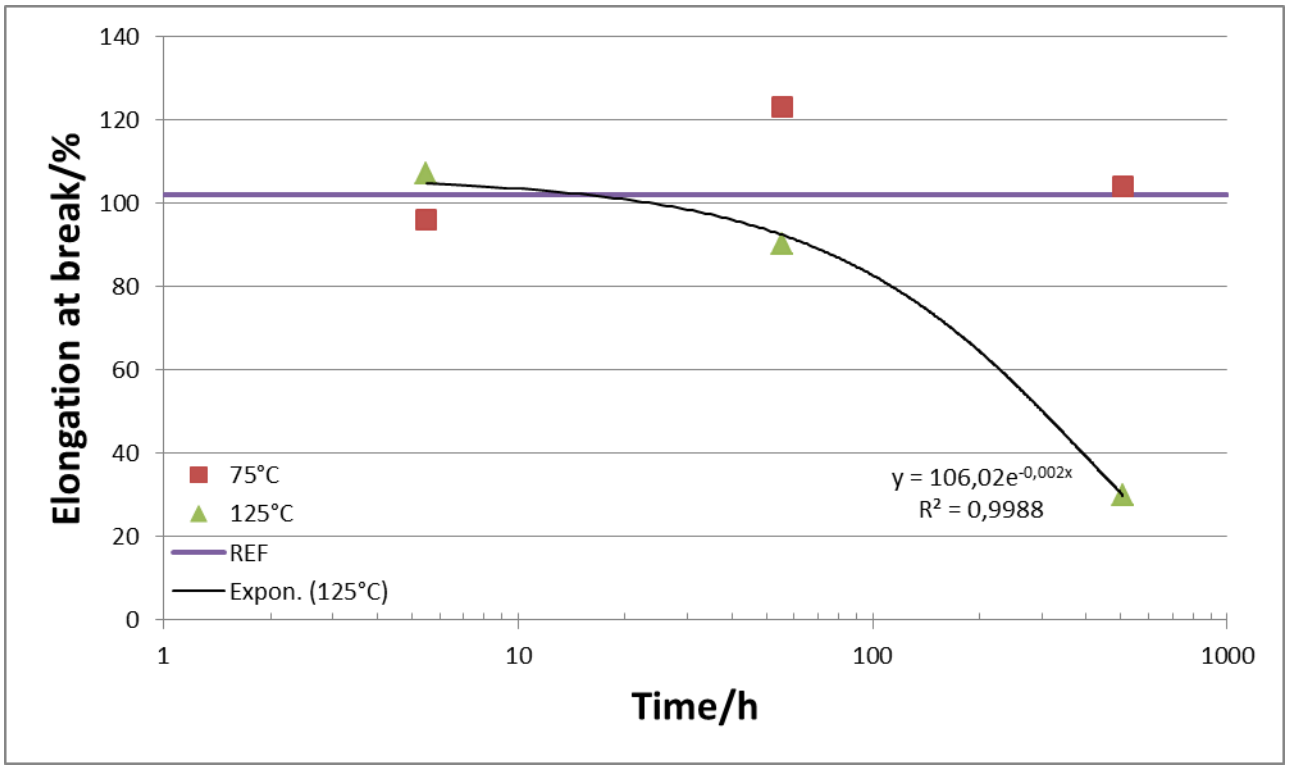

Figure 12: Elongation at break as function of thermal ageing time at two different temperatures.

4.3 Hardness measurements

4.3.1 EPDM

The results of hardness measurements for EPDM are shown in Figure 13 and 14. Hardness of EPDM samples did not change when they underwent ageing treatments. Hardness is not thus very sensitive ageing indicator for this EPDM blend in these ageing environments.

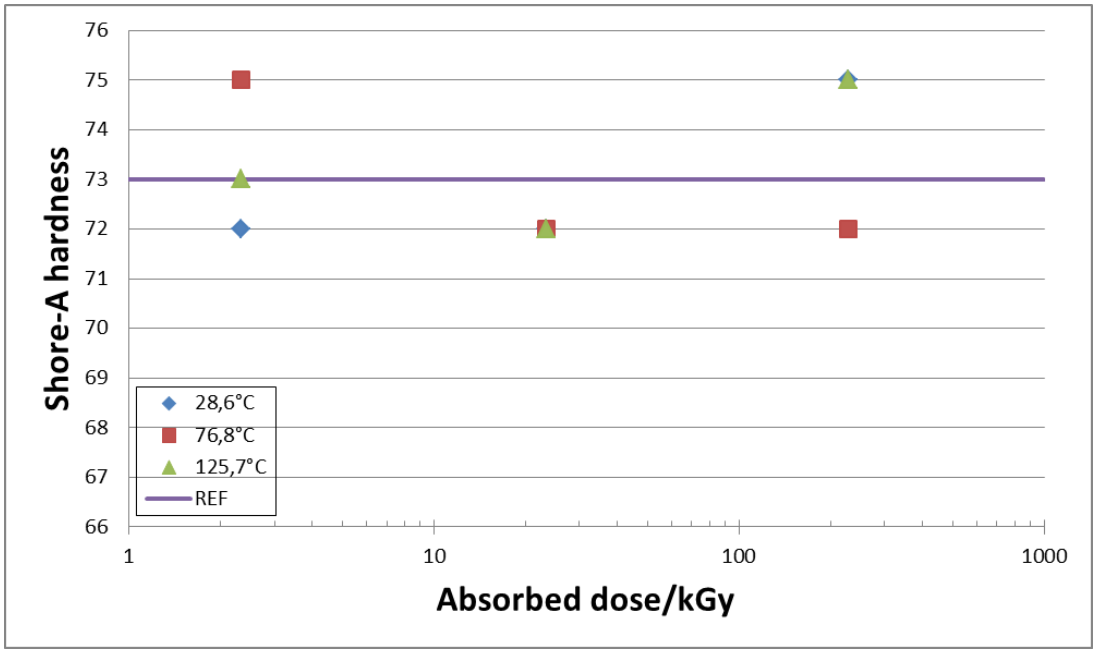

Figure 13: Shore-A hardness results for EPDM samples as function of absorbed doseat different temperatures.

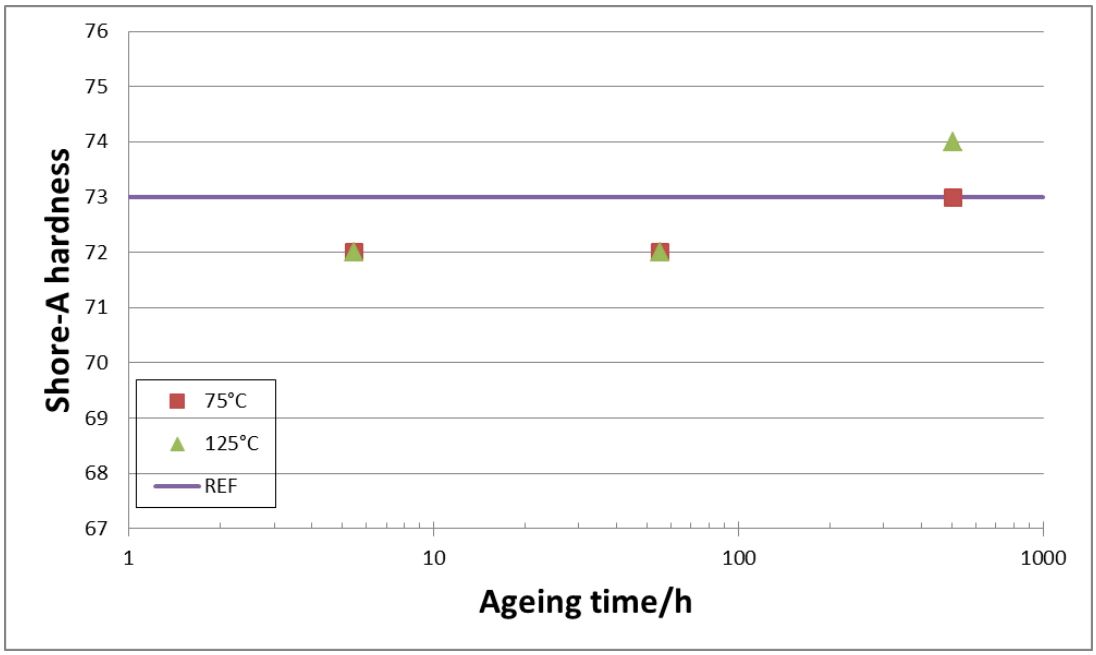

Figure 14: Shore-A hardness results for EPDM samples as function of thermal ageing time at different temperatures.

4.3.2 CSM

The hardness measurement results for Lipalon are shown in Figure 15 and Figure 16. CSM sample measurement results showed more scatter than EPDM samples due to the convex measurement surfaces. However, the obtained results at each ageing environment are considered to be reliable and increase of inflexibility was observed after certain ageing treatments. The increasing absorbed dose has a clear effect on the measured hardness. At absorbed doses up to 23,3 kGy no change in hardness is observed but when the absorbed dose was increased to 228 kGy, the hardness increased 16% at room temperature, 19% at 76,8°C and 30% at 125,7°C. Bare thermal ageing did not result in similar increase in hardness when the ageing temperature was 75°C. Three weeks ageing at 125°C however resulted to 19% increase in hardness.

The chlorine content of CSM is known to have an effect to the hardness of CSM. Generally lower chlorine content can increase hardness [Šarac et al. 2016, Gillen et al. 2006]. A change in chlorine content could be thus explaining the observed change in hardness, but in order to confirm this, an elementary analysis of the sample would be required. Also changes in crystallization degree could have an effect to the measured hardness since crystalline regions have higher hardness compared to amorphous ones. Additional scanning electron microscope (SEM) analysis would reveal the possible changes in microstructure.

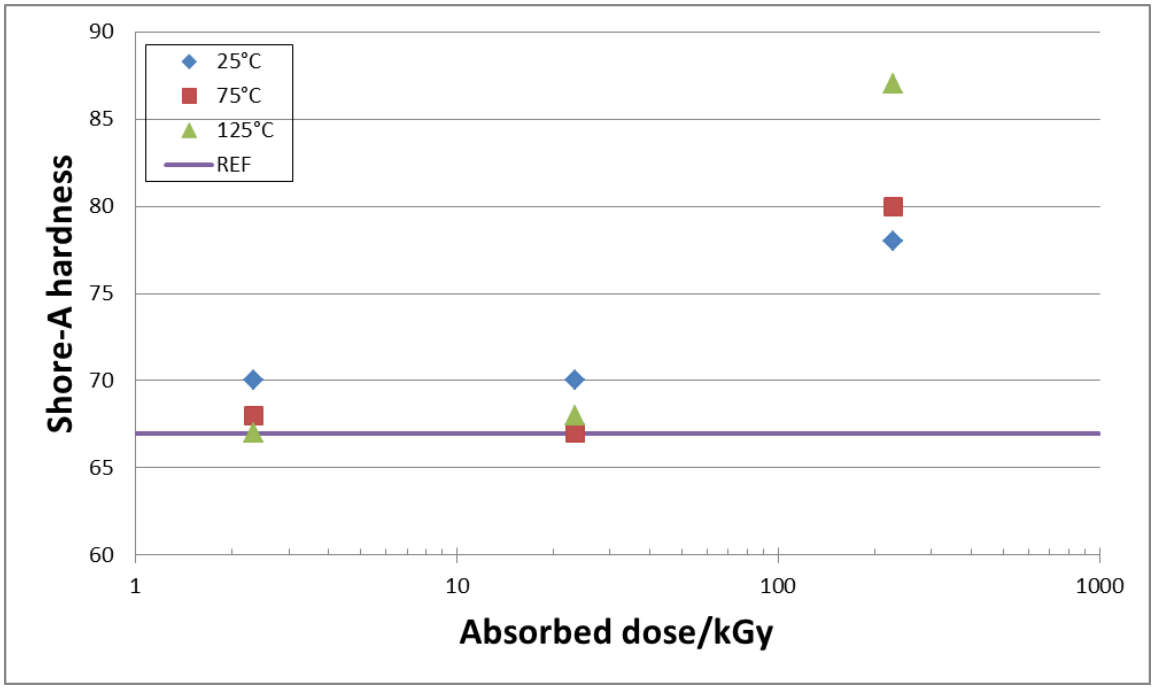

Figure 15: Shore-A hardness results for CSM (Lipalon) samples as function of absorbed dose at different temperatures.

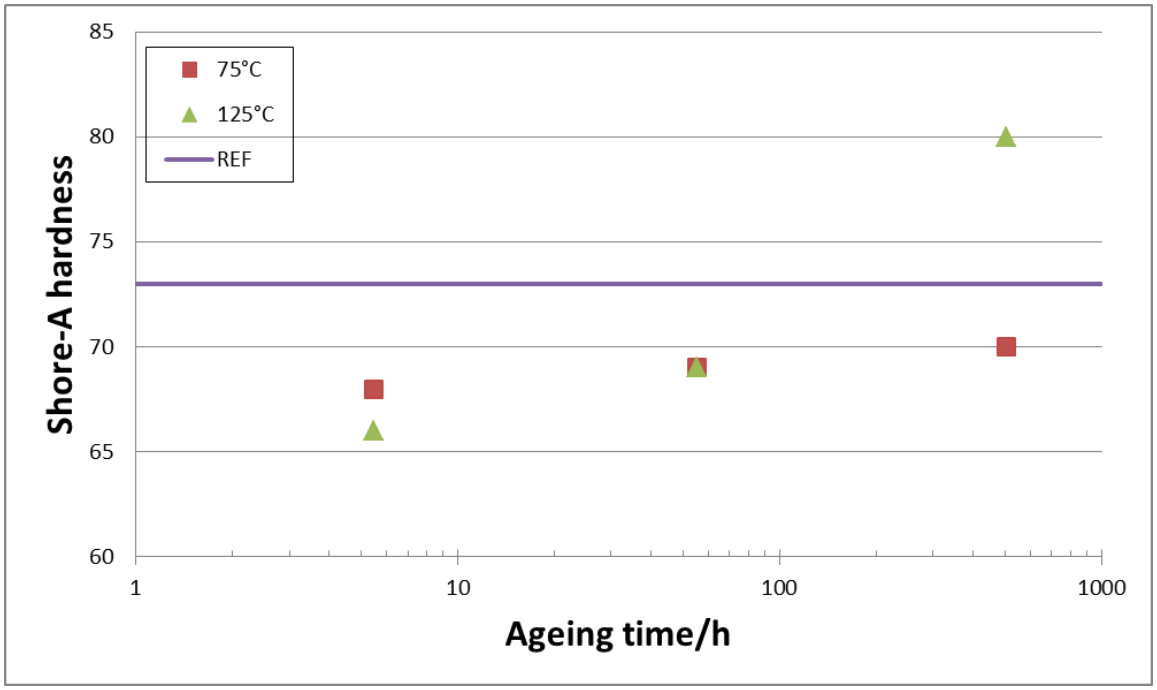

Figure 16: Shore-A hardness results for CSM (Lipalon) samples as function of thermal ageing time at different temperatures.

4.4 OIT measurements

4.4.1 EPDM

OIT (Oxidative Induction Time) was measured for reference sample and samples that were irradiation aged at near room temperature with total dose of 228 kGy, thermally aged at 125°C for 508 hours and simultaneously irradiated (228 kGy) and thermally aged at 125°C for 525 hours (ageing conditions of 3, 12 and 15, respectively, from Table 1). The measured OIT curve conducted in oxygen atmospheres for these four samples are illustrated in Figure 17- Figure 20. Four distinct reactions can be distinguished from the measured spectra as can be seen from Figure 17. Transitions numbered 1-3 in Figure 17 are most likely related to decomposition of different additives and their more detail examination would require more information on the ingredients of the studied EPDM compound. Transition number 4 is related to the decomposition of the base polymer. The degradation has an effect to the transition positions, shape and size. In addition, the sample size (quite small, some milligrams) and the heterogeneity in polymer structure may have an effect to the properties of the measured spectra. OIT for the reference sample was determined to be 58,9 min.

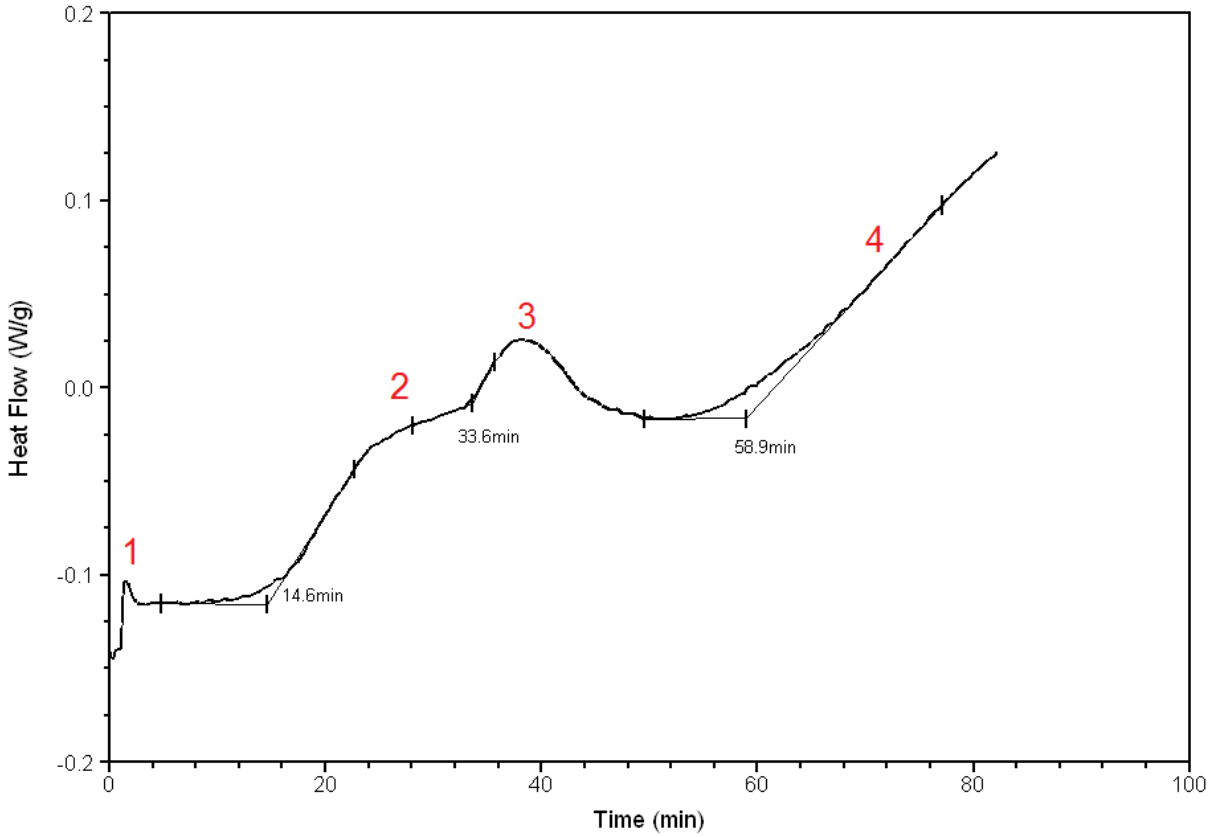

Figure 17: OIT curve in oxygen atmosphere for EPDM reference sample.

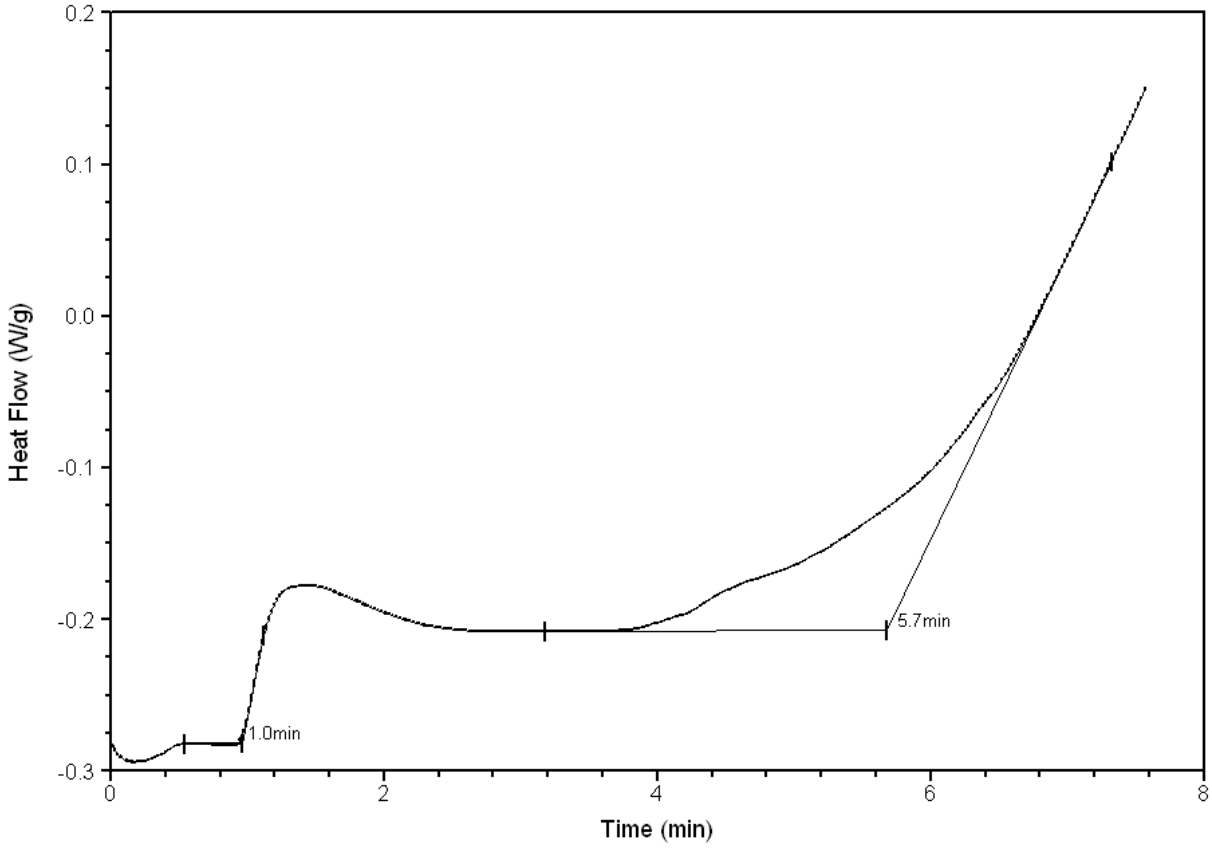

Figure 18: OIT curve in oxygen atmosphere for EPDM sample irradiated with 228 kGy.

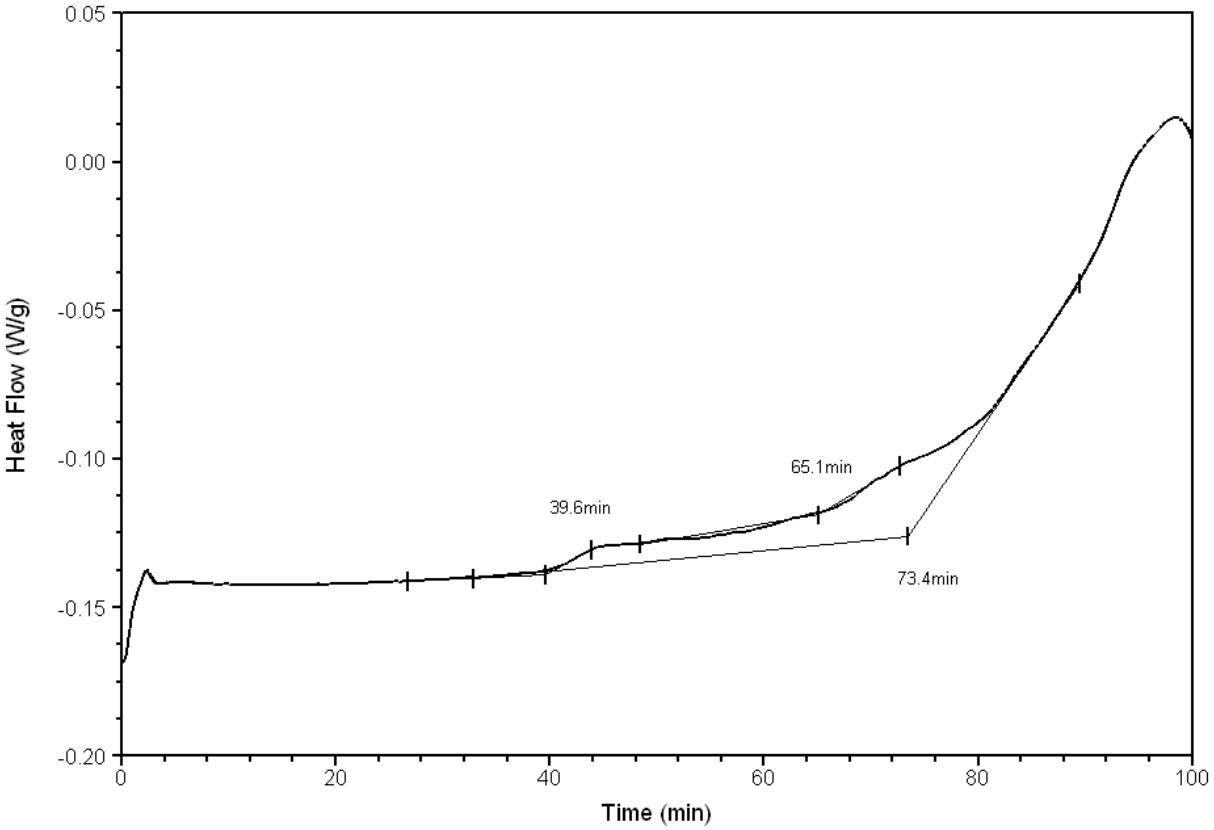

Figure 19: OIT curve in oxygen atmosphere for EPDM sample aged at 125°C.

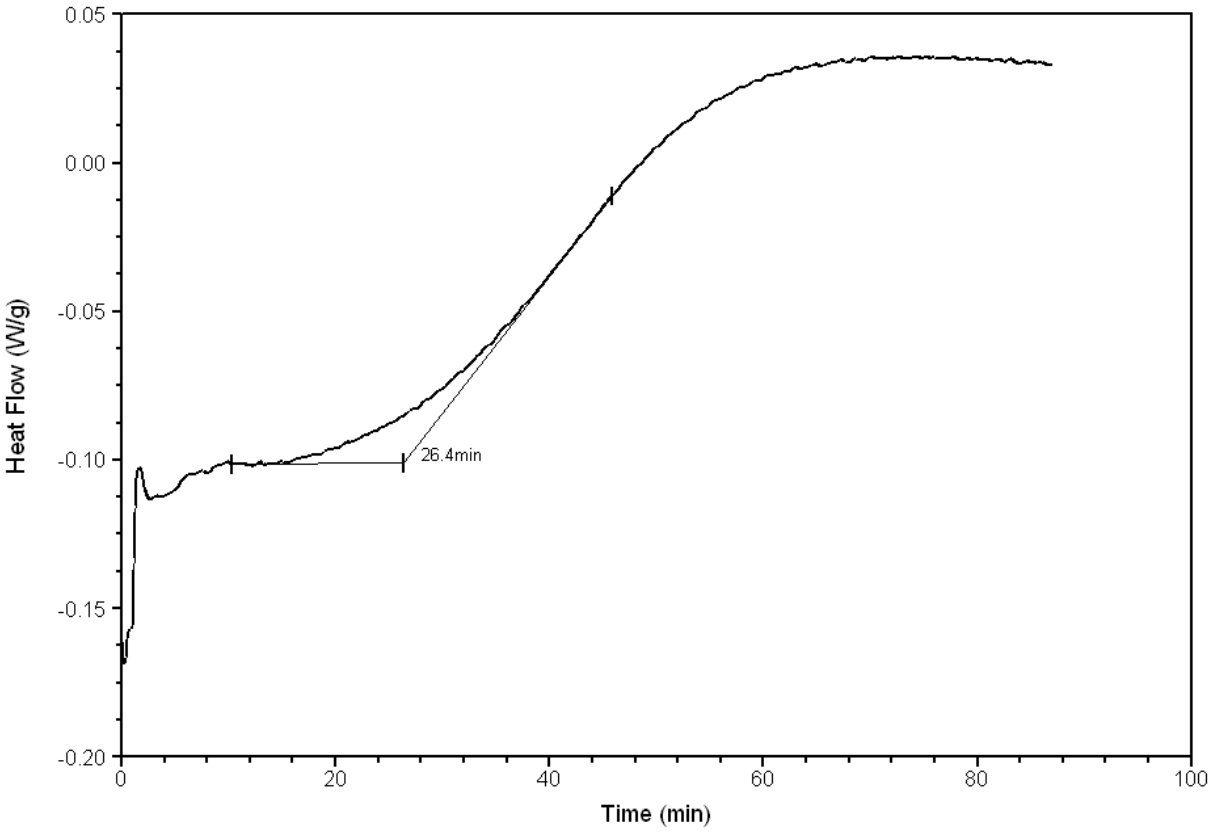

Figure 20: OIT curve in oxygen atmosphere for EPDM sample aged at 125°C with simultaneous exposure to 228 kGy of gamma-radiation.

OITs defined for the samples aged at conditions 3, 12 and 15 were 5,7 min, 73,4 min and 26,4 min, respectively. The measured OIT with the sample aged at condition 3 is smaller than the reference value by a factor of ca. 10 and roughly five times smaller than the corresponding value with the sample aged at condition 15. The OIT result obtained for the thermally only aged sample at condition 12 was somewhat higher than the reference value, but repetition OIT measurement yielded in OIT of 45,1 min. There is thus a quite large scatter in the measurements which is considered to conclude from the same factors that have effect on the measured curve properties. The difference between reference and ageing conditions 3 and 15 is however considered to conclude from differences on oxidation behaviour. The results suggest that irradiation conducted at near room temperature yields in increased oxidation compared to situation when irradiation is done at elevated temperature. This observation is aligned with the tensile testing results.

4.4.2 CSM

OIT measurements with CSM (Lipalon) samples did not result in clear OIT spectra, where OITs could be properly defined. This is thought to be concluded from the structure of CSM and lack of primary antioxidants within it. Similar results have been reported before in [Spång, 1997].

5. Conclusions

Two commonly used rubber compounds peroxide vulcanized EPDM and CSM (tradename Hypalon) rubber cable jacketing materials were artificially aged thermally and irradiated by using gamma radiation, both simultaneously and separately. The ageing parameters (temperature, dose rate and absorbed dose) were defined to be similar to those present during a DBA. The aged samples were studied by tensile testing, hardness measurements and DSC analysis. Tensile strength was not thought to be a good indicator for material degradation for these materials since it was not effected very strongly by the ageing treatments, except slightly after exposure to the most aggressive ageing environments. Based on the elongation at break results obtained with EPDM samples, it can be stated that moderate increase (ca. 75-125°C) in temperature during exposure to ionizing radiation hinders the degradation process. According to these findings and previously reported results in literature [Ito 2007, Placek et al. 2008], different additives used in EPDM compound have an effect to the nature and magnitude of the synergistic degradation yielding from exposure to heat and gamma radiation. CSM (Hypalon) seemed to be more susceptible to both irradiation and thermally induced ageing and only small synergistic effects rising from simultaneous exposure to radiation and heat could be observed. In case of both materials, sufficient amount of degradation needs to be generated before hardness could be used as a degradation indicator. OIT measurements results were aligned with elongation at break measurements in case of EPDM. For CSM samples no OIT could be defined.

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