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PRE AND POST-SWELLING MECHANICAL BEHAVIOR OF A WATER-SWELLING ELASTOMER

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ABSTRACT
Swelling elastomers are a very recent development in the world of advanced polymers, and are being successfully used in the form of packers and other sealing elements in various oilfields. Improved design of sealing elements and prediction of seal performance under different well conditions require a good knowledge of mechanical response of the swelling elastomer. This study reports results of hardness and tensile testing carried out on disc and ring samples of a water-swelling elastomer. Material properties of the elastomer were measured before swelling and periodically after swelling for a total testing time of 15 weeks, under water salinities of 0.6%, 12%, and 25%, and temperatures of 25°C, 50°C, 80°C, and 97°C. Reported results can be used by oilfield engineers as prequalification of the elastomer for downhole applications, and by designers using numerical simulations for improvement of elastomer-based sealing and packer design.
Keywords: Water-swelling elastomer, pre and post-swelling properties, hardness testing, tensile testing, elastic modulus, fracture stress, percent elongation

1. INTRODUCTION

Swelling elastomers undergo dynamic swelling when exposed to water or oil. Swell packers consist of swellable elastomer sections bonded to petroleum pipes. Many mature fields (which account for more than two-thirds of the world's oil and gas production) have been traditionally abandoned after serious production declines, because of the difficulties and large cost associated with rework. A relatively new technology, swellable elastomer packers (SEPs), has now been successfully employed for workovers, sidetracks, and redrills, putting abandoned wells back into production [1]. When oilfields are producing substantial amounts of unwanted water or gas, increased recovery from maturing reservoirs is possible through shut-off of unwanted water and gas by the deployment of swelling elastomer sections to segment horizontal wells [2]. Swellable elastomers have been successfully used for cementless completions [3], for well completion together with cement jobs [4], and for zonal isolation in openhole completion of foam-drilled horizontal wells [5].

For selection of suitable packers for a given set of field conditions, for improvement of sealing design, for evaluation of seal integrity, and for modeling and simulation of swelling elastomer applications, material properties of the elastomer at various stages of swelling must be known. Resistance of water-swelling and oil-swelling elastomer seals to differential pressures at a given temperature was investigated by Al-Yami et al [6]. Material response such as volume and thickness swelling, compression set, and tensile set of fresh and exposed samples of a water-swelling elastomer was studied earlier by the authors [7]. This paper reports the results of progressive swelling on hardness and tensile properties of an EPDM-type water-swelling elastomer.

2. EXPERIMENTAL SETUP

Based on actual well conditions in local oilfields, four temperatures (room/ambient, 50°C, 80°C, and 97°C) and three brine concentrations (0.6%, 12% and 25%) were selected for the tests. Disc samples

(25 mm diameter, 6 mm thickness) were used for hardness tests and ring samples (16mm inside diameter, 3 mm thickness) for tensile tests, at the end of each week of swelling. Total swelling time was 15 weeks. A Shore Durometer (fitted with scale "A" for soft rubbers) was used for hardness measurement of elastomer samples, in accordance with *ASTM D2240*. Tensile tests were conducted in line with *ASTM D412* test standard, to determine modulus of elasticity, fracture strength, and fracture strain (or percent elongation). Hook-type attachments were used with a tensile testing machine (fitted with a 5 kN load cell for rubber-type materials), at a loading speed of 500 ± 50 mm.

3. RESULTS AND DISCUSSION

3.1. Hardness

Variation of hardness with progressive swelling is illustrated in Fig-1 for disc samples kept in 0.6% brine solution at different temperatures. Similar other graphs (for other concentrations) show that there is a general trend of decreasing hardness as swelling increases. This is as expected; swelling obviously increases sample volume, thereby decreasing its density and making the elastomer softer; thus lower hardness values. However, hardness does not continually decrease but exhibits a fluctuating behavior, sometimes even showing a slight increase before decreasing again. We know that salt is one of the constituents in these elastomers, so there is a two-way transport of brine; from the solution into the elastomer, and from the elastomer into the solution. This can be because of break-away of salt from the elastomer, or changes in the cross-link structure, or both. This may have a direct bearing on density (and thus hardness) fluctuation. In graphs for constant concentration, curves for higher temperatures are generally lower. Higher swelling at higher temperatures causes more softening, thus the lower hardness curves. When temperature is kept constant, we observe that hardness curves for higher concentration solutions are generally higher than those for lower concentrations. This should be expected as there is lesser swelling of elastomer in the higher-concentration solutions, and lower swelling yields higher hardness.

3.2. Tensile Properties

Tensile tests were initially conducted on 5 ring samples to get average properties of the original elastomer (before swelling); Fig-2. Surprisingly, stress-strain curves for this elastomer are almost linear in nature (unlike the significantly nonlinear behavior of normal rubbers), so it is easy to perform linear curve fitting for determination of the elastic modulus. Average values of before-swelling fracture stress (σ_f), fracture strain (ε_f) and elastic modulus (E) were 19.4 MPa, 427%, and 1.6 MPa.

Tensile tests were later conducted on 3 ring samples for each condition after every week of swelling. Sample graphs for change of σ_f, ε_f, and E with swelling (or swelling time) for samples exposed to different concentrations and temperatures are shown in Figures 3, 4, and 5. There is a general trend of decreasing σ_f and E as swelling increases, which is as expected. Swelling increases sample volume, thereby making the elastomer softer. Softer material obviously results in lower values of these tensile properties. As for fracture strain (ε_f), one would generally expect a softer material to elongate more. However, in the case of such water-swelling elastomers, softer samples (after more swelling) fracture rather quickly at low loads, thus resulting in lower fracture strains with increasing swelling.

Fracture stress and elastic modulus curves for higher concentration solutions are generally higher than those for lower concentrations. This is in line with usual behavior; there is lesser swelling of elastomer in the higher-concentration solutions, and lower swelling yields higher hardness, resulting in higher values of σ_f and E. Fracture strain curves for higher concentration solutions are also generally higher than those for lower concentrations. This appears to be in contradiction with the natural expectation of more elongation for softer material. As explained above, elastomers become softer with swelling, but they also become increasingly weaker, thus rupturing very quickly at low loads. This results in lower values of percent elongation with higher swelling. As in the case of hardness, tensile properties do not decrease continually but exhibit a fluctuating behavior, sometimes even showing a slight increase before decreasing again. The reason is explained above, based on the two-way transport of brine (from the solution into the elastomer, and from the elastomer into the solution).

4. REFERENCES

[1] Al-Douseri KMM, Barnes C, Young D, Smith PE (2010) "Swellable packers provide a brownfield water management solution in open and cased hole," SPE Oil and Gas India Conference and Exhibition (OGIC), 20-22 January 2010, Mumbai, India

[2] Mahrooqi MA, Hinai G, Marketz F (2007) "Improved Well and Reservoir Management in Horizontal Wells Using Swelling Elastomers," SPE PAPER # 107882-MS, SPE Annual Technical Conference and Exhibition, 11-14 November 2007, Anaheim, California, USA

[3] Rogers H, Allison D, Webb E (2008) "New Equipment Designs Enable Swellable Technology in Cementless Completions," SPE PAPER # 112302-MS, IADC/SPE Drilling Conference, 4-6 March 2008, Orlando, Florida, USA

[4] Cooper K, et al. (2008) "Completion of a Horizontal Well With Swellable Packers To Control Water Production," SPE PAPER # 116263-MS, SPE Annual Technical Conference and Exhibition, 21-24 September 2008, Denver, Colorado, USA

[5] Allison D, Folds D, Harless D, Howell M, Vargus G (2009) "Optimizing Openhole Completion Techniques for Horizontal Foam-Drilled Wells," SPE Paper # 125642-MS, SPE Eastern Regional Meeting, 23-25 September 2009, Charleston, West Virginia, USA

[6] Al-Yami AS, et al. (2008) "Lab Investigation of Oil Swelling Elastomers for Smart Well," SPE Paper # 19403-MS, Offshore Technology Conference, 5-8 May 2008, Houston, Texas, USA

[7] Qamar SZ, Hiddabi SA, Pervez T, Marketz F (2009) "Mechanical Testing and Characterization of a Swelling Elastomer," *Journal of Elastomers and Plastics*, **41** (5), September 2009, p 415-431

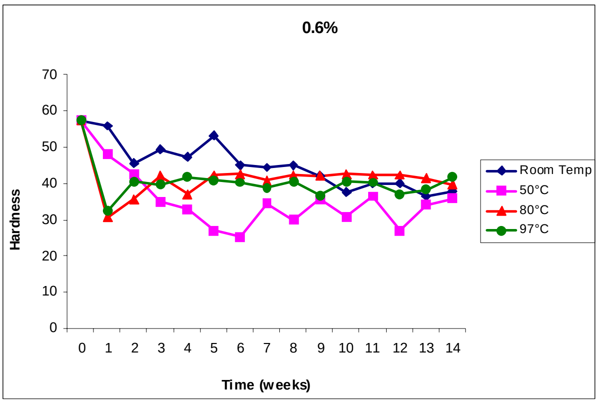

Figure 1. Variation of hardness with swelling time in 0.6% solution

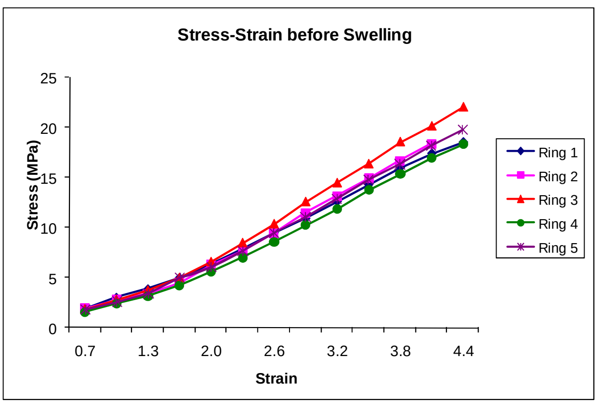

Figure 2. Stress-strain behavior of 5 ring samples before-swelling

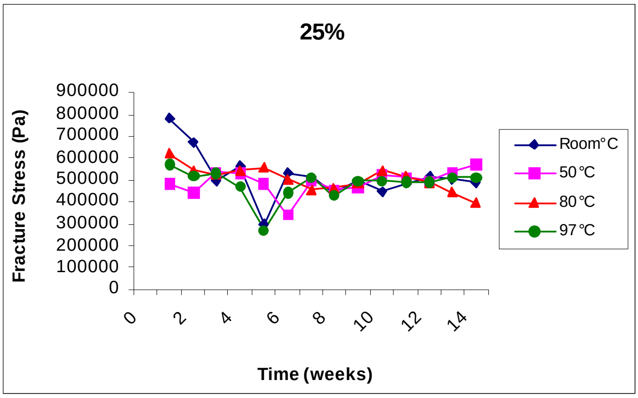

Figure 3. Variation of fracture stress with swelling time in 25% solution

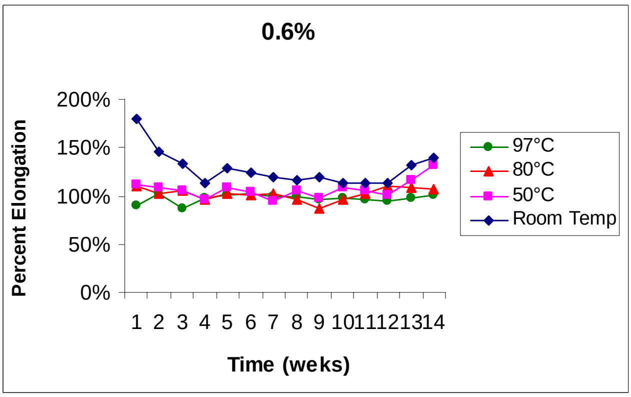

Figure 4. Variation of percent elongation with swelling time in 0.6% solution

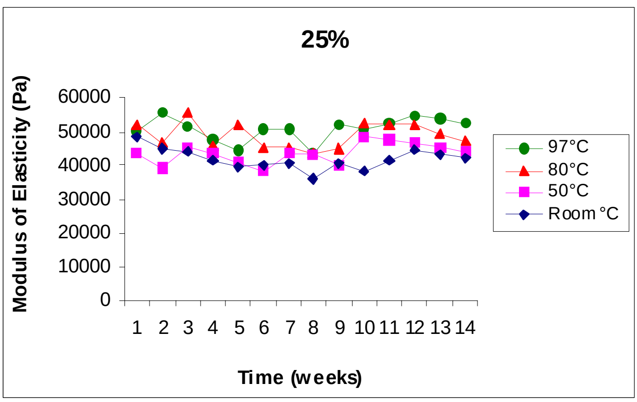

Figure 5. Variation of elastic modulus with swelling time in 25% solution