Environmental stress cracking behavior for HDPE regarding MWD

High-density polyethylene (HDPE) is a polymer used for many packaging applications. During service life, the material can be exposed to substances, like household detergents, that can affect its mechanical behavior. Environmental Stress Cracking (ESC) may occur in polymers through the combined action of mechanical stress and active chemicals. ESC is related to local plasticization, craze/crack initiation and its/their propagation and it can lead to the premature failure of the component [1].

The ESC phenomenon shares many aspects with slow crack growth naturally occurring in polymers continuously subjected to mechanical stress [1], as in the case of pressurized pipes; the evolution in time of the fracture process is caused by the material viscoelasticity. The lifetime of a given product is thus determined by the sum of the initiation time, required for a crack to start growing, and the propagation time, needed for the crack to advance through the component thickness. In the presence of some substances these phenomena occur faster and, in fact, known ESC agents such as detergents are commonly used to accelerate testing on pipe materials [1].

Other property to be consider for crack propagation is Chain structure, [2] sited that the performance of a simple life analysis produced a similar result, with the more ESC-resistant materials generally having higher values of initiation time, ti and total failure time, tf. At low applied G values however, the analysis shows that HIPS-B can be more ESC-resistant than HIPS-A, as reflected in the initiation plots. Importantly, the proposed test method and resulting analysis is shown to discriminate between high and low ESC-resistant material grades.

Otherwise [3] cited that primary material property that contributes to the ductile failure of HDPE pipes is density or crystallinity; consequently, the ductile failure of HDPE pipes is independent of molecular weight, molecular weight distribution and branching (short and long) distribution. Therefore, authors propose that testing at higher (above- ambient) temperatures causes the residual stresses in the pipe to relax to some extent. This causes the pipe to perform better as residual stresses are known to help accelerate the fracture process. Consequently, one has to be careful about drawing conclusions from tests performed on compression molded specimens that are devoid of the microstructure and residual stresses that are typical of extruded pipes.

ESC has been investigated using several methods including chemical compatibility, time-to-failure, and strain hardening. The former for example, as in Hansen and Just (2001), has enabled the identification of polymer-liquid pairs having a higher tendency to stress crack as judged from the proximity of their solubility numbers. This allows

the determination of polymer-liquid pairs which are inert and thus safe for mutual contact. The downside of these methods, however, is that they do not provide sufficient information for use as design criteria in the development of load-bearing components.

Existing standards in usage, such as the Bell telephone (ASTM (2015a)), full-notch creep (ISO (2004)) and bent strip tests (ISO (2006)) tend only to provide a relative indicator of stress-cracking resistance; furthermore, they do not provide any information as to the mechanisms affecting the fracture rate of the material [4]

The focus of the [1] was to make reliable predictions of the material HDPE in ESC behavior under service life conditions. For this purpose, the investigation also includes the propagation stage following crack initiation. More importantly, tests at different temperatures were performed in view of quantifying the accelerating effect that temperature has on fracture behavior, thus allowing service life predictions at room temperature to be made. For this purpose, the applicability of a **time-temperature superposition** scheme was evaluated, and the relevant initiation and propagation master curves were obtained; to the authors knowledge, this has never been attempted in conjunction with a fracture-mechanics based description of ESC.

[1] cited that slow crack growth and environmental stress cracking resistance of two HDPEs used for the manufacturing of bleach bottles were assessed, at different temperatures, using a LEFM approach. Time-temperature equivalence was successfully applied to fracture data. The master curves in air have the same shape with a ductile to brittle transition observed for both materials. Its onset for the bimodal HDPE was delayed with respect to the monomodal grade as expected from the different molecular weight distribution of the two polymers.

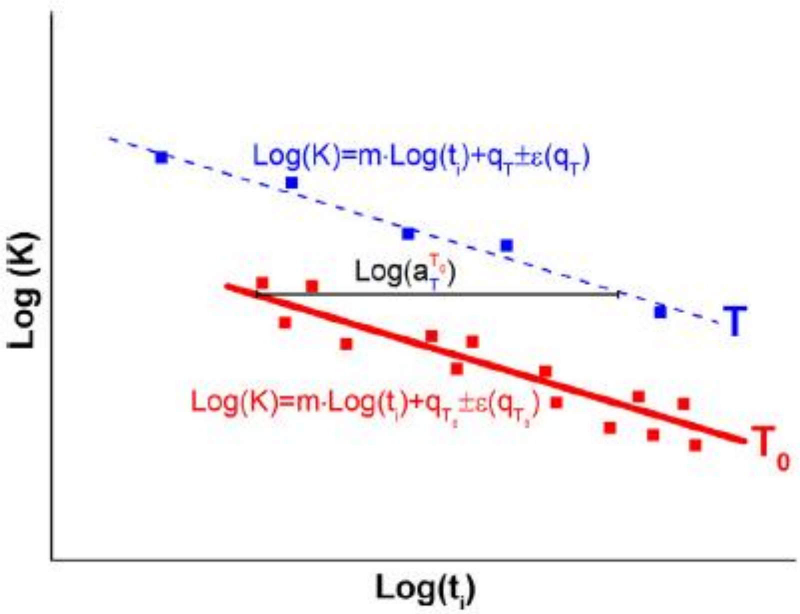
This document analyzes its procedure an evaluate data by the procedure learned on classes, specifically application of principles of rheology like Time temperature superposition (TTS) on results set by the author and make a comparison of the findings

in order to understand the variation among procedures and explain how ESC are affected by the change of temperature.

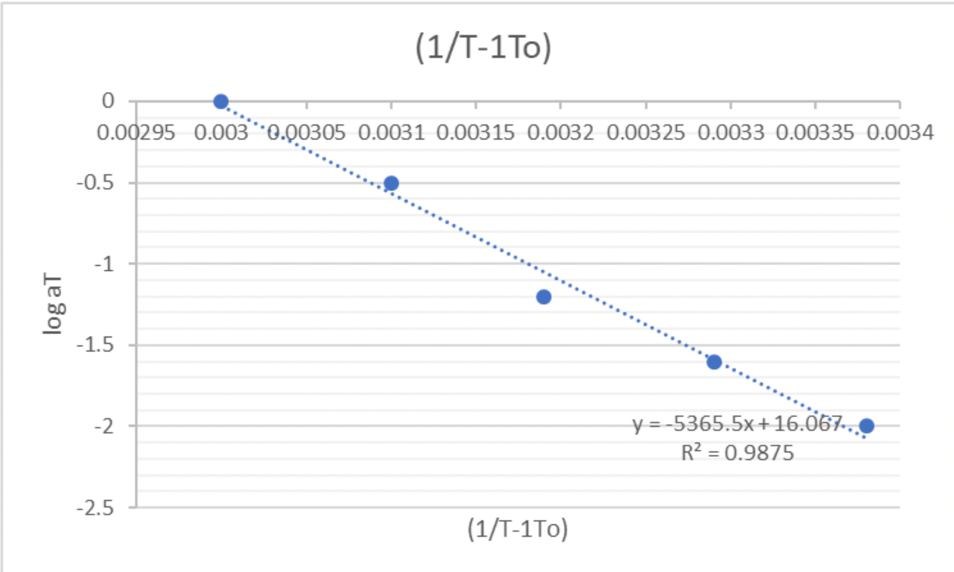
Time temperature superposition can be used to obtain the master curve and with it to estimate the viscoelastic parameters of a defined polymer. Common data in horizontal shift when Tan del is plotted regarding frequency show different values at different temperatures. Once the Vertical shift is applied all values are aligned in the plot of tan del regarding Complex moduli, the trend generated by this shift must be suitable for the change ot temperatures consider in the experimental test, it is important to consider that the objective is to predict further position at different temperatures. The selection of the parameter for the shift appliance is critical for getting a suitable curve. aT factor is got from plotting tan Del vs frequency.

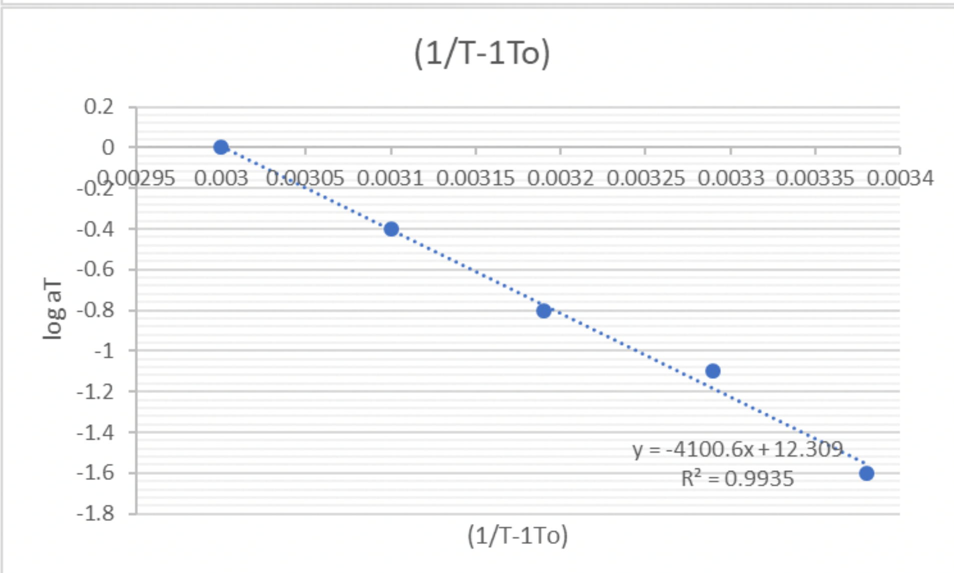
The paper evaluated considered a set temperature To, and Log K vs Log ti were plotted through lineal elastic fracture mechanics for getting a m (slope) and calculating the x-axis interception. At this point the current document propose a different way to solve it, it is possible to get the horizontal shift factor by plotting tan del versus frequency, it is because author mentions results for the two analyzing polymers are on hand. After doing this regarding the temperature that needs to be evaluated you should consider that the setting number is smaller than 1 if the T>Treference and the setting number>1 if T<Treference. Once the frequency is plot versus tan del an aT is modify until it makes the curves overlapped is necessary to plot ln aT vs (1/T – 1/To) where the slope is Ea/R. Ea/R values alloys to determine G´ and G´´ in other temperatures different to what are experimentally tested by using Arrhenius type and WLF equation.

The following plot shows briefly the method that the author used for getting a master curve for the polymers analyzed.



The following plots were created based on the aT values considered in [1] for both polymers, and it show the representative trend gotten of shift values, best fit. The first one is for HDPE-BI and the second one for HDPE-MONO.:





For plotting the master curves, it would be guess the aT values for get a good correction, then once the correction is applied the trend can be compare to the original charts

Conclusions

ESC behavior showed to be very related to MWD, in this paper was not possible to analyze further due to original document avoid a lot of critical information required to do it. But Behavior of two polymers evaluated show that Temperature are also highly related to the behavior of ESC, so as much rubber behavior the material has the ESC is more controlled, and inversely. Using Master curve can can be predicted how additional temperatures could affect the performance of the pipes, in this study the samples. Tg of the polymers evaluated are not noted but it is expected that HDPE-BI that lower because of the trend generated. HDPE with additives can be considered to work against the common wear generated by the fluid, it is a work environment at which the pipes are subjected. Additional studies needs to be performed to define thinning tendency on the wall of pipes caused by the corrosion factors of fluid, even when mechanical properties of tensile strength, fatigue and V-bending would have been performed, thinning and its understanding is critical for failures caused by a manufacturing mistakes of process missing. Other option to wide this study is to analyze from the capillary test point of view.

Nevertheless, it is important to remark that environment fluid can modify drastically the response of crack, it could be a next step of this paper, wider the study analyzing the trend of response of cracking considering the chemical reactions caused by additional fluids, different Ph and composition can be considered.

References

[1] Time-temperature equivalence in environmental stress cracking of high-density polyethylene Marco Continoa,∗, Luca Andenaa, Marta Rinka, Giuliano Marrab, Stefano Restab, 2018

[2] A fracture mechanics approach to characterising the environmental stress cracking behaviour of thermoplastics M.A. Kamaludin a,⇑, Y. Patel a, J.G. Williams a,b, B.R.K. Blackman, 2017

[3] Analysis of ductile and brittle failures from creep rupture testing of high-density polyethylene (HDPE) pipes. Rajendra K. Krishnaswamy *, 2005

[4] Fracture mechanics testing for environmental stress cracking in thermoplastics, M.A. Kamaludin, 2016