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Artificial and Natural Weathering of Chlorinated Polyvinyl Chloride (CPVC)

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Abstract The effects of natural and artificial weathering on mechanical properties of Chlorinated Polyvinyl Chloride (CPVC) pipe material are investigated. Tensile specimens, prepared from locally manufactured CPVC commercial pipes (4-in Schedule 80) were exposed for periods ranging from 2 weeks to 18 months in the harsh weather conditions of Dhahran, Saudi Arabia. The accelerated artificial weathering was carried out in the Q- Sun Xe-3-HS Xenon Test Chambers for periods ranging from 100 to 3000 hours. Standard tensile tests were performed before and after exposure. The tensile test results show that natural and accelerated artificial weathering had limited effects on the tensile and fracture strengths and modulus of elasticity of the material. However, the deterioration of the fracture strain is noticeable for exposure periods as short as 15 days of natural exposure and 100 hours of artificial UV exposure. Visual analysis of exposed specimens revealed that both types of exposures resulted in the discoloration of the specimens.

Introduction

Chlorinated Polyvinyl Chloride (CPVC) is a thermoplastic produced by chlorination of Polyvinyl Chloride (PVC) resin. The basic molecular building blocks of the CPVC molecule are chlorine, derived from salt, and ethylene, which comes from oil or natural gas. CPVC piping systems have been installed and operated since 1959, and initial installations are still performing faultlessly [1]. The effect of adding more chlorine to the PVC molecule is to primarily raise the glass transition temperature (T_g) of the base resin from 95^{o}C to the 115-135^{o}C range [2, 3]. But CPVC pipes like most thermoplastic pipes with sufficient good quality UV screens and heat stabilizers have sufficient weather resistance to withstand normal exposure that occurs before installation. This resistance depends on the ambient temperature, humidity and geographical location. Jakubowicz [4] found that the relative durability of PVC materials in different outdoor exposures can be very different depending on the variation in UV radiation, temperature, time of wetness, pollutants and other factors at various locations. The high intensity of solar radiation and the long period of sunlight exposure coupled with temperatures reaching 50ºC in summer are ingredients that can cause the breakdown of PVC and CPVC pipes used in Saudi Arabia [5, 6]. The extents of degradation of the PVC pipe exposed at the Dhahran (Saudi Arabia) sites were compared to those exposed in Florida [5]. For instance, the tensile strength of white poly(vinyl chloride), PVC, pipes exposed for 24 months in Dhahran decreased by 43% while an exposure of the same duration in Florida resulted in only a 26 percent decrease in the property [5]. Merah [6] has found that among the CPVC tensile properties that are most affected by natural weathering for 9 months is the fracture strain; it was found to decrease by more than 20% after one month outdoors in Dhahran. The degradation in fracture toughness was found to be similar to that of fracture strain but the yield strength and the modulus of elasticity were slightly affected by weathering [6]. The service life of plastics under such harsh conditions is reported to be dramatically reduced [7]. Tong and White [8] found that photo-oxidation of crystallizing polymers may lead to chemi-crystallization that causes significant modifications in the residual stress distribution. They noticed that the major effect is the change in the stress is near the surface which may explain why the tensile strength is not affected.

Gonzalez et al. [9] reported that one of the major problems associated with PVC is its sensitivity to weathering. Furthermore, the presence of oxygen and humidity induces changes in its mechanical properties. Summers and Rabinovitch [10] found that when air temperature varied in the range of 26ºC to 36ºC during the period of exposure the surface temperature of plastics exposed to sunlight can be much higher (by as much as 60ºC for common plastics depending on color and thickness) than that of the surrounding air due to heat build-up. The high temperature is also known to significantly affect the weathering process of polymer materials [11-13]. Weathering of PVC causes a decrease in percentage elongation within a short time of exposure [14-17]. Yield strength and modulus of elasticity of PVC specimens under tensile testing tend to slightly increase over a limited aging time and will decrease after extended weathering [14-17]. Discoloration of the PVC pipes was also observed by Ragab and Alawi [14].

The above literature review shows that while PVC has had its fair share of weathering investigations, very limited work on the weathering of CPVC has been published. In this paper, natural and artificial weathering influence on the physical and tensile properties of CPVC is investigated. The mechanisms responsible for the degradation of the mechanical and physical properties of CPVC are reported in this study.

Experimental Procedure

Tensile specimens were prepared following the procedure described in earlier work [18, 19] and exposed in Dhahran (26° 32' N, 50° 13' E) in accordance with the general guidelines of ASTM D1435-99 standard practice for outdoor weathering of plastics [20]. Specimens were exposed in fixed angle racks such that the area to be tested is facing south at an angle of 45° without backing at about 1.0 m from a usually dusty concrete ground. The longest exposure period of the samples was 18 months. To evaluate the continuous weathering effects on the CPVC pipe material the samples were collected after exposure periods of 0.5, 1, 2, 3, 6, 9, 12 and 18 months. The as-received samples were tested and used as baseline data.

The UV exposure tests were carried out in the Q-Sun Xe-3-HS Xenon Test Chambers equipped with 6000 W borosilicate glass-filtered xenon arc filaments. The conditions for accelerated UV exposure are as follows: UV Filter – DAYLIGHT: Q; UV sensor – 340 nm; Irradiance: 0.5 W/m^2; Humidity: 40% (Minimum); Chamber Air temperature: 40±3°C; Black panel temperature: 57±3°C. The intensity of radiation source was periodically checked with 340 nm radiometer.

A 50-kN Instron 5569 electromechanical material testing system was used to conduct tensile tests. The system is equipped with a specialized data acquisition, data reduction and data plotting software. Tensile tests were performed at room temperature according to the ASTM Standard D638-01 [21] method of test for tensile properties of plastics at a strain rate of 6×10^{-4} s^{-1} (5 mm/min). A 25-mm extensometer was used to measure the deformation in the gauge length of the specimen.

Photographs of exposed and unexposed specimen surfaces were taken using a digital camera for natural and accelerated exposure conditions. Visual observation of the specimens and analysis of the photographs were used to qualitatively describe the change of specimen surface color due to exposure.

Results and Discussion

Effect of Natural Weathering on Mechanical Properties

Table 1 illustrates the average values of the tensile properties (modulus of elasticity, E, tensile strength, σ_{ut}, stress at fracture σ_f, and fracture strain, ε_f) of CPVC pipe material for natural exposure periods ranging from 0 to 18 months. The table includes also the number of tests for each case and standard deviations in the experimental results.

The insignificant effect of weathering on CPVC ultimate strength is observed. This was expected given that the damage due weathering is mainly a surface phenomenon [8]. Similarly, the modulus of elasticity and the fracture strength are found to be slightly sensitive to weathering. The fracture strain however, experiences an abrupt reduction in value that starts after ½ month of outdoor exposure (Fig. 1). Despite the scatter in the experimental results, evidenced by the reported standard deviation, on the average around 20% decrease in the fracture strain is caused by only 15 days of natural weathering. This reduction reaches 38% after an additional ½ month of exposure. Following the first month, the average value of the fracture strain remains almost constant. This decrease in fracture strain is similar to that reported by several researchers for PVC and CPVC [6, 17, 22, 23]. Oxidation may have occurred due to high radiant exposure and increased temperatures of harsh environment conditions of Dhahran. As fracture strain is generally thought of as measure of material toughness, its reduction is an indication of lower toughness. Merah [6] showed that fracture toughness of the material decreased in a manner similar to that of the fracture strain.

Table 1. Average tensile properties with standard deviation (STDV) of CPVC for different outdoor exposure periods

Exposure Time [Months]	No. of Tests	E [MPa]	STDV	σ_{ut} [MPa]	STDV	σ_f [MPa]	STDV	ε_f [%]	STDV
0	8	2871.0	260.9	47.0	1.0	41.2	1.4	21.3	4.3
0.5	4	2863.6	276.2	46.3	1.1	40.8	1.6	17.2	2.4
1	3	3302.1	26.3	48.1	0.8	47.9	0.7	13.2	1.4
2	4	2702.6	123.2	46.4	1.1	42.6	1.7	17.1	2.4
3	4	2989.6	251.3	47.9	0.7	44.1	1.2	16.4	1.5
6	4	2979.5	166.8	48.0	0.7	42.9	1.9	16.3	1.6
9	4	2817.6	145.4	46.8	0.6	46.4	0.9	12.8	2.0
12	4	2703.4	158.4	46.4	0.6	46.4	0.5	13.1	2.6
18	5	2879.7	184.4	47.1	0.8	44.1	1.3	14.1	1.7

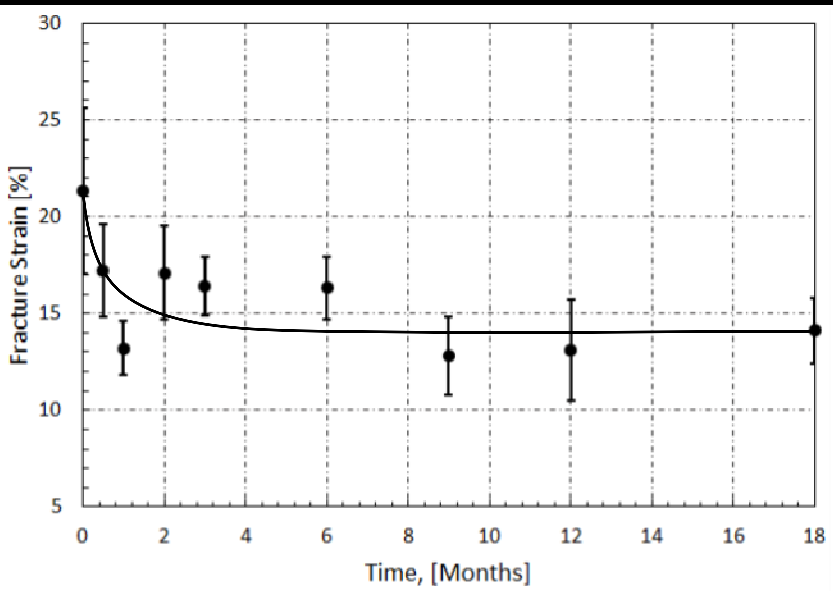

Fig. 1. Variation of CPVC fracture strain with outdoor exposure time.

Effect of Artificial Weathering on Mechanical Properties

Table 2 illustrates the average values of the tensile properties of CPVC pipe material for different accelerated artificial exposure to UV radiation in the conditions specified above. The table includes also the number of tests for each case and standard deviations in the experimental results. It can be concluded from these results that, similar to natural weathering, the effect of artificial accelerated weathering on the tensile strength, fracture strength and the modulus of elasticity is marginal. The material however, looses 1/3 of its fracture strain (Fig. 2) after only 100 hours of artificial exposure. The fracture strain continues to decrease down to about 40% for 300 hours. The present results given an indication exposure at periods longer than 300 hours seem to bring about less degradation and even recovery of toughness. The reason for this recovery may be explained by heat induced material softening that could be expected to occur with prolonged exposure to hot and humid weather. In general, the reduction in fracture strain (embrittlement) is caused by oxidation brought about by exposure to UV combined with heat (Temperature 57°C), oxygen and moisture (RH = 40%). Dehydrochlorination is believed to be the photoreaction responsible for degradation of CPVC toughness observed under these conditions.

Table 2. Average tensile properties with standard deviation (STDV) of CPVC for different accelerated artificial exposure to UV radiation

Exposure Time [Months]	No. of Tests	E [MPa]	STDV	σ_{ut} [MPa]	STDV	σ_f [MPa]	STDV	ε_f [%]	STDV
0	8	2871.0	260.9	47.0	1.0	41.2	1.4	21.3	4.3
100	6	2618.3	234.5	48.2	0.9	44.6	2.3	14.2	5.3
300	7	2626.2	181.6	48.0	1.3	42.3	0.7	12.5	2.9
1000	4	3035.0	345.4	47.2	1.3	44.4	2.4	15.1	4.2
3000	4	2742.3	396.8	48.3	1.1	-		15.3	5.7

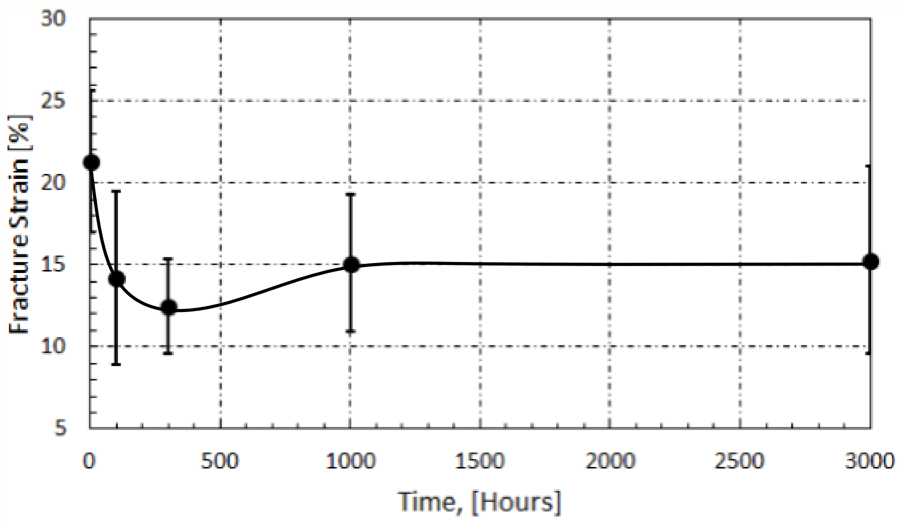

Fig. 2. Variation of CPVC fracture strain with UV exposure time.

Effect of Artificial Weathering on Physical Properties

As can be seen from the photographs of exposed and unexposed specimens of Fig. 3 discoloring of the CPVC samples surface after 100 hours of UV exposure is very light. A significant color change of the specimen surface starts at the exposure period of 300 hours by the gradual increase in the tanning of the specimen surface with the color becoming brown (deep tan) at 3000 hours. The observed gloss loss and deep tan may have been caused by oxidation produced mainly by the combination of UV radiation, temperature and humidity in the chamber. It has been noticed that the surface gloss loss due accelerated artificial weathering is more pronounced than that of natural weathering causing more severe degradation translated by 33% of reduction in toughness for 100 hours of exposure as compared to 20% for ½ month natural exposure.

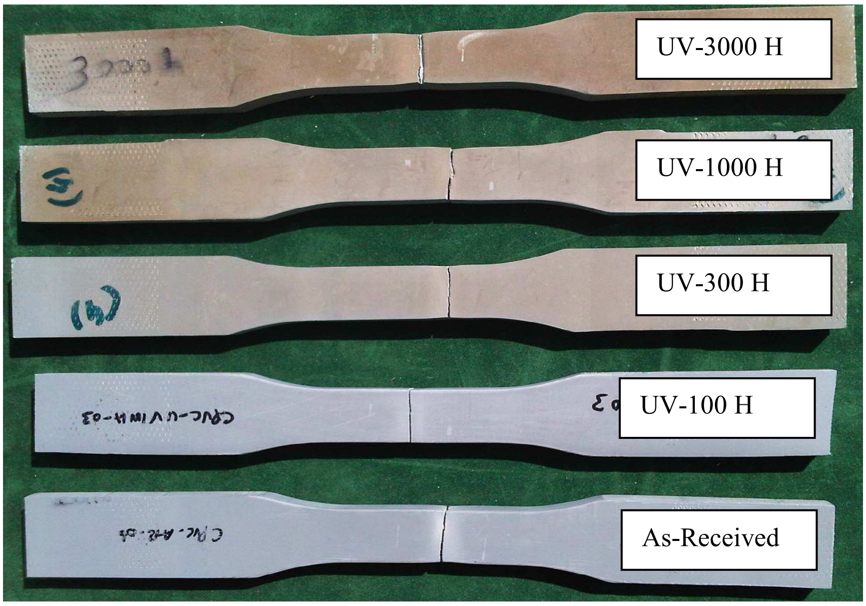

Fig. 3. Discoloring of CPVC specimen surface caused by UV

Conclusions

A large number of tensile specimens were prepared, weathered, tested and analyzed to determine the artificial and natural weathering effects on the mechanical properties of CPVC pipe material. The analyses of the results lead to the following conclusions:

- Among the tensile properties that are most affected by natural weathering is the fracture strain which was found to abruptly decrease at short exposure periods (15 days) with longer exposure periods causing gradual degradation. The yield strength, fracture strength and modulus of elasticity are slightly affected by natural weathering up to 18 months.
- Similar to natural weathering, the effect of artificial accelerated weathering on tensile strength, fracture stress and modulus of elasticity are marginal. The percent fracture strain however, shows an abrupt decrease in average value (about 33%) after only 100 hours of exposure in weathering chamber continuing to decrease to 40% for 300 hours. Similar to natural weathering exposures at periods longer than 300 hours seem to bring about less degradation in toughness.
- Visual analysis of exposed specimens revealed that both types of exposures resulted in the discoloration and gloss loss of the specimens with artificial weathering producing a lot more damage translated by a deep tan of the exposed surface.

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References

[1] http://www.ppfahome.org/cpvc/faqcpvc.html
[2] "Modern Plastics Encyclopedia", 57-58, 1994
[3] S. Brann and M. Knight "Consider CPVC for Process Applications", *Chemical Engineering Progress*, 36-41, Dec 1994.

[4] I. Jakubowicz, “Effect of Artificial and Natural Ageing on Impact-Modified Poly(Vinyl Chloride) (PVC)”, *Polymer Testing*, 20, 545-551, 2001.

[5] I. Hussein, S. H. Hamid, and J. H. Khan, "Poly(Vinyl Chloride) Pipe Degradation Studies in Natural Environments", *Journal of Vinyl and Additive Technology*, Vol. 1, 137-141, 1995.

[6] N. Merah, "Natural Weathering Effects on Some Properties of CPVC Pipe Material", *Elsevier’s Journal of Materials Processing Technology*, Vol. 191/1-3, 198-201, 2007.

[7] A. L. Andrady, S. H. Hamid, X. Hu and A. Torikai, “Effects of Increased Solar Ultraviolet Radiation on Materials”, *Journal of Photochemistry and Photobiology B: Biology*, Vol. 46, 96-103, 1998.

[8] L. Tong and J. R. White, "Residual Stress Distribution Modification Caused by Weathering in Polypropylene and Polystyrene", *Polymer Engineering and Science*, Vol. 37(2), 321-328, 1997.

[9] A. Gonzalez, J. M. Pastor and J. A. De Saja, “Monitoring the UV Degradation of PVC Window Frames by Micro Hardness Analysis," *J. Polym. Sci*. Vol.38, 1879-1882, 1989.

[10] J. W. Summers, and E. B., Rabinovitch**,** "Weather Ability of Plastics Compared at Different Exposure Locations”, *Journal of Vinyl Technology*, Vol. 1, 55-60, 1983.

[11] A. L. Andrady, “*Plastics and the Environment*”, John Wiley & Sons, 2003.

[12] Guang-Xin Li, Yun-Min Chen, and Xiao-Wu Tang, “Geosynthetics in Civil and Environmental Engineering” Berlin, Springer, 2008.

[13] M. Puterman, "Natural and Accelerated Weathering of PVC and Polypropylene Waste Water Pipes" *J. Materials and Structures*, Vol. 22, 170-175, 1989.

[14] A. R. Ragab and H. Alawi, "Weathering Effects on Some Mechanical Properties of Polyvinyl Chloride Pipes", *Journal of Test. and Eval*., Vol. 18, 45-52, 1990.

[15] E. B. Rabinovitch, J. W. Summers, and W. E. Northcott, "Changes in Properties of Rigid PVC During Weathering," *Journal of Vinyl Technology*, Vol. 15, 214-218, 1993.

[16] S. El Raghi, R. R. Zaharan and B. E.Gebril, "Effect of Weathering on Some Properties of Polyvinyl Chloride/lignin Blends," *Materials Letters*, Vol. 46, 332-342, 2000.

[17] L. P. Real, A. P. Rocha and J. L. Gardette " Artificial Accelerated Weathering of Polyvinyl Chloride for Outdoor Applications: The Evolution of Mechanical and Molecular Properties," *Polymer Degradation and Stability*, Vol. 82, 235-243, 2003.

[18] M. Irfan-Ul-Haq, *Crack Propagation in CPVC at Different Temperatures*, M. Sc. Thesis, King Fahd University of Petroleum and Minerals, 2000.

[19] N., Merah, Irfan-ul-haq, M. and Khan, Z., “Temperature and Weld Effects on Mechanical Properties of CPVC”, *J. of Materials Processing Technology*, vol. 142/1, 247-255, 2003.

[20] "Standard Practice for Outdoor Weathering of Plastics" *American Society for Testing and Materials*, Designation: ASTM D1435-99, 1999.

[21] "Standard Test Method for Tensile Properties of Plastics”, *American Society for Testing and Materials*, Designation: D638-01, 2001.

[22] Vandana Singh a, Swati Mohanb, G. Singh a, P.C. Pandey, R. Prakash , “Synthesis and Characterization of Polyaniline–Carboxylated PVC Composites: Application in Development of Ammonia Sensor”, *Sensors and Actuators*, B 132 99–106, 2008.

[23] J. F. Rabek. *Polymer photodegradation: mechanisms and experimental methods*; Chapman and Hall, UK, 1995.