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Resistance to Prolonged Hot Water Exposure

Radel® PPSU

Summary

Evaluating an engineering plastic for suitability for long-term use in hot water environments usually requires a quantitative assessment of that resin's retention of physical and mechanical properties after exposure to hot water for long durations, and the monitoring of these properties as a function of time. In this study, the properties of two Radel® polyphenylsulfone (PPSU) resins were evaluated after exposure up to 8,000 hours in 60 °C (140 °F) and 90 °C (194 °F) water. The two resins were:

- Radel® R-5000 NT, a standard unmodified injection molding grade of PPSU resin
- Radel® R-4200 NT, a proprietary PPSU-based alloy developed as a lower cost alternative to Radel® R-5000 resin that retains most of the unique performance attributes of R-5000

The properties evaluated in this study include tensile strength, tensile modulus and elongation, flexural strength and modulus, weld line tensile strength and elongation, notched Izod impact, tensile impact and instrumented falling dart impact Dynatup.

After 8,000 hours in 60 °C (140 °F) water, no change in any resin property evaluated was noted for either the R-5000 or R-4200 resin. Unlike other engineering plastics tested, after 8,000 hours in 90 °C (194 °F) water, the properties of both resins were still largely unchanged, with reductions in the tensile elongation being the only exception. Despite the reductions in elongation noted with prolonged exposure to 90 °C (194 °F) water, both resins remained decidedly ductile and tough after exposure to this highly accelerated condition. In fact, R-5000 maintained its characteristic super-toughness marked by Izod impact values > 12.0 ft-lb/in even after 8,000 hours in 90 °C (194 °F) water. Based on the results from this study, both the R-5000 series resins and R-4200 should be regarded as leading candidates for high-performance components use in hot water plumbing systems.

Introduction

When considering engineering plastics for use as functional components in hot water plumbing systems, an important selection criterion should be the retention of physical and mechanical integrity of the plastic under prolonged exposure to hot water under conditions at least as severe, but preferably more severe than what the engineered part will experience in actual service. As functional hot water system components can be expected to last over 20 years, it is often impractical to test the longevity of the material under normal use conditions. Increasing the temperature of the system is a commonly used means of accelerating the test, especially for plastic materials, which tend to follow a predictable Arrhenius-type of dependence on temperature. For physical-chemical processes involving plastics, a temperature increase of 10 °C (18 °F) typically accounts for a doubling in the rate of the physical or chemical change in the material.

As the hot water operating temperature of most household plumbing systems is 60 °C (140 °F), it is of interest to examine the effect of long-term 60 °C (140 °F) water exposure on the polymeric resins of interest. As discussed above, however, it may be unlikely to discern any property changes with 60 °C (140 °F) water exposure over practical testing durations. For this reason, it is common to accelerate the testing by using a water temperature 20 °C to 30 °C (36 °F to 54 °F) higher than the temperature of intended use. For the purpose of our study, 90 °C (194 °F) water exposure was employed as an accelerated condition alongside the 60 °C (140 °F) testing. With a temperature 30 °C (54 °F) higher than the target, an acceleration factor of up to 8X can realistically be achieved based on the activated process relationship alluded to above.

Udel® polysulfone (PSU) has a proven history in a wide variety of plumbing applications thanks to several key attributes:

- Stability against hydrolysis by hot water
- Dimensional stability and low water uptake
- Good creep resistance
- Good environmental resistance, especially toward hot chlorinated water

This study focuses on two high-performance engineering resins based on PPSU. PPSU resins exhibit all the attributes of PSU and, in addition, offer enhanced chemical resistance as well as exceptional mechanical toughness. The two resins evaluated in this study were neat Radel® PPSU resin, sold by Solvay Specialty Polymers under the grade designation R-5000 in natural form (which is designated R-5100 when opaque or pigmented to specifications) and R-4200 NT.

Experimental

ASTM D638 tensile (Type I) and flexural bars of 0.125 inch nominal thickness were first injection molded using conventional techniques. Plaques (4 x 4 x 0.125 inch) were also molded for instrumented impact measurements. In addition to the above sample types, weld line tensile specimens were prepared by molding double-gated Type I tensile ASTM D638 specimens to produce a butt weld knit line at the center of the specimen gauge section. The samples were laid flat in individual layers on stainless steel wire trays in constant temperature closed-loop recirculating baths which were controlled at 90 °C (194 °F) and 60 °C (140 °F), respectively. The 90 °C (194 °F) bath consisted of a 90-gallon stainless steel tank which was controlled at the desired temperature via a recirculating process water heater. An identical set up was run for the 60 °C (140 °F) test, except that the tank for this bath was made out of polypropylene instead of stainless steel. The water supply used was potable water from the municipal water supply of the city of Alpharetta, GA. The heated water was analyzed and found not to contain any within the 0.1 ppm detection limit of our analysis. The lack of chlorine is important as the intent of this study was to isolate the effect of hot water alone from the oxidizing effects of chlorine.

Test specimens were removed from the bath after 250, 500, 1,000, 2,000, 4,000 and 8,000 hours and subjected to ASTM mechanical property testing at room temperature per the test specifications listed below. No attempt was made to remove the absorbed water from the samples through drying prior to testing. The mechanical tests conducted are shown in Table 1.

Table 1: Mechanical properties testing

Property	ASTM Test Method
Tensile strength and elongation	D638
Weld line tensile strength	D638
Flexural strength	D790
Notched Izod impact	D256
Tensile impact	D1822
Instrumented falling dart impact (Dynatup®)	D3763

Results and Discussion

Table 2 shows mechanical properties of the two resins as-molded and following 8,000 hours exposure to water at 60 °C (140 °F) and 90 °C (194 °F) .

The mechanical properties of both resins showed no significant change after 8,000 hours in 60 °C (140 °F) water. The change in values between the as-molded column and the exposed column are well within the experimental errors of the various measurements. No changes were seen at any of the five intermediate time intervals examined, which are excluded here for the sake of brevity.

The 90 °C (194 °F) water exposure experiment showed that most properties were again either unchanged or only slightly affected, as listed in Table 2. To give a better feel for the nature of the changes over time at this exposure condition, plots of various mechanical properties over the exposure duration are shown in Figures 1-10.

Figures 1 and 2 depict the tensile strength and modulus, both of which are clearly unchanged within the variability of the measurement over the 8,000-hour period. Tensile elongation at break is one of the properties affected, as shown in Figure 3. There is considerable scatter in the elongation data, but a downward trend is evident culminating in an elongation level of about 20 % for both resins. This elongation level is still high for all practical purposes, represents very good resin ductility and is well past the yield points of both resins.

Flexural strength and modulus properties are depicted in Figures 4 and 5, respectively. With these properties no significant change is recorded over the 8,000-hour test. Weld line tensile strength and elongation (Figures 6 and 7) also show very good stability and retention of the original values. Impact properties are plotted as a function of exposure duration in Figures 8 through 10. Notched Izod, tensile impact and instrumented impact all exhibit constancy over the entire test period. The retention of the very high notched Izod of Radel® R-5000 NT under this aggressive test protocol is particularly unique and noteworthy.

Table 2: Retention of mechanical properties of Radel® PPSU after 8,000-hour exposure to 60 °C (140 °F) and 90 °C (194 °F) water

Property	As-Molded	After 8,000 Hours at 60 °C (140 °F)	After 8,000 Hours at 90 °C (194 °F)
Radel® R-5000 NT			
Tensile strength [psi]	11,200	11,000	11,400
Tensile modulus [ksi]	375	361	361
Tensile elongation at yield [%]	8.0	7.8	7.3
Tensile elongation at break [%]	72	61	22
Flexural strength at yield [psi]	17,200	17,100	17,800
Flexural modulus [ksi]	362	364	366
Notched Izod impact [ft-lb/in]	13.1	13.3	12.7
Tensile impact [ft-lb/in²]	232	252	242
Dynatup impact – max. load [lb]	1,570	1,620	1,490
Dynatup impact – total energy [ft-lb]	48.0	44.5	41.2
Weld line tensile strength [psi]	10,500	10,200	10,500
Weld line tensile elongation [%]	17	21	13
Radel® R-4200 NT			
Tensile strength [psi]	11,000	11,100	11,700
Tensile modulus [ksi]	420	380	393
Tensile elongation at yield [%]	6.7	6.6	6.0
Tensile elongation at break [%]	44	72	21
Flexural strength at yield [psi]	17,700	17,800	18,500
Flexural modulus [ksi]	378	408	413
Notched Izod impact [ft-lb/in]	2.8	2.5	1.9
Tensile impact [ft-lb/in²]	180	191	185
Dynatup impact – max. load [lb]	1,400	1,400	1,320
Dynatup impact – total energy [ft-lb]	45.6	46.8	42.1
Weld line tensile strength [psi]	10,500	10,500	11,000
Weld line tensile elongation [%]	11.6	25	7.9

Figure 1: Tensile yield strength after aging in 90 °C water

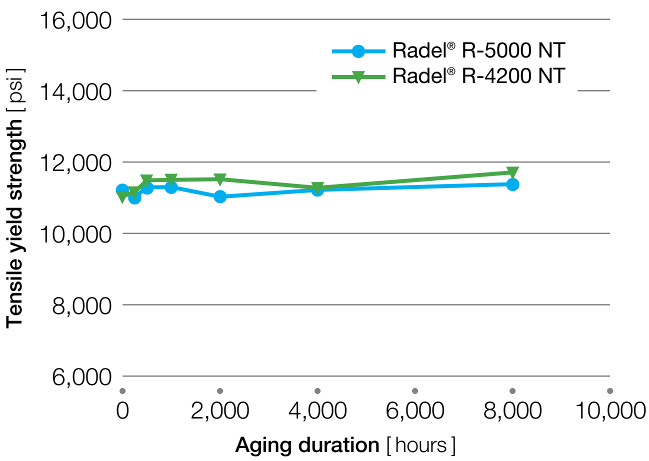


Figure 2: Tensile modulus after aging in 90 °C water

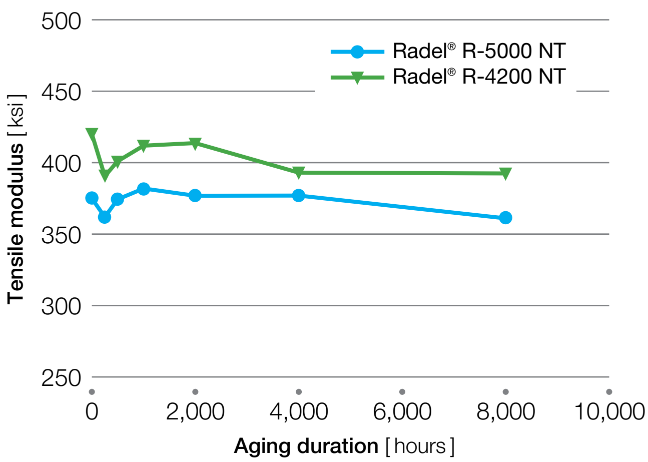


Figure 3: Tensile elongation after aging in 90 °C water

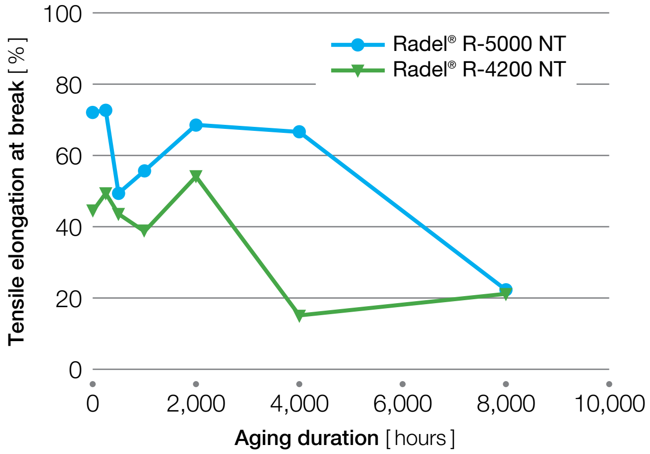


Figure 4: Flexural yield strength after aging in 90 °C water

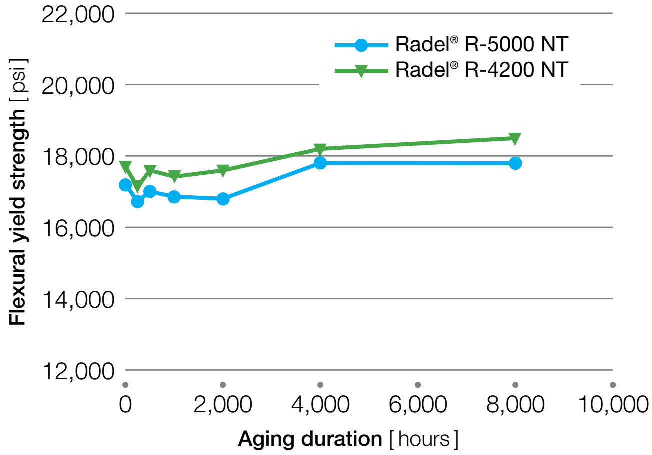


Figure 5: Flexural modulus after aging in 90 °C water

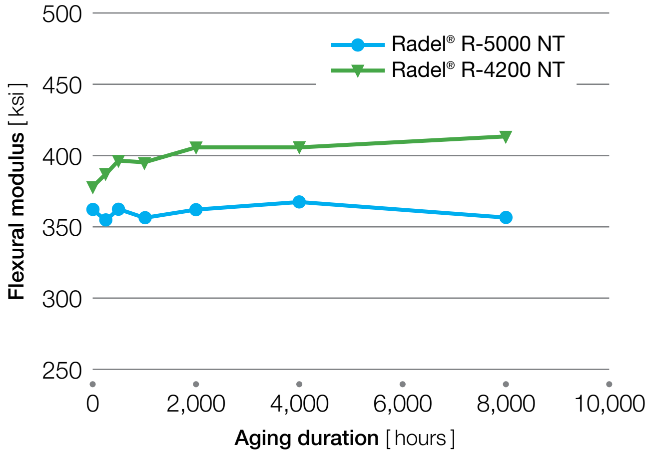


Figure 6: Weld line tensile yield strength after aging in 90 °C water

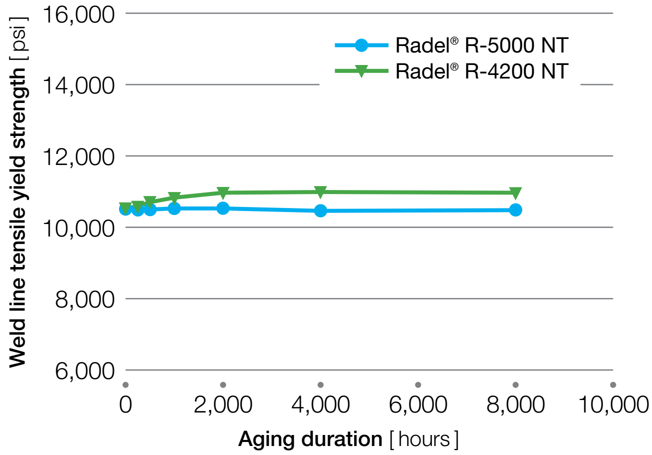


Figure 7: Weld line tensile elongation after aging in 90 °C water

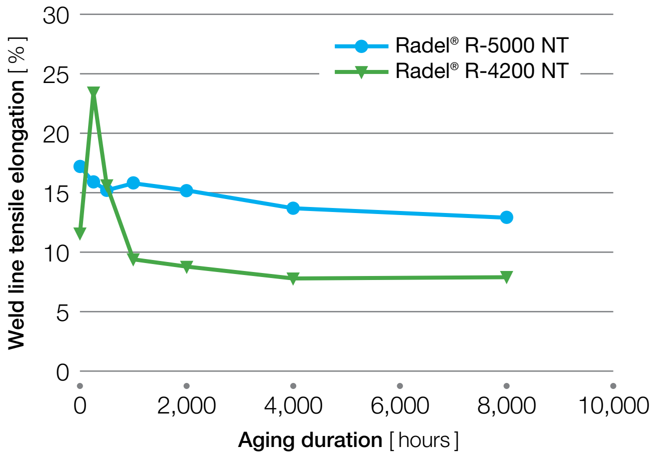


Figure 8: Notched Izod impact after aging in 90 °C water

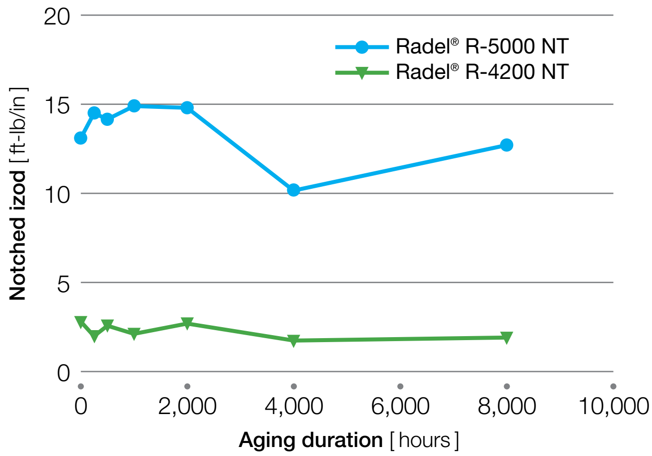


Figure 9: Tensile impact after aging in 90 °C water

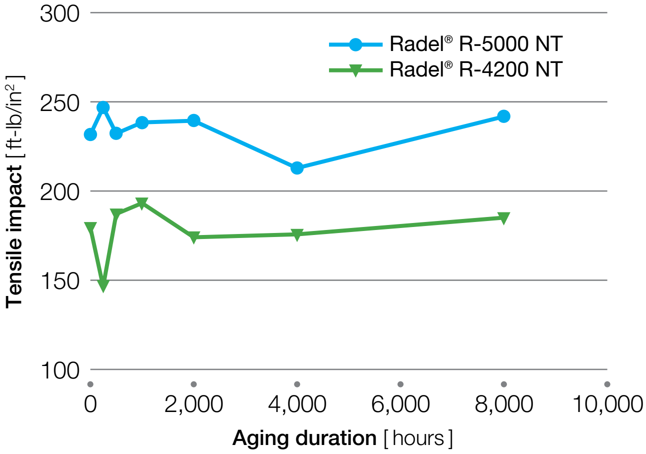
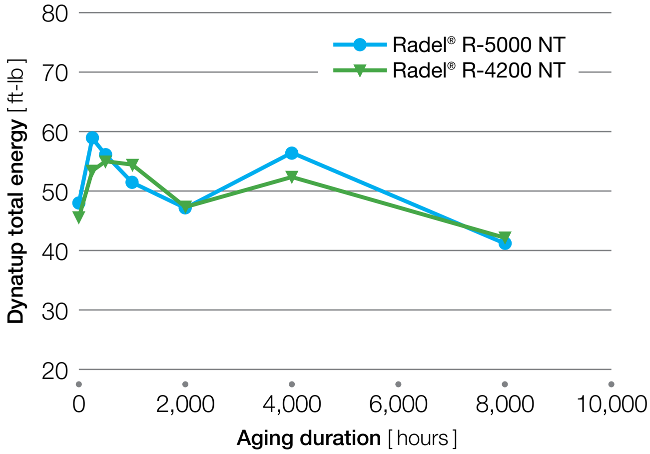


Figure 10: Dynatup instrumented impact after aging in 90 °C water



Conclusions

The results of this study demonstrate that Radel® PPSU resins are generally unaffected by prolonged exposure to hot water at temperatures as high as 90 °C (194 °F). The resins uniquely retain all strength, stiffness and impact properties. Tensile elongation is somewhat reduced but a practical level of elongation is maintained. The hydrolytic stability attributes highlighted here, along with the other important engineering properties displayed by these resins, like dimensional stability, low moisture uptake and ease of fabricability, make these materials particularly suited to replace many metals in functional plumbing parts and components of hot water systems.

Since each plumbing application has unique performance requirements and design criteria, it is important that specialized testing be conducted by the design engineer to evaluate the resin under conditions that simulate the function of the component in service. The hydrolytic stability evaluation results reported here are not a substitute for such testing.

For more information please contact your Solvay Specialty Polymers representative.

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