Cross Linked Rotomolded Polyethylene Storage Tanks Offer Superior Resistance To Rupture

1. Introduction:

Polyethylene is a diverse polymer material used in many products and applications. This diversity is due to the material's ability to be produced with a wide range of properties and characteristics such as impact strength (toughness), chemical resistance, design flexibility, and overall mechanical strength. Such diversity provides engineers and designers greater flexibility in selecting the proper polyethylene resin grade for the intended application. This also requires them to be aware of the strengths and weaknesses, or limitations, of each of the commercially available polyethylene resin grades. Failure to truly understand the materials physical properties can result in premature failure of the designed product and in a worst-case scenario, catastrophic failure.

There is a strong correlation between a material's toughness and its resistance to rupture. In fact, the more resistant a polyethylene resin grade is to rupture the tougher it is considered to be. Rupture is defined as failure due to tensile stresses that are orders of magnitude higher than the yield stress of the material. In thick polyethylene products such as in pipes and tanks, the failure mode due to rupture is in the form of crack initiation and subsequent propagation through the thickness. Factors such as density (crystallinity), temperature and the presence of residual stress or stress concentrators such as notches and defects all influence the rupture resistance of polyethylene. In general, linear polyethylene resin grades that are high in density are less resistant to rupture than those lower in density. However, high density linear polyethylene resin grades are ***notch sensitive***. That is, they are unable to deform or yield upon impact, and thus cannot resist crack propagation once it's initiated. Unfortunately, in the area of rotomolded storage tanks the presence of notches is unavoidable. Whether they are at the surface of the rotomolded article (such as a surface scratch), or within the materials thickness, notches can develop during de-molding, handling, transportation, loading, and unloading of the rotationally molded storage tanks. These notches can and will ultimately grow to form cracks that will propagate throughout the materials cross section. In the case of linear polyethylene resin grades, the resulting stresses experienced during filling and discharging of the stored liquid and the natural expansion and contraction of the polyethylene material will accelerate this propagation and lead to the "un-zipping" (catastrophic failure) of the rotomolded tank.

The problem of notch sensitivity in rotationally molded storage tanks can be eliminated by using **cross linked** polyethylene resin. In this material, the molecular chains that make up the polymer are chemically bonded together, or bridged, to form a continuous three dimensional structure. This allows the impact energy to be dissipated throughout the infinite chain of molecules, or three dimensional structure. In the case of linear polyethylene however, the impact energy is always localized and thus the generated stresses are higher. In addition to enhancing the overall mechanical properties of polyethylene, these "bridges" or "cross links" act as crack arrestors and do not allow the polyethylene material to unzip due to crack propagation.

Because un-zipping of the polymer chains can lead to catastrophic failure in linear polyethylene resins, Poly Processing Company conducted a comparative study on rupture resistance and notch sensitivity of both cross linked and linear high density polyethylene. Rotomolded tanks, from both materials, were subjected to high impact and over-pressurization to study their rupture behavior and the effect of notch sensitivity on crack propagation. This study and all associated tests were witnessed and supervised by an outside engineer with advanced degrees in Mechanical and Materials Engineering and an expertise in the area of polymer science and engineering.

2. Comparative Study:

Two sets of rotomolded polyethylene tanks having a storage capacity of 3,000-gallons were used in this comparative study. Each set consisted of two tanks, one made from cross linked polyethylene and the other from linear polyethylene. Table 1 lists the trade name of these two resin grades used in this study and their relevant physical properties. The rotomolded tanks were fabricated in accordance with the instructions and guidelines highlighted in ASTM D1998. This insured that these tanks met the quality requirements of optimum cure and proper fabrication.

Table 1: Physical Properties of each of the two resin grades.

Material	Trade Name	Color	Melt Index (g/10min)	Density (g/cm^3)	Tensile Strength (psi)	Low Temperature Impact (ft. lbs. at –40 C)	ESCR[1] (Hours, 10% Igepal)
Linear PE	TR-942	Natural (white)	2	.943	3000	68	250
Crosslinked PE	PolyCL	Natural (yellow)	22	.946	3290	71	>2000

[1] ESCR: Environmental Stress Crack Resistance

Two tests were selected for this study, a drop test and pressurization to failure test. The high loads placed on the tank allowed us to test the rupture resistance and notch sensitivity of linear and cross linked polyethylene resin grades in a condensed time period. The following paragraphs provide a detailed summary of the two tests and the results they generated.

A. The Drop Test:

The first test in this comparative study was the drop test. Each tank in the first set was filled with 7000 pounds of water, and lifted with a crane, one at a time, to a height of 15 feet. This height is comparable to that used in the testing of polyethylene drums used for fuel storage. Once the rotomolded tank reached the desired height it was released and allowed to free-fall onto the concrete surface below. Figures 1 and 2 are pictures of the two tanks after the drop test. It can clearly be seen from these pictures that the linear tank, figure 1, has catastrophically failed. This catastrophic failure and its associated crack propagation appeared to be consistent with the un-zipping characteristic found in linear polyethylene resin grades. On the other hand, the cross linked polyethylene tank, figure 2, did not fail or develop any cracks.

We then filled the exact same Poly Processing Crosslinked Tank, the same tank that had just been dropped, but this time with 11000 pounds of water. That's over 15 times the weight of an empty tank. We dropped it from the same height, to the same surface with the same results, no damage to the tank

To prove the tank was not damaged and to demonstrate the outstanding robustness of our Crosslinked Polyethylene Tanks, we dropped the same tank for a 3rd time. This time we went as high as the crane would go, 45 feet in the air which is 5 times the height of the tank. It held 11000 pounds of water which is 15 times the weight of the empty tank. Once again no damage to the tank after the 3rd drop.

Figure 1 HDPE (Linear)
Polyethylene

Figure 2 XLPE
Crosslinked Polyethylene

B. The Pressurization to Failure Test:

Each tank in the second set was completely filled with water and using a 5.5 horse power heavy duty water pump, was pressurized until failure or rupture. The manway opening was completely sealed and the pump was connected to the tank through a standard 2 inch diameter pipe fitting. This technique simulates the normal filling characteristics of a tanker truck loading a bulk storage tank in the field. The pressure inside the tank was measured using a standard dial gauge. Figure 3 shows the catastrophic failure of the linear polyethylene tank after the pressure inside the tank reached 9 psi. The failure of the tank was the result of multiple fracture lines, or cracks. The smooth fractured surfaces indicate a brittle failure.

Figure 3 HDPE (Linear)
Polyethylene

Figure 4 XLPE
Crosslinked Polyethylene

Figure 4 shows the cross linked polyethylene tank which failed after reaching internal pressure of 10 psi. Unlike the linear tank, only a 6 inch lesion was formed on the dome of the tank due to the pressurization. This clearly demonstrates the excellent resistance of cross linked polyethylene to crack propagation or un-zipping. Further analysis of this lesion revealed that it developed at one of the top corners of the stiffening gussets found on the dome, which is a stress riser location. Also, this lesion exhibited a ductile failure mode due to the presence of elongated plastic strands.

3. **Summary**:

This comparative study, conducted by Poly Processing Company, clearly demonstrates the higher resistance of cross linked polyethylene to rupture and catastrophic failure in high impact and over pressurization conditions. It also demonstrates the ability of cross linked polyethylene to resist crack propagation or un-zipping, a characteristic linear polyethylene does not have. The drop and pressurization to failure tests also demonstrate the overall superior performance of the cross linked polyethylene material and the added factors of safety that this material provides.

Complete video footage of the drop test and pressurization test can be found at
www.polyprocessing.com/technical-resources/video-library/

References:

1. Peacock, Andrew J. Handbook of Polyethylene, Structures, Properties, and Applications.

2. A. Brent Strong, Plastics, Materials and Processing, Second edition.