Poly Processing Company
Team Innovation

Repair of Rotomolded Polyethylene Parts

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1- **Introduction**:

Polyethylene, in its many resin grades and densities, is by far the most widely used plastic in the world. Its relatively low cost, when compared to other commercial plastics such as Polycarbonate and Nylon, and its wide range of material properties have facilitated the utilization of polyethylene (PE) in many product applications and manufacturing processes.

This paper highlights the main methods or techniques that are available for repairing both linear and crosslinked PE rotomolded parts. Such products are in many applications where significant loads are encountered and more stringent performance standards are required. Even though products are designed with a safety factor, failures can and do occur due to unforeseen loading scenarios and/or product use beyond the manufacturers designed service factor. When replacement of these PE parts due to damage is not an option, proper repair becomes the only feasible choice short of complete replacement.

2- **Bonding Characteristics of Polyethylene**:

Polyethylene has a number of desirable properties that include, but are not limited to, excellent chemical resistance and inertness. This chemical resistance is due to the lack of free electrons within the polymer network and the low or negligible polar component of the carbon-carbon and carbon-hydrogen bonds that comprise the polyethylene structure. This environment of low electron reactivity causes the polyethylene material to have low surface energy. This low surface energy will not facilitate proper wetting and spreading of the adhesive onto the polyethylene surface, thus making polyethylene difficult to patch or repair. Also, polyethylene is not porous and therefore does not lend itself to mechanical surface attachment, that is, joining an adhesive to a surface because the adhesive flows into the cavities on the surface and therefore creates a mechanical attachment. While properties such as chemical resistance and inertness are highly desirable in applications like chemical storage and electrical insulation, they present a challenge in applications where joining, assembly, printing, and repair are required because all of these require a high surface energy.

The strongest bond that can be achieved is one that is chemical in nature, that is, where electrons are shared. Since polyethylene is highly inert and has no free electrons to share, it cannot be bonded, repaired, or welded through normal chemical processes. Some manufacturing operations, such as printing, have found a way to overcome this difficulty by increasing the surface energy of the polyethylene through some special treatment technique. Through flame, corona, or plasma treating the surface, the chemical composition, or polarity, of the surface molecules can be altered. This alteration will increase the surface energy and allow enhanced bonding characteristics. Unfortunately, surface treating as a method of repair of polyethylene products is not practical. Although the surface of the part can be treated, such as the outside of a polyethylene bottle that is to be printed or that will have a label attached adhesively; it is difficult to fully treat the surfaces of a crack or a defect. Cracks or pinholes go through the thickness and rarely spread sufficiently to have access to the actual surfaces that need to be joined. Therefore, especially across the thickness, any bonding that occurs will be weak and will not withstand typical design loads.

Another technique, besides the use of adhesives that is used to bond materials is to bond materials together by fusion. In this technique, the two parts to be joined are brought into actual physical contact and the heated. Proper polymer fusion bonding requires that the molecules on both sides of the bond become mobile and interdiffuse. For thermoplastic material this is achieved through the addition of thermal energy (heat) which causes the viscosity of the polymers decrease and also increases the mobility of the molecules. The decrease in viscosity and the increase in mobility of the polymer chains will allow them to interdiffuse, and thus form a strong bond. It's this same decrease in viscosity and increase in mobility that allows thermoplastic polymers to be shaped and molded through the addition of heat beyond the softening or melting temperature. Thus in the absence of chemical bonding (as with adhesives), thermal repair (fusion) becomes a more viable option.

3- **Thermal Repair**:

A- Linear Polyethylene:

Repair using heat (thermal energy) is by far the most common method for the repair of thermoplastic material, such as linear PE, which soften and melt upon the application of heat, and which are not readily joined by adhesives. Regardless of how this thermal energy is generated, sufficient thermal energy must be applied to allow the plastic polymer chains to interdiffuse and weld together. This repair method is commonly referred to as plastic welding. Examples of some repair or welding processes include:

a- *Fusion Welding*: The thermoplastic polymer is heated to the viscous or melt state and then pressure is applied to cause the polymer chains to interdiffuse and bond together again. The heat (or energy input) can be generated through a number of methods, such as hot plate, ultrasonic, and vibration. (Some may be surprised that ultrasonic vibrational energy inputs will cause fusion to occur since they are not necessarily high heat input methods. However, they are high-energy input methods, which are just as effective as heat in causing the molecules to interpenetrate or diffuse.

b- *Extrusion welding:* Heated gas or air is blown onto the surface being repaired (or the parts being welded) and simultaneously onto a filler rod that is fed through an extrusion tool (usually hand-held) to fill the defect or weld joint. The polymer used in the filler rod is the same type ads the parts to be joined (that is, in the case we are discussing, polyethylene). The hot air softens the surface of the part and simultaneously melts (or partially melts) the filler rod. Pressure can also be applied using a metal tab to enhance the bonding and filling of the injected polymer. This repair process is also used for permanent assembly of parts, such as fittings and connectors, on large rotomolded plastic tanks.

c- *Spin welding:* Even though this process is more tailored to the assembly of two relatively flat plastic parts together, there are certain instances where Spin Welding is used for repair. In this process, one of the two parts is fixed while the other is rotated at high angular velocity. The rotating part is moved into position where it just touches the part to be repaired and frictional heat causes the polymer along the contact surfaces to melt. Permanent assembly or weld is created upon cooling. Due to the nature of this process, it's only suitable on repair applications where one of the components is circular. Also, large defects are difficult to repair using this method because of the need for higher thermal energy that can be obtained with spinning. This method of repair is common on plastic tanks and gas pipes that develop holes or circular defects.

There are a number of disadvantages associated with the above methods of repair. These methods can have a detrimental effect of final part quality. Residual stresses are created upon repair or weld completion due to cooling effects. The high heating rates that are required for proper interdifusion of the polymer chains causes a sharp thermal differential between the repair area and the surround unheated plastic. This sharp differential in temperature profiles leads to the creation of localized residual stresses upon cooling that reduce the material's mechanical properties at the repair or weld location. A pull or tensile effect is generated between the repaired areas and the non-repaired areas during the cooling process. In addition to the development of residual stresses upon cooling, thermal degradation of the polymer can result especially when the thermal energy used exceeds optimum recommended levels. Also, the application of this thermal energy further consumes the Antioxidant and Stabilizer packages at the repaired area making it weaker. For these reasons, thermal repair of tanks that are used in high-end applications, such as the storage of sodium hypochlorite, is not recommended and is not practiced at Poly Processing Company.

B- Crosslinked Polyethylene:

As indicated earlier, in the absence of chemical bonds, proper bonding or repair of polyethylene requires the molecules or molecular chains to interdiffuse. Crosslinked polyethylene is a material in which the molecular chains are chemically tied or bridged together during the molding process. Even though this bridging substantially increases the chemical resistance and mechanical properties of the rotomolded part, the crosslinking also restricts the mobility of these molecules and their ability to interdiffuse. Poly Processing Company has developed a proprietary process that allows the repair of pinholes or voids that might develop in crosslinked polyethylene rotomolded tanks without reducing the service life of these tanks. This process can also be applied to other rotomolded products made from crosslinked polyethylene that have similar types of defects.

A layering technique has been developed such that one can build on the original material and completely seal the defected area. The use of controlled steady state heating, coupled with timely addition of new crosslinked powder material, allows a more uniform thermal gradient to develop. This slow gradual heating allows the creation of fusion bonds as well as, the creation of chemical bonds and new crosslinks. This occurs not only within the newly added material but also, between the new material and the original rotomolded crosslinked polyethylene part. The heat applied is sufficient to initiate the crosslinking reaction or bridging in the newly added material and to initiate some bonds with the part to be repaired. The final result of this process is a repaired area that has similar mechanical properties as the original rotomolded part.

With the help of Louisiana Tech University, a study was conducted to investigate the consequences of this repair technique, developed at Poly Processing, on final part quality. Tensile, impact, and bent strip tests were conducted on repaired samples. The results were compared to control samples that did not have any defects in them. The data gathered from these tests show a minimal loss in mechanical properties using the Poly Processing method of repair on crosslinked polyethylene parts.

a- Tensile Strength Test:

Using Type III samples, per ASTM D 638, Standard Test Method for Tensile Properties of Plastics, 3 sets of 5 samples each where cut from a ¼ " thick rotomolded part. Simulating a pinhole and/or a void defect, a 3/8" hole was drilled 50% (halfway) in one set of samples and 100% of the thickness in another set of samples. These were then repaired using the layering technique developed at Poly Processing. The third set (control set) was not drilled.

Figure 1 shows the average tensile strength for each of the three sets. The control sample is displayed as 0% thickness drilled and the others are 50% drilled and 100% drilled. We can see that the process of repair did not reduce the strength of the material since both of the repaired sets had about the same strength as the original (within the experimental variation limits). It remained approximately the same, especially when we include the standard deviation within each set as indicated in table 1 below. There is a slight decrease in the overall ductility of the material. This is an indication that the repaired region is stronger than the bulk or original resin material.

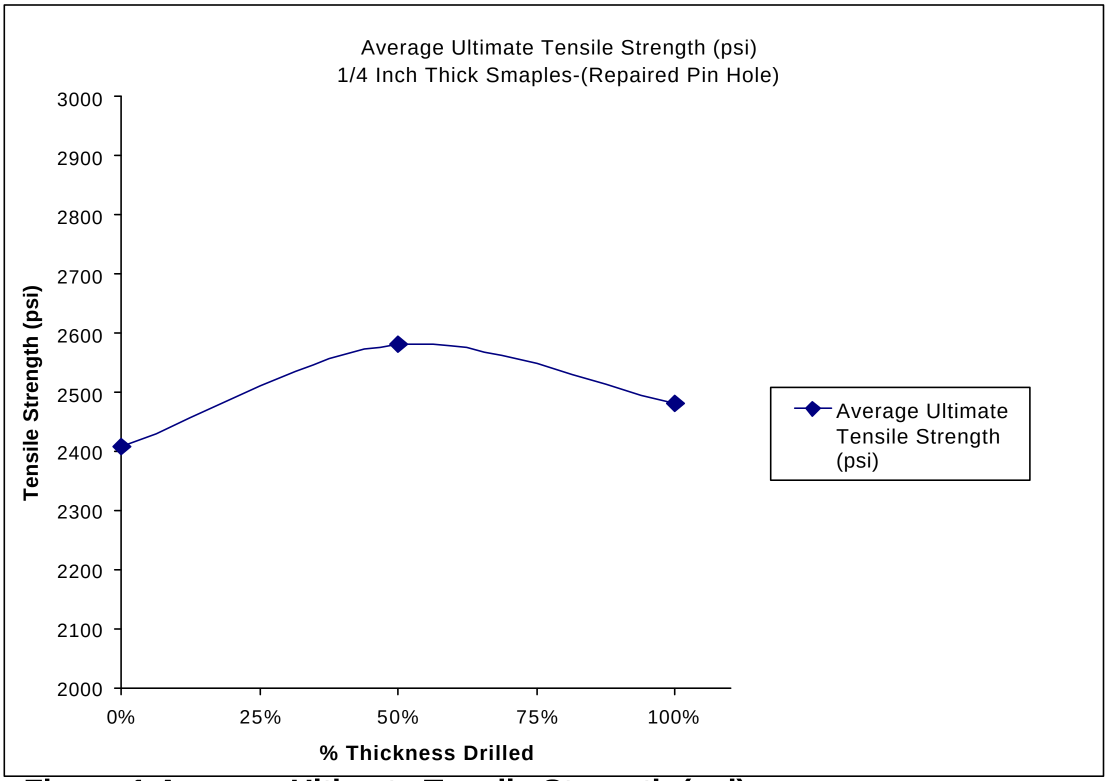

Figure 1 Average Ultimate Tensile Strength (psi)

Table 1: Tensile Strength Data, samples pulled at a strain of 2 inches per min.

Hole Depth % Thickness	Average Tensile Strength (psi)	Standard Deviation of Strength (psi)	Average Ductility (Strain) (%)	Standard Deviation of Strain (%)
No Hole	**2408**	**143**	**49**	**12**
50% Drilled	**2580**	**106**	**40**	**20**
100% Drilled	**2480**	**66**	**30**	**8**

b- Impact Test:

For this test, 4" X 6" samples cut from a 1" thick rotomolded part were used to evaluate the effect of the Poly Processing repair method on the original impact strength of the rotomolded tank. This evaluation was done using the general guidelines for dart drop impact testing specified in ASTM D 1998, Standard Specification for Polyethylene Upright Storage tanks, Sec 11.3. As in the tensile test, the samples were divided into five sets and 3/8" diameter holes were drilled and repaired in four of the five sets. The depths of the holes were 25%, 50%, 75%, and 100%. The samples were impacted using an impact load of 200 ft. lbs. and was performed at ambient, 0° F, and –40° F temperatures. Table 2 lists the results of the impact testing where the samples were evaluated as simple pass (without shattering) or fail (shattering or full penetration).

Table 2: Impact testing at different temperatures.

Hole Depth (% of thickness)	Temperature		
	Ambient	0 (°F)	- 40 (°F)
No Hole	2 Pass	2 Pass	2 pass
25% Drilled	1 Pass	2 Pass	2 pass
50% Drilled	2 Pass	2 Pass	2 pass
75 % Drilled	2 Pass	2 Pass	2 pass
100% Drilled	1 Pass	2 Pass/ 2 Fail	3 Fail

From the above table we can conclude that for repaired pinholes having a depth up to 75% of the wall thickness, no loss in Impact strength is experienced. As for pinholes that completely penetrated the wall, for lower temperatures there is a reduction in the impact strength. Further analysis revealed that this reduction is only present when the load is dropped directly on the repaired area. When the load was applied 2 inches away from the repaired area, the impacted samples passed at the lowered temperatures.

c- Bend (Peal) test:

For this test 3 sets of samples, 5 in each set, were slightly bent and the ends of each sample were mechanically joined so that the bend was restrained. The samples were then conditioned for one hour and further bent using a vise. Similar to the tensile and impact tests, two sets had 3/8" holes in them. Each 2" X 12" sample was cut from a ¼ inch thick, rotomolded part. Table 3 lists the results of this test, which was also conducted at lower temperatures. All the tested samples passed. The purpose of the severe strain test is to verify the proper bonding of the repaired area to the original rotomolded material. Failure is the occurrence of cracks in the sample.

Table3: Bend Test:

Hole Depth (% of thickness)	Temperature (F)		
	Ambient	20 (F)	0 (F)
No Hole	1 Pass	1 Pass	3 Pass
50% Drilled	1 Pass	1 Pass	3 Pass
100% Drilled	1 Pass	1 Pass	3 Pass

4- **Mechanical Repair**:

This method of repair is applicable for both linear and crosslinked polyethylene. It utilizes mechanical means and compatible components to seal and repair cracks or holes that can be found in rotomolded hollow parts. It is by far the most widely used method of repair for products or tanks that are already in the field. Blind fittings, plugs, and sleeves (for pipes) are a few examples of the many components that are used in this method of repair. This repair process starts by removing or routing out the damaged area. For example, if we detect a hole or a crack on the side of a tank, that area is routed out. As expected in most mechanical repair applications, due to its application simplicity, the removed area is circular is shape. Depending on the size, location, and nature of the crack, the routed out area can also be oval in shape. Based on the size of this circular cutout one can select the appropriate component or components for sealing and repair. These components can be assembles, threaded, or press fit to cover and seal the routed or removed area.

Repair of rotomolded parts using mechanical means is usually accomplished without the need to heat the damaged area prior or during the repair process. This eliminates the development of residual stresses or the degradation of the polymer, upon cooling due to the thermal gradient that is generated during the repair process. Nevertheless, great care needs to be taken when conducting mechanical repair. One needs to insure that the routed out area is smooth and free of sharp edges that can lead to stress risers. These sharp corners can themselves be starting points for new cracks. To illustrate this further, the natural continuous expansion, contraction, and filling of storage tanks are loading mechanisms that cause stress to develop within the walls of the tank. If a stress riser is present due to improper routing or repair, the stress level at that point can exceed the overall strength of the polymer material thus crack initiation and propagation will occur. The impact of this potential hazard is more profound in rotomolded parts that are made out of linear polyethylene (LPE) than crosslinked polyethylene (XLPE) due to the tendency of LPE to catastrophically unzip due to repeated loading.

4- Other Methods:

The methods of repair described in this paper are not an exhaustive list but are provided to give a general idea of what options are available. It is worth mentioning that it is uncommon to find these methods used in-concert with the above described repair methods.

a- *Repair Patch Kits*: A typical repair kit consists of a repair patch made out of a compatible polyolefin, a master filler, and a hot melting adhesive. Surface preparation may or may not be required prior to the start of the repair process.

b- *Adhesives and sealants*: Technological enhancements in materials have led to the development of adhesives and sealant materials that can better bond with polyethylene. These materials are usually proprietary and have a polyolefin component in them. They are mostly used for cosmetic outside surface repair. When chemical compatibility is not an issue, these repair materials can be used to repair and seal cracks and very small holes.