Polypropylene-Lined Steel Vessels
Material Properties and Design Considerations
Fisher|Moore

Introduction

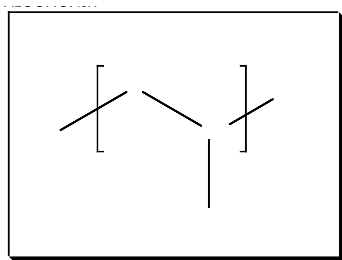
Polypropylene is a commodity plastic in which materials from different sources often vary in composition and mechanical properties. Besides variations in copolymer content, which will be discussed below, additives such as fillers, stabilizers, flame retardants, and processing aids may also be present. One major producer of polypropylene, Huntsman Polymers, has four major varieties of polypropylene[1]:

Material	Number of Grades	Melt Flow Index Range
Homopolymer	39	1 - 35
Impact Modified Copolymer	72	0.4 - 100
Random Copolymer	34	1 - 35
Specialty Grades	25	0.5 - 110

The melt flow index is used to characterize the material and is inversely proportional to the number average molecular weight (N_a) of the polymer. This example serves to illustrate the breadth of polypropylene material available and why proper selection, testing, and quality assurance is needed to insure a high-quality lined-steel vessel.

Chemistry and Mechanical Properties

Polypropylene is an alkane-based polymer which has a repeat unit which corresponds to the following structure:



The position of the methyl pendant group must be carefully controlled otherwise the resulting material will not have acceptable mechanical properties. There are three types of side group variations possible in polypropylene, isotactic in which all the methyl groups are aligned on one side of the chain, syndiotactic where the methyl groups alternate from side to side, and atactic in which the positions of the methyl groups are random. The polymerization of propylene is dependent on organometallic catalysts to position the methyl groups into the high-strength isotactic confirmation and was not successfully perfected until the late 1950's.

It was soon recognized that the polypropylene homopolymer suffered from a number of deficiencies including a high glass-transition temperature (T_g) and poor toughness or impact strength. A comparison between the polypropylene and polyethylene homopolymers is very instructive:

Property	Units	ASTM	Polyethylene	Polypropylene
Tensile Modulus	psi	D638	136,000	240,000
Flexural Modulus	psi	D790	170,000	120,000
Notched Izod Impact	ft. lbs/in	D256	3.2-4.5	0.7
Tensile Elongation at Break	%	D638	>700	600
Continuous Use Temp.	°F	-	210	180
Glass Transition Temp.	°F	D746	-112	0
Melt Temp.	°F	D4591	260	297
Coef. Thermal Expan.	in/in/°F	D696	$7\text{-}11 \times 10^{-5}$	8×10^{-5}

Shortcomings in the mechanical properties of the polypropylene homopolymer are corrected by copolymerization with ethylene to create either random or block copolymers. However, this improvement comes with a tradeoff. In the case of the polypropylene random copolymer the resulting material is less crystalline. While this increases the low temperature impact strength, the material is now more flexible and suffers from increased deflection at elevated temperature arising from an increase in the coefficient of thermal expansion. In the case of the polypropylene block copolymer the material shows an improvement in the low temperature impact strength without increased flexibility.

Schiers has reviewed the use of Fourier transform infrared spectroscopy (FTIR) to differentiate between polypropylene homopolymer, random, and block copolymers.[2] It is also possible to observe differences in polypropylene varieties using differential scanning calorimetry (DSC) which would reveal variations in the T_g and T_m and the effects on cooling rate on crystallinity. The determination of the melt flow index is a further guarantee of material similarity based upon molecular weight.

Design Considerations

In the case of any thermoplastic lined-steel vessel it is important to consider the effects of thermal stress which is part of the normal process conditions. Compared to metals, polymers generally have a lower modulus and a greater coefficient of thermal expansion and are therefore are more susceptible to dimensional changes as a function of temperature. Expansion of the material is associated with temperature increase and results in the material being placed into tension. Contraction of the material arrises from a temperature decrease and results in compressive forces being applied to the material.

A rough approximation thermal stress can be determined from the following equation:

$$\sigma = E\alpha\Delta T \qquad \textbf{Equation 1}$$

where σ is the resulting stress which is a product of the elastic modulus E, the coefficient of thermal expansion α, and the change in temperature ΔT. A positive stress value indicates tension and a negative value is associated with compression.

Using Hooke's law the strain is determined as follows:

$$\varepsilon = \frac{\sigma}{E} \qquad \textbf{Equation 2}$$

Equation 1 and 2 can be rewritten as follows:

$$\varepsilon = \alpha\Delta T \qquad \textbf{Equation 3}$$

The total longitudinal deformation can be expressed by the following equation:

$$e = L\varepsilon \qquad \textbf{Equation 4}$$

where *L* is equal to the length of tank wall.

Using Equation 3, Equation 4 can be rewritten to express the longitudinal deformation as a product of the coefficient of thermal expansion, the change in the temperature and the length of the tank wall:

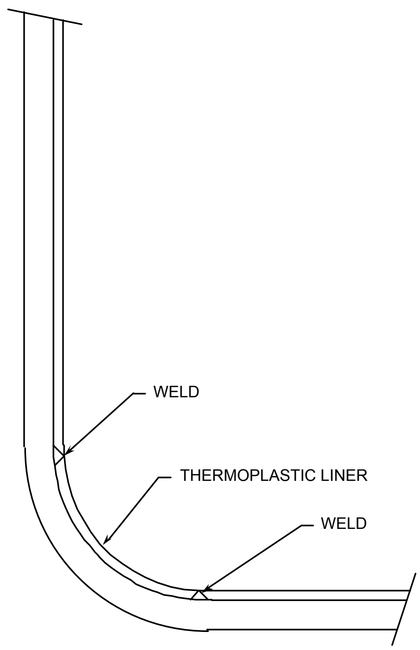
$$e = \alpha\Delta TL \qquad \textbf{Equation 5}$$

Given the value of 8 x 10^{-5} in/in/°F for α, a change of temperature of 10° F, and a tank length of 100 feet, the resulting longitudinal deformation is equal to approximately 1 inch. This result is equally valid for both polypropylene and Kynar 2850 PVDF since the coefficient of thermal expansion values for both of these materials are roughly equivalent.

Compared to the thermoplastic liner, the exterior metal shell will expand very slowly upon a 10° F temperature increase. In the case of the thermoplastic loose liner this constraint will result in compressive stresses building in the vertical corners and shear stresses increasing along the horizontal corners. In now becomes a matter of the ability of the welds to withstand the applied stress over sustained period of time without the onset of crack and liner penetration. Given a 10° F temperature decrease, the sidewall will contract causing the vertical corner welds to be placed in tension and while the interior vertical welds are placed into compression. Over time this deflection in the side wall may lead to failure of the interior vertical welds.

The primary function of the thermoplastic liner is to provide corrosion resistance, however in these situations force the liner to provide a critical mechanical component upon which the entire success of the vessel is dependent. A 10° F temperature change is extremely conservative with greater further temperature changes only adding to the stress on the liner.

In the case of a bonded thermoplastic liner this stress buildup will be dissipated along the sidewall through the high-strength epoxy thermoset adhesive and back into the steel supporting structure. Any residual stresses are further accommodated by a design in which the joints between adjacent thermoplastic lining sections are welded outside of the thermoformed corners. An example of this approach is shown in the following figure:



Given the presence of unrelieved stress in the corners of the loose liner design it is important to remember the potential effect of environmental stress cracking or crazing in which the stress required to initiate a failure is greatly reduced in the presence of different solvents. This problem occurs in the glassy regions of a semicrystalline polymer such as polypropylene and is not dependent on the ability of the solvent to permeate and solvate the thermoplastic. While the mechanism of this phenomenon is not well understood, it has been implicated in past polymer failures. [3] Given the lower crystallinity in polypropylene copolymers, environmental stress cracking will be of greater concern in these materials.

Material and Technical Specifications

Given the variations in polypropylene material available, any sheet material or welding rod used in tank fabrication must be accompanied by a certificate of compliance from the manufacturer which guarantees a minimum compliance with ASTM D4101-03b Standard Specification for Polypropylene Injection and Extrusion Materials.

Both the sheet material and the welding rod should be tested with FTIR spectroscopy, DSC, and the melt flow index in order to indicate material compatibility and melting characteristics. Any equipment using to heat, weld or form the material must be calibrated with a NIST traceable standard. All incoming material must be tracked by shipment or lot number in order to ensure its use in this specific job.

Technicians performing hot-air rod or extrusion welding must be qualified by past experience to perform this work. In addition these technicians must be certified to perform this work on behalf of the company. As part of the certification process the welding technicians must submit either hand welded or extrusion welded samples for tensile testing which demonstrate an 80% weld factor where the weld factor is defined as the ratio of the welded sample tensile strength divided by the tensile strength of the unwelded sample.[4]

The requirements outlined in this section are not meant to be onerous and represent good practices which will ensure the fabrication of a quality product.

Conclusions

Given the size of the lined vessel, it is important to use a design which will reduce the presence of stress in the corners in order to fabricate a vessel with maximum service life Because of the many varieties and sources of polypropylene, the sheet and weld rod must be analyzed and tracked to ensure material compatibility. It is recommended that the polypropylene used in this process be a block copolymer.

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[1] http://www.huntsman.com/polymers/

[2] Scheirs, John, **Compositional and Failure Analysis of Polymers**, John Wiley & Sons, New York, 2000, p. 176.

[3] Van Krevelen, D. W., **Properties of Polymers, Their Correlation with Chemical Structure; Their Numerical Estimation and Prediction From Additive Group Contributions**, Elsevier, New York, 1997, p. 738.

[4] Deutscher Verband fuer Schweisstechnik, Document XVI-491-86, Testing of Welded Joints of Thermoplastics (1986).