RECENT INNOVATIONS IN REINFORCED THERMOPLASTIC PIPE

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ABSTRACT

Reinforced Thermoplastic Pipe (RTP) is a technology that is reducing the cost of constructing pipelines while improving reliability. RTP combines high performing materials with high strength reinforcements in a unique construction to create a spoolable high pressure pipeline system. This construction is well suited to a variety of applications.

As a result of the benefits of RTP, it has been rapidly accepted by industry. Oil and gas producers have indicated a strong interest in utilizing RTP with an expanded application envelope. As a result, test programs were conducted to define the suitability of RTP for more applications. At the same time, the introduction of new materials has resulted in new variations of RTP that service a wider range of applications.

The cost of constructing produced gas, oil, and water pipelines has been steadily increasing in past years due to many factors including the limited availability of skilled labor. There continues to be a desire to tie in new wells faster due to limited construction timeframes. Pipeline reliability is an ongoing issue for the industry. RTP provides solutions to all of these challenges.

Keywords: reinforced, thermoplastic, pipe, composite, spoolable, plastic

INTRODUCTION

RTP is an alternative to traditional pipelining materials. RTP is composite spoolable pipe that offers high pressure capability, corrosion resistance, reliability, ruggedness, and demonstrated efficiency of installation. Applications include oil and gas gathering, and water transfer.

Configuration

The configuration of RTP is shown in Figure 1. It consists of three basic layers including a thermoplastic liner, helically wrapped continuous high-strength fiber reinforcement and an external thermoplastic jacket. The liner acts as a bladder, the fibers provide strength, and the jacket protects the load-bearing fiber reinforcements. This construction does not contain any thermoset resins and provides an excellent combination of strength, corrosion resistance, flexibility, and ruggedness. The flexibility of RTP allows it to be spooled for efficient handling, transportation, and installation. RTP is typically available with pressure ratings from 2.1 MPa to 10.3 MPa in 54 mm, 77 mm, and 99 mm internal diameter sizes.

Connections

RTP is terminated or joined by either custom metallic fittings or electrofusion fittings which are installed with portable equipment. An example of a metallic fitting is shown in Figure 2. The fittings typically terminate the pipe with a standard lap-joint flange or with a butt weld transition. Pipe-to-pipe couplings allow one length of RTP to be connected directly to another. The fittings clamp the pipe, including the fiber reinforcement, securely in place. A vent hole is included in fittings and allows the annulus of the pipe (the space between the liner and jacket which contains the fiber reinforcement layer) to vent freely at each fitting. This allows any gases that may have permeated through the liner to escape, and prevents any pressure buildup in the annulus. Metallic fittings are typically supplied with a coating or plating for protection from internal corrosion and erosion. External corrosion control of installed metallic fittings is achieved by the application of moisture resistant wrap, cathodic protection, or both.

Design and Qualification

The design, qualification and construction of RTP are governed by industry standards and guidelines. The primary industry document specific to this technology is API RP 15S, "Recommended Practice for the Qualification of Spoolable Reinforced Plastic Line Pipe", which is published by the American Petroleum Institute (API). This recommended practice includes guidelines for determining pressure ratings, service factors, and minimum performance requirements. It also includes guidelines for manufacturing, quality control tests, and typical installation methods. API RP 15S uses proven ASTM testing methods for establishing long-term performance. The regression testing used to establish the allowable pressure rating of the pipe is performed in accordance with the requirements of ASTM D2992, "Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings". The derivation of the pressure rating from the regression test results is illustrated in Figure 3. Compliance with the requirements of API RP 15S is specified in CSA Z662-07, "Oil and Gas Pipeline Systems".

Installation

The primary benefit of RTP is cost savings due to ease of installation. Installation methods include trenching, plowing, and liner insertion. The inherent efficiencies of RTP installation have the additional benefit of reducing environmental impact. Reduced or eliminated needs for heavy equipment, smaller trench sizes, and smaller right of ways all contribute to reducing the amount of ground disturbance and environmental impact. The reduction in crew size and hot work also results in improved safety performance when installing RTP.

Unspooling of the pipe from the transportation spools can be accomplished with minimal time, equipment, and manpower. The fittings can be installed above ground before lowering the pipe into the trench, or installed afterward in bell holes. Required trench sizes are smaller than those typically used for steel pipe installation enabling chain ditching to be used. Bedding and backfilling requirements are similar to those for steel pipelines.

Long continuous lines can be very efficiently installed using a pipeline plow which is able to trench, install the pipe, and cover the trench in a single-pass operation. Metallic coupling fittings can also be plowed.

For remediation of a failed pipeline, RTP can be pulled through with the existing pipeline acting as a conduit. If the conduit is large enough, coupling fittings can also be installed in this manner. The RTP then acts as a freestanding liner and does not depend on the conduit for structural support.

Recent Innovations

The benefits of RTP have led to rapid market acceptance. More than 8 million meters of RTP have been installed in North America. Oil and gas producers have indicated a strong interest in utilizing RTP with an expanded application envelope. As a result, test programs were conducted to define the suitability of RTP for more applications. At the same time, the introduction of new materials has resulted in new variations of RTP that service a wider range of applications. The following innovations along with related experimentation and results will be discussed in more detail:

1. The use of RTP in applications containing aromatic hydrocarbons.
2. The use of RTP in applications containing high pressure CO_2.
3. The use of new thermoplastic materials to expand the maximum operating temperature of RTP.
4. The use of new reinforcement materials to expand the cyclic pressure suitability of RTP.

1. THE USE OF RTP IN APPLICATIONS CONTAINING AROMATIC HYDROCARBONS

It has been acknowledged qualitatively that the exposure of thermoplastic materials such as HDPE to aromatic hydrocarbons plasticizes the polymer, resulting in significant changes to the mechanical properties. Testing was conducted to quantify the suitable exposure limits to aromatic hydrocarbons for RTP manufactured with HDPE.

EXPERIMENTAL PROCEDURE

Simulated crude oil was prepared with various concentrations of solvents: 0%, 5%, 10%, 15% and 25% (v/v), where the solvent is a mixture of aromatics (xylene, toluene) and cyclo-aliphatic (cyclohexane) with identical volume. IRM 902 was used as the base crude oil. ASTM D638 Type-I dumbbell tensile bar specimens cut from the HDPE liner of RTP were exposed to these mixtures at 20ºC and 40ºC. Mechanical property testing was conducted on specimens after saturation at 20ºC and 40ºC, defined as when the weekly weight difference was less than 0.01 gram. The testing was performed using Instron Model 4202 machine according to ASTM Standard D638.

RESULTS

Figure 4 shows the effect of both temperature and aromatic hydrocarbon saturation on the yield strength of HDPE samples from RTP liner. It is observed that both increasing temperature and increasing concentration of solvents decrease the yield strength of HDPE. However, the yield strength of samples saturated in a high concentration of solvents at 20ºC still remains greater than with no exposure at 60ºC. Similarly, the yield strength of samples saturated in a high concentration of solvents at 40ºC still remains greater than with no exposure at 60ºC.

Figure 5 shows the effect of both temperature and aromatic hydrocarbon saturation on the modulus of HDPE samples from RTP liner. It is observed that both increasing temperature and increasing concentration of solvents decrease the modulus of HDPE. The modulus of samples saturated in a high concentration of solvents at 20ºC still remains greater than with no exposure at 60ºC. However, the modulus of samples saturated in a 5% concentration of solvents at 40ºC is similar to that with no exposure at 60ºC.

DISCUSSION

Extensive testing has been used to determine the pressure rating of RTP at 60ºC that has not been exposed to solvents. It is therefore of interest to compare the material properties of unexposed RTP liner at 60ºC to the resultant material properties of samples of RTP liner after exposure to solvents at 20ºC and 40ºC to determine suitable operational exposure limits at these temperatures.

The yield strength and modulus of samples exposed to 25% solvents at 20ºC exceed those of unexposed samples at 60ºC. This suggests that an exposure limit of 25% solvents is suitable for applications with temperatures of 20ºC and less for the type of RTP tested.

The yield strength of samples exposed to 25% solvents at 40ºC exceeds that of unexposed samples at 60ºC. However, the modulus of exposed samples at 40ºC falls below that of unexposed samples at 60ºC once the concentration of solvents exceeds 5%. This suggests that an exposure limit of 5% solvents is suitable for applications with temperatures of 40ºC for the type of RTP tested.

2. THE USE OF RTP IN APPLICATIONS CONTAINING HIGH PRESSURE CO_2

A concern with CO_2 is that it can permeate into thermoplastic materials. If the pipeline is depressurized rapidly, there is potential for blistering of the pipe as CO_2 will try to escape back into the pipeline. If blistering occurs, this could weaken the materials and lead to failure of the pipe. A study was conducted to investigate and test the effects of rapid depressurization of high pressure CO_2 gas on RTP.

EXPERIMENTAL PROCEDURE

A test procedure was designed in accordance with API RP15S Appendix D, “Blowdown Test Procedure”. A 2 m length of 99 mm ID 10.3 MPa RTP was chosen for this study, complete with crimp style test end fittings including standard 75 durometer fluoroelastomer O-ring seals. The test pipe was initially filled with CO_2 gas at 5.5 MPa and 21℃ and then pressurized with nitrogen to obtain a total pressure of 10.3 MPa psi. The pipe was then heated and held for 140 hours at 60℃ and 11.4 MPa. The test pipe was depressurized at 6.9 MPa/min from 11.4 MPa to 0 MPa. The pipe was removed from the vessel, inspected, and then dissected. An optical microscope was also used to inspect for surface blemishes, cracks and voids. ASTM D638 Type-I dumbbell tensile bar specimens were cut from the liner of the test pipe and tensile tested according to ASTM D638. Subsequent to the single cycle test, a second test pipe 3 m long was tested through 10 cycles following a similar procedure to that described above.

RESULTS

No blistering was observed on the liner or jacket inner or outer surfaces. The glass fiber reinforcement layers also did not exhibit any damage. The HDPE liner did not collapse or show any indication of stress deformation. Optical micrographs (x100 magnification) of a typical sample of HDPE liner surface exposed only to air were compared to the CO_2 exposed HDPE liner surface. There was no alteration in surface appearance. No cracks, blisters, or voids were observed. None of the 75 durometer O-ring seals which were installed and compressed in the normal groove locations of the Flexpipe end fittings showed any sign of blistering or deformation.

Mechanical properties of dumbbell specimens cut from the tested pipe liner were tensile tested and compared to base data of HDPE liner as shown in Table 1. Average yield strength and elongation at yield remained similar to the baseline data.

DISCUSSION

The results of the testing found no evidence of degradation of any of the materials in RTP after numerous pressurizations, pressure holds at 60ºC and rapid depressurizations. These results suggest that the type of RTP tested is suitable within the experimental test parameters of 5.52 MPa partial pressure CO_2, up to 10.3 MPa overall system pressure, 60℃ and 10 rapid depressurization cycles.

3. THE USE OF NEW THERMOPLASTIC MATERIALS TO EXPAND THE MAXIMUM OPERATING TEMPERATURE OF RTP

RTP has typically been manufactured using HDPE in the liner and cover. Due to the material properties of HDPE, such RTP has been limited to a maximum allowable operating temperature of 60℃. The recent use of specific polypropylene materials in the liner and cover of RTP has allowed this maximum allowable temperature rating to increase to 93℃, making RTP suitable for a wider range of applications. Testing has been conducted to confirm the performance of RTP manufactured with these new materials at these higher temperatures.

EXPERIMENTAL PROCEDURE

RTP samples manufactured using new thermoplastic materials were tested in accordance with API RP 15S as specified for Type 1 RTP in Table 13.1 of CSA Z662-07. The following testing was conducted on 77mm ID 10.3 MPa RTP:

1. Short term destructive burst testing conducted at a pressurization rate of 0.17 MPa/second and a temperature of 20ºC.
2. Hold tests at 93 ºC and at various elevated pressures conducted in accordance with ASTM D1598.

RESULTS

The short term destructive burst tests reached pressures of 60.8 MPa, 62.4 MPa and 65.2 MPa. These results are a high multiple of the targeted pressure rating of 10.3 MPa.

High pressure hold tests at 93ºC are ongoing and have been holding pressure without rupture at a variety of pressures including 32.1 MPa, 32.4 MPa and 34.1 MPa. The number of hours accumulated to date are 1176 for the samples at 32.1 MPa and 32.4 MPa and 840 for the sample at 34.1 MPa. These hold tests will be used to develop a long term regression curve to determine the pressure rating of this pipe.

DISCUSSION

The RTP with new thermoplastic materials displayed exceptional short term and long term pressure capacity. Testing is continuing to meet the full requirements of CSA Z662-07 including the requirement for Type 1 RTP to be qualified in accordance with API RP 15S.

4. THE USE OF NEW REINFORCMENT MATERIALS TO EXPAND THE CYCLIC PRESSURE SUITABILITY OF RTP

RTP using glass fibers for reinforcement has been shown to have adequate ability to withstand the levels of pressure cycling found in the vast majority of oil and gas gathering applications and some oilfield water transfer and injection applications. However, some oilfield water applications have more severe levels of pressure cycling. This has prompted the development of RTP with galvanized steel cords for reinforcement. Testing has been conducted to confirm the performance of RTP manufactured with this type of reinforcement.

EXPERIMENTAL PROCEDURE

RTP samples manufactured using new reinforcement materials were tested in accordance with API 17J as specified for Type 3 RTP in Table 13.1 of CSA Z662-07. The following testing was conducted on 99 mm ID 10.3 MPa RTP:

1. Short term destructive burst testing conducted at a pressurization rate of 0.31 MPa/second and a temperature of 20ºC.
2. Cyclic pressure testing conducted at a pressurization rate of 1.38 MPa/second and depressurization rate of 1.38 MPa/second at a temperature of 60ºC.

RESULTS

The short term destructive burst tests reached pressures of 36.4 MPa and 36.3 MPa. These results can be compared to the targeted pressure rating of 10.3 MPa.

Cyclic pressure tests at 60ºC are ongoing. Samples cycling with a range of 0-10.3 MPa each cycle have exceeded 182,500 cycles without failure. 182,500 cycles is equivalent to 25 cycles per day for a 20 year design life.

DISCUSSION

The RTP with new reinforcement materials displayed exceptional short term pressure capacity. It has also been found to be suitable to handle a large number of high pressure cycles. This type of pressure cycling can be encountered in some oilfield water injection systems. Testing is continuing to meet full requirements of CSA Z662-07 including the requirement for Type 3 RTP to be qualified in accordance with API 17J.

CONCLUSIONS

As a result of the benefits of RTP, it has been rapidly accepted by industry. Oil and gas producers have indicated a strong interest in utilizing RTP with an expanded application envelope.

Test programs were conducted to define the suitability of an existing type of RTP for additional applications. Results showed that the type of RTP tested is suitable for use in applications with aromatic hydrocarbons and other solvents up to a solvent concentration of 25% for temperatures up to 20℃ and a concentration of 5% at 40℃. Also, test results showed that the type of RTP tested is suitable for applications containing CO_2 within the experimental test parameters of 5.52 MPa partial pressure CO_2, up to 10.3 MPa overall system pressure, 60℃ and 10 rapid depressurization cycles.

Also, the introduction of new materials has resulted in new variations of RTP that service a wider range of applications. The use of specific polypropylene materials in the liner and cover of RTP has allowed this maximum allowable temperature rating to increase to 93℃. The development of RTP with galvanized steel cords for reinforcement allows RTP to be used in applications with more severe pressure cycling parameters.

The cost of constructing produced gas, oil, and water pipelines has been steadily increasing in past years due to many factors including the limited availability of skilled labor. There continues to be a desire to tie in new wells faster due to limited construction timeframes. Pipeline reliability is an ongoing issue for the industry. RTP provides solutions to all of these challenges.

TABLE 1:

Tensile Test Results of Samples of RTP Liner after High Pressure CO_2 Gas Testing

Specimen Types	Yield Strength (MPa)	Elongation at Yield (%)
No Exposure to CO_2	24.2	17.4
After One Exposure to High Pressure CO_2	23.6	16.9
After Ten Cycles of Exposure to High Pressure CO_2	24.5	16.1

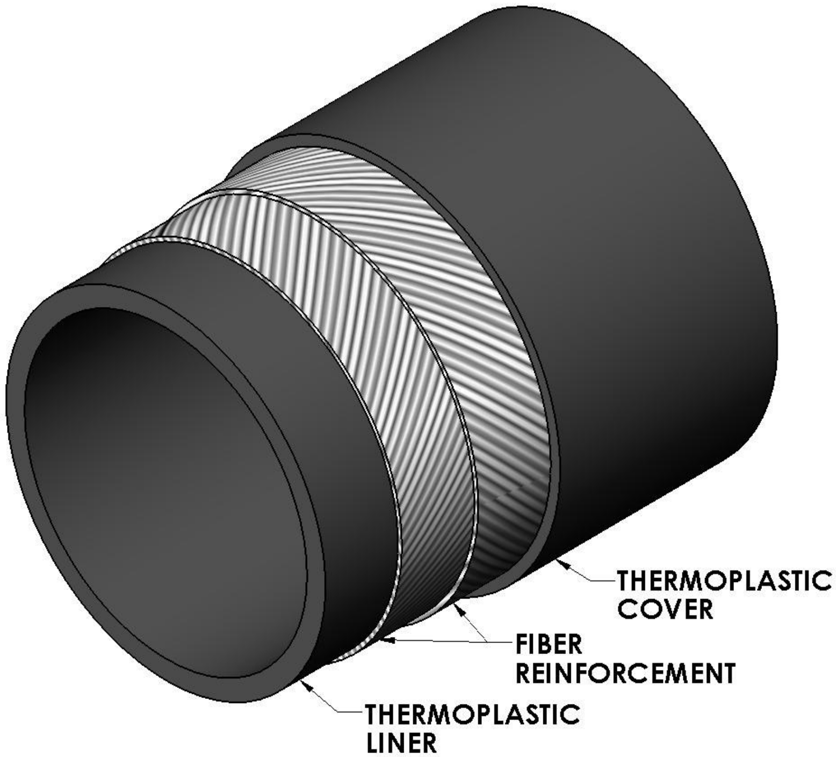

FIGURE 1 – RTP Configuration

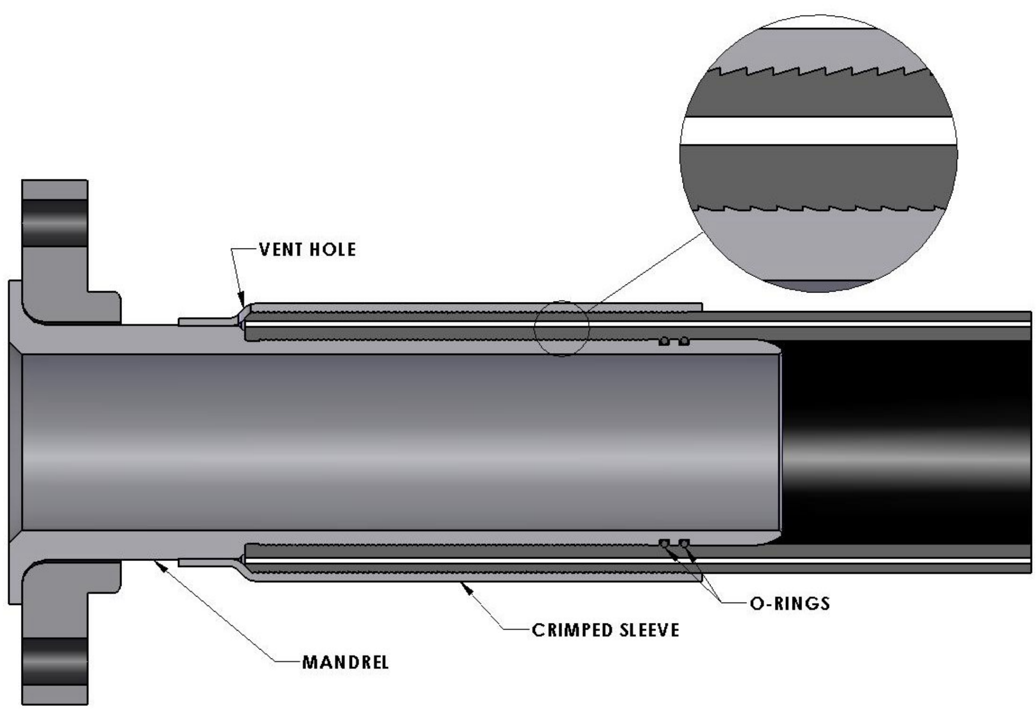

FIGURE 2 – Example of Metallic Fitting For RTP

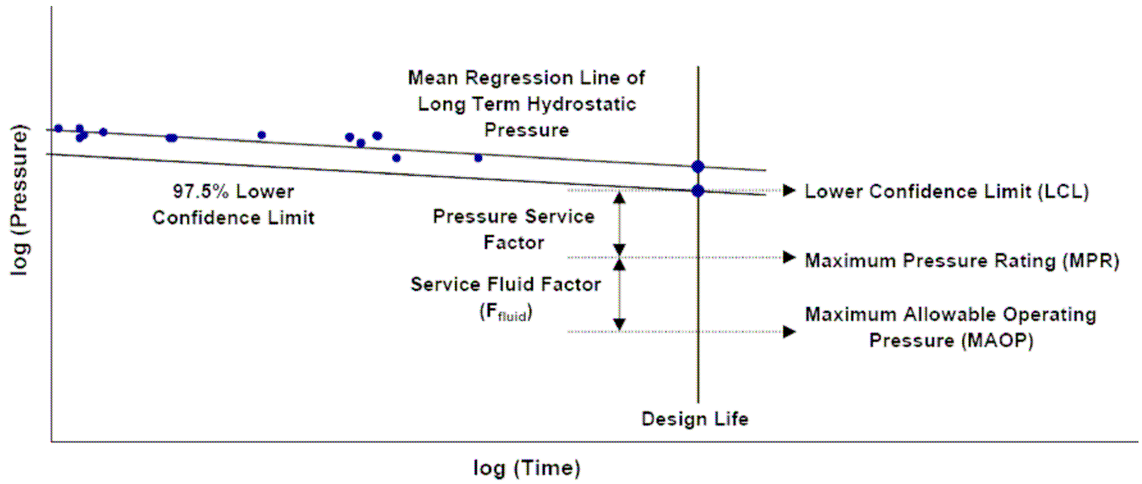

FIGURE 3 – Method of Determination of Pressure Rating

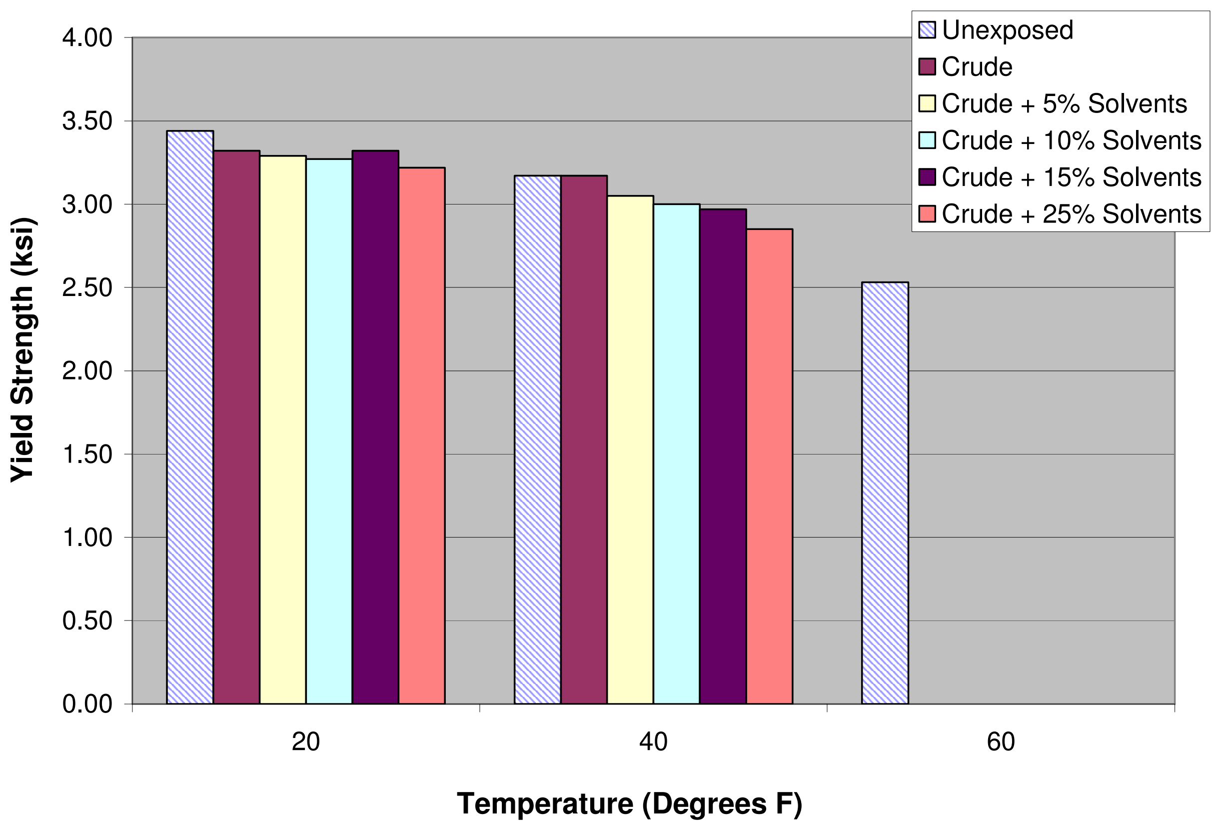

FIGURE 4 – Effect of Temperature and Exposure to Solvents on Yield Strength of HDPE

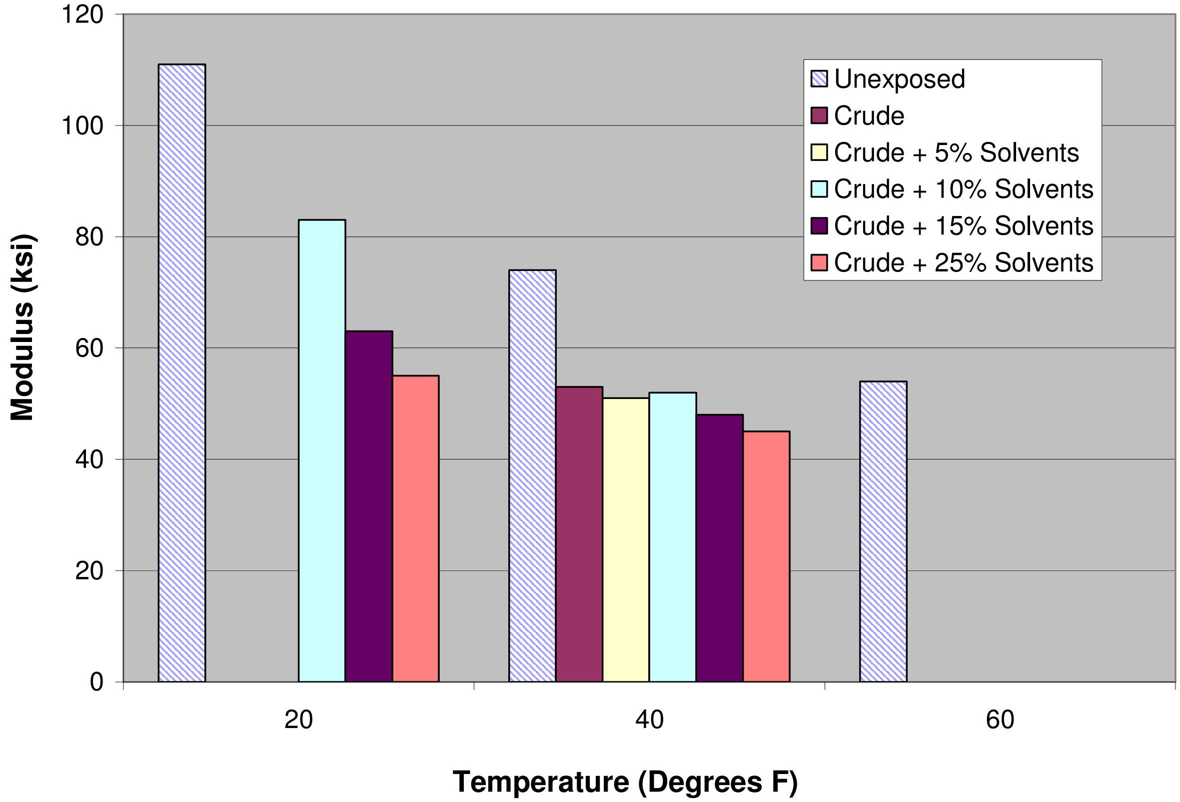

FIGURE 5 – Effect of Temperature and Exposure to Solvents on Modulus of HDPE