COLLABORATION IN DEVELOPING A NEW GUIDE MATERIAL FOR WEST TEXAS ROD-LIFTED WELLS

Courtney Richardson, Occidental
Esteban Oliva, Jesus Abarca, and Clayton Brown, Tenaris

ABSTRACT

Failures due to rod and tubing wear account for approximately 50 to 70% of the operating expense in rod-lifted systems. The industry has made significant improvements in reducing this wear by isolating the steel components during their relative movement by using different materials as sacrificial elements between them. The rod guide is one of these sacrificial elements and is available in several shapes and compositions. One of those compositions, and the most successful one, is the plastic guide. In the pursuit of the best plastic for West Texas wells, Occidental and Tenaris teamed up to assess polyketone plastics with varied concentrations of glass fiber and options to reduce the friction factors of this polymer on the tubing inner diameter.

This paper describes the features of the selected polymer, the different configurations considered, an overall view of the qualification program, and key quality assurance steps necessary to comply with the Tenaris Quality Management System. Finally, Occidental's implementation of the guides and the results from the operations are discussed.

Since March 2020, Tenaris started supplying guides with this polymer to Occidental. To the date of this publication, more than 100,000 guides have been installed with zero failures of the guides reported.

CURRENT SUCKER ROD GUIDING OPTIONS AND PRACTICES

Sucker rod pumping systems (SRP) are a great solution for the needs of the operators to deliver the value of their assets in a safe and economically viable way. However, this artificial lift system presents many challenges, and it is necessary to mitigate their impact on the system reliability and performance. One of these challenges is the effect of the rods and the tubing being in contact in many locations along the wellbore, from surface to the pump. With this contact and the movement of the rod string, factoring in loading ranging from tension to compression, a wide variety of contact mechanisms are identified in this assembly, such as sliding movement of the rod on the tubing inner diameter (ID), hammering (slapping) of the rod on the tubing, buckling of the rod under compressive loads, and loosening of the pin-coupling connection due to compressive loads.

These mechanisms may happen simultaneously, creating combined stresses, elevated friction, plastic deformation, and material wear, negatively impacting the reliability of the SRP system, and both operators and manufacturers are focused on finding solutions to the problems.

What Are the Main Functions of Rod Guides?

Prevent Wear: To avoid loss of material through wear on the tubing or sucker rod, several guides can be placed along the length of the sucker rod(s) to prevent metal-to-metal contact over a portion of the wellbore.
Centralize Rod: Minimizing eccentric rod body movement inside the tubing will help prevent buckling and reduce localized combined stresses on the rod body.

Polymers have proven to be one of the most effective options to deliver these functions. There are many shapes, materials, and methods of fixing a guide to a sucker rod. The most practical mechanism is by injection molding a polymer-based material directly onto the rod body. This uses the natural compression, contraction, and friction of the material to hold the guide in place. Another method of attaching the guide is a field-installed "snap-on" guide. However, these have been noted as have poor holding force, and generally, the guides either slide to one of the upset ends of the rod or detach completely. Other snap-on guides may use an epoxy to glue the guide into place; this is common for fiberglass (FG) rods to ensure the high temperature of injection molding does not negatively affect the FG sucker rod. Finally, there are coupling-style "wheeled rod guides" that use rolling wheels to centralize the rod. These are generally run with pony rods through a section of the well and can become quite costly. In addition to the cost, wheeled rod guides face a number of challenges:

- The roller pin used to fix the wheel in the housing can break, leaving the tool ineffective.
- Wellbore solids can enter the wheel spaces and lock them, preventing rotation of the wheel.
- The assembly is typically long, with a diameter close to that of the rod coupling, and adds stiffness, creating a high combined stress to the adjacent rods.

The Plastic Molded Guide

A plastic injection-molded rod guide is the current industry preference due to several characteristics of plastics:

- **Ability to be injection-molded:** offers a variety of shapes and polymers
  - Straight vane short, long, or long and wide
  - T-shaped vane
  - Helicoidal-shape vane
  - Slant vane, and others
- **Use of additives:** Can adjust properties to suit specific applications (e.g., abrasion resistance, temperature rating, and friction reduction).
- **Economics:** Injection-molded plastics can be installed in multiple sets that allow for economies of scale during manufacturing. Thermoplastics can be ground and re-used to support recycling and sustainability initiatives.

Thermoplastics are plastic polymer materials that soften, become pliable/moldable at a certain elevated temperature, and become solid again upon cooling. They have three temperature-dependent states: glassy state, rubbery plateau, and liquid flow.
Metal guides are largely outdated due to their tendency to wear out the tubing.
Thermoset materials include epoxies, urethanes, and polyester resin, among others. Thermosets are "cured" to a solid through an irreversible chemical reaction. Thermosets have an advantage in high temperature application over thermoplastics but are more difficult to produce.

Fig. 1 shows a depiction of different materials used for sucker rod guides

Thermoplastics have a variety of available base resin compounds that offer different properties.

Glass Transition Temperature (T_g) is the gradual and reversible transition from a hard and relatively brittle "glassy" state into a viscous or rubbery state as temperature increases. Fig. 2 shows a typical T_g plot.

In many cases for thermoplastic materials, the T_g is used as the baseline to design the material performance in the application. As it is intended to have uniform mechanical properties, the material is targeted to operate either before or after the T_g. However, as thermoplastics technology continues evolving, this criterion has started to be less strict, and there are materials that are designed to operate successfully at multiple regions in their T_g curves.

Other important properties of thermoplastics are shown in Table 1.

Additives

Within any of the base resin plastics, fillers, stabilizers, and additives such as glass fiber or minerals may be added to:

- Reduce cost
- Regulate shrinkage
- Provide wear resistance
- Processability improvement
- Lubricative properties
- Improve mechanical properties

Glass Fiber

Glass fibers (GF) are commonly added to plastics to increase the mechanical attributes of a guide such as tensile strength, flexural modulus, abrasion wear resistance, and hardness.

Glass fiber is one of the most important additives in thermoplastics for oil and gas applications. It is measured in weight percent (wt%). The best impact on the plastics properties is seen in ranges from 5 to 40 wt%. In general, most of the thermoplastics react similarly to increases in GF wt%. The mechanical properties of the thermoplastic such as yield strength, tensile modulus, flexural strength, and flexural modulus all increase up to 45 wt% of GF. In some plastics, the increment in GF also has a positive impact on the temperature rating for oil and gas applications.

A negative effect of GF in plastics used for tribological applications like SRP is an increase in tubing ID wear, especially when lower lubricity fluids are present (i.e., high water cut wells). This mechanism, however, is still poorly understood, and data to date point to a balance between 20 and 40 wt% of GF. This sweet spot balances the wear resistance of the guide material to the potential for wear on the tubing. Finally, increases in GF can increase the brittleness of the material and make it more susceptible to cracking.

Hygroscopy is the plastic's ability to collect and hold water molecules. it is a phenomenon which can affect a plastic's properties and performance.
Nylon and **PPA** have been extensively used in the industry. However, these base resins are highly hygroscopic, and their physical properties decay significantly as they absorb water. Fig. 3 shows the most highly hygroscopic thermoplastics.
PPS is a balanced choice for economics and material performance.
PK, PEEK, PAEK are great candidates for the most demanding wellbore conditions.

Frequently the base plastics are trademarked, protected by patents, and manufactured by one or very few certified suppliers. Examples of such protected plastics are polyketone, PEEK, PAEK. These base plastics are bought by "compounders", or manufacturers who modify the base plastic by incorporating additives to target specific properties for certain applications. These compounders are the suppliers that prepare the plastics used in oil and gas applications.

Wear Resistance

Wear resistance is a complex phenomenon dependent on many variables such as the coefficient of friction, surface roughness, hardness, thermal conductivity, applied load, and velocity. As with many other SRP cases, it is extremely difficult to replicate the wellbore conditions with standardized laboratory tests. The most commonly used tests to characterize wear resistance are:

- ASTM G77: Standard Test Method for Ranking Resistance of Materials to Sliding Wear Using Block-on-Ring Wear Test
- ASTM G99: Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus
- ASTM D3702 and JIS K7218: Standard Test Method for Wear Rate and Coefficient of Friction of Materials in Self-Lubricated Rubbing Contact Using a Thrust Washer Testing Machine
- ASTM D4060: Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser

All methods have advantages and limitations with significant data scatter. The data generated via thrust washer methods is most commonly quoted in the thermoplastics industry. The output parameters from these tests are coefficient of friction (CoF), wear factor (K). Lower CoF and K values denote better wear resistance.

WHY ANOTHER MATERIAL—OCCIDENTAL REQUEST

Occidental's performance with conventional rod guide materials in their enhanced oil recovery (EOR) installations was showing unsatisfactory results, especially with accelerated tubing wear and guide integrity deficiencies. Occidental's vision was to pursue a guide that encompassed the following features:

1. Very low hygroscopicity. Based on the past performance of other guide, there was a long list of failures related to this property. The water absorption played a role in many of the failures Occidental experienced in other plastic guide materials.
2. Handle a broad range of temperatures, possess a high yield strength in terms of plastics and polymers, and be very resistant to chemical/acid degradation.
3. Top value generation with a price point significantly below that of PEEK and premium plastics that were too expensive for Occidental wells.

Occidental experimented some with polyketone guides with zero additives, using just virgin resin, and initially had satisfactory results from the material point of view. The issue with the virgin resin was guide displacement under only moderate side loading, which was concerning for more challenging wells. This drove Occidental to find the ideal amount of GF content, while staying under the 30 to 40 wt% glass range where Occidental experienced wear on tubing from the guide vanes.

Additionally, PK was already being used in other applications with success. Tubing centralizers performing well was a key observation. It seemed to have very good mechanical properties and was performing suitably in other well installations.

PK20 MATERIAL PROPERTIES

The thermoplastic polymer commercially known as polyketone (aliphatic polyketone) started from Shell under the brand name Carilon in the mid-1990’s but was discontinued in 2000. It underwent a rebirth in 2013 after the Hyosung Corporation in South Korea acquired the patent and invested significant time in development and improvements. This resulted in a plastic with a higher temperature rating, better processability and overall molding properties, strength, superior chemical resistance, hydrolytic stability, and improved friction and wear characteristics.

Polyketone is being used in industrial applications where its chemical resistance and potential for reinforcement with carbon or glass fibers allow for the creation of parts and components to replace metals. The low CoF and high wear resistance makes it ideal for parts such as bushings and wear rings in consumer machines (e.g., printers, copiers, and kitchen appliances).

In oil and gas applications, PK can be used as a layer in tubulars to prevent corrosion and wear, even in relatively high-temperature environments. It has a very low permeation coefficient compared to other materials when facing aliphatic and aromatic hydrocarbons. Polyketone’s consistent mechanical properties remain relatively uniform along a wide range of temperatures and humidities. These properties, together with the low coefficient of friction and wear properties, make it a good choice for tribological applications. In summary, the mechanical and tribological properties, low water absorption, and chemical resistance make it a great candidate to test in oil and gas applications like tubing liners, tubing centralizers, or rod guides.

In oil and gas applications, mechanical properties such as tensional, flexural, and impact strength are used to evaluate a polymer for guiding rods. However, guides are primarily subjected to compression and flexion in rod pumping applications. Flexural and compressive strengths are thus used when selecting a polymer with improved performance for guiding applications.

Fig. 4–6 show typical behavior of reinforced polymers with fiber glass under tension, compression, and flexion, respectively. The dashed line in Fig. 5 shows the maximum expected stress region from a 7-in. long guide under standard working conditions.

Glass Fiber As an Additive to Polyketone

As explained above, glass fiber improves the overall mechanical properties in thermoplastics. Based on developments initiated since the recent launch of polyketone into the industry, the sweet spot seems to be in the proximity of 30 wt%. However, in the application discussed in this paper, a lower GF content was favored to reduce wear on the tubing wall. Therefore, the decision was made to select 20 wt% GF. The plastic datasheet (Fig. 7) indicated that the mechanical properties and temperature rating of the material would be a good fit for the EOR applications.

Silicone As Additive to PK

Silicon is a boundary lubricant which migrates to the surface over time. This typically creates the need for a break-in period. However, it’s migration time is shorter than PTFE, and the migration rate is viscosity dependent. This is an excellent friction reducer over most surfaces, especially when operating PK on PK (i.e., guides inside lined tubing). Finally, silicon performs best as a friction and wear reducer in high speed/low load applications, such as rod guides. Fig. 8–9 show a comparison of wear testing results and friction coefficients for PK and other thermoplastics.

MANUFACTURING & QUALITY CONTROL

As the operating conditions of oil wells get more demanding, the ability of the guide to deliver its intended functionality with high reliability become more important. New technologies allow for the development of better methodologies to verify the internal and external integrity of guides and for characterization of the expected integrity per polymer. Testing, both destructive and nondestructive, should be performed with the aim of improving the injection process, lowering porosity, and creating stronger adhesion to the rod body. Even under simple conditions such as extreme weather or hot and cold temperature cycling, it is recommended to simulate the temperature changes and perform testing on the guides to understand the effects in operational and storage conditions. Fig. 10 shows typical cracks after exposure to freezing temperatures.

The use of new technologies such as computational fluid dynamics (CFD) have proven useful in understanding traditional failure mechanisms associated with turbulence and corrosion-erosion at the end of the guides. Improved geometry and hydrodynamic designs have shown positive results to prevent the creation of washout areas and high turbulence zones over the rod.

The use of digital techniques such as imaging correlation allow for weak points on guides to be identified and improved. Fig. 11 shows a severely flexed guide with the weakest points identified.

Tomography is another methodology used to check for internal integrity and voids. The distribution of these voids can be quantified and improved by means of molding design or by the injection process. Fig. 12 shows an example of these.

Thermoplastics use **injection molding** to form the guide around the body of the rod. Process parameters must be continuously controlled to mitigate defects regarding:

- High porosity
- Cold welds and fissures
- Guide wall thickness and seal strength

Proper raw material, dehumidification, and injection process control is required to prevent excessive porosity inside the guide (Fig. 13). The use of recycled guide material (re-grind) can often lead to excessive porosity.

A guide will have welds inherent to the injection process, but poor process control (pressure, temperature, injection rate) and equipment maintenance can lead to "cold welds" and/or internal shrinkage, leading to premature rod guide body cracking or failure (Fig. 14).

Guide geometry, shape, and profile, as well as the sealing of the ends of the guide, must ensure the wall thickness allows sufficient bonding strength to prevent the guide from detaching from the rod body (Fig. 15).

FIELD INSTALLS AND RESULTS

Application Profile

EOR well applications of the PK20 guides range from well depths of 5,000 to 8,000 ft, comprised of mostly vertical producers in mature water and CO_2 floods. These wells typically have mild to moderate dogleg severity in the bottom third of the well, with side loading averages 100 to 300 lb. These wells produce approximately 200 to 500 bbl/D total fluid, have a high water cut, and have average gas-oil ratios ranging between 1 to 2 scf/bbl. Bottomhole temperatures range from 100 to 125 ºF with moderate to severe corrosivity, up to 2% H_2S, and are treated with either batch or continuous corrosion inhibitor programs. The polished rod velocity of these wells is typically up to 1,500 in./min on conventional units per Occidental best practices, with pump sizes ranging from 1.25-in. insert pumps to 2.25-in. tubing pumps.

Guides Installed

The PK20 guides underwent the full research, development, and manufacturing feasibility period throughout the second half of 2019 and first quarter of 2020. By March 2020, the first production batch became available, and the first strings were deployed in active oil wells. Through March 2022, nearly 100,000 PK20 guides have been manufactured and installed in Occidental wells, with no failures of the guides reported.

Performance

Although installs have steadily continued, the installed inventory had not been properly tracked until late 2021. Therefore, the database was not capable of identifying which wells and what rod tapers were specifically installed with PK20 guides until after that date.

However, Occidental does have a careful well intervention program where failures are investigated and registered. Data available in this program has not found failures associated to the installed PK20 guides. Also, in the few events where there were interventions due to other reasons in wells furnished with PK20 guides, the inspections of the rods and the guides showed all the components were in good shape and capable of continuing operations.

With these observations and monitoring from the wells, Occidental has strong arguments to support the continued installation of PK20 guides. Additionally, as installation data is further recorded, it will be recommended to evaluate the impact of the guide material on the tubing ID wear, the performance of the artificial lift system, and the friction forces generated between the guides and the tubulars.

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[1] Engineering ToolBox, (2005). Thermoplastics - Physical Properties.
https://www.engineeringtoolbox.com/physical-properties-thermoplastics-d_808.html
[2] MATWEB. Material Property Data (2022). Flexural Strength Testing of Plastics
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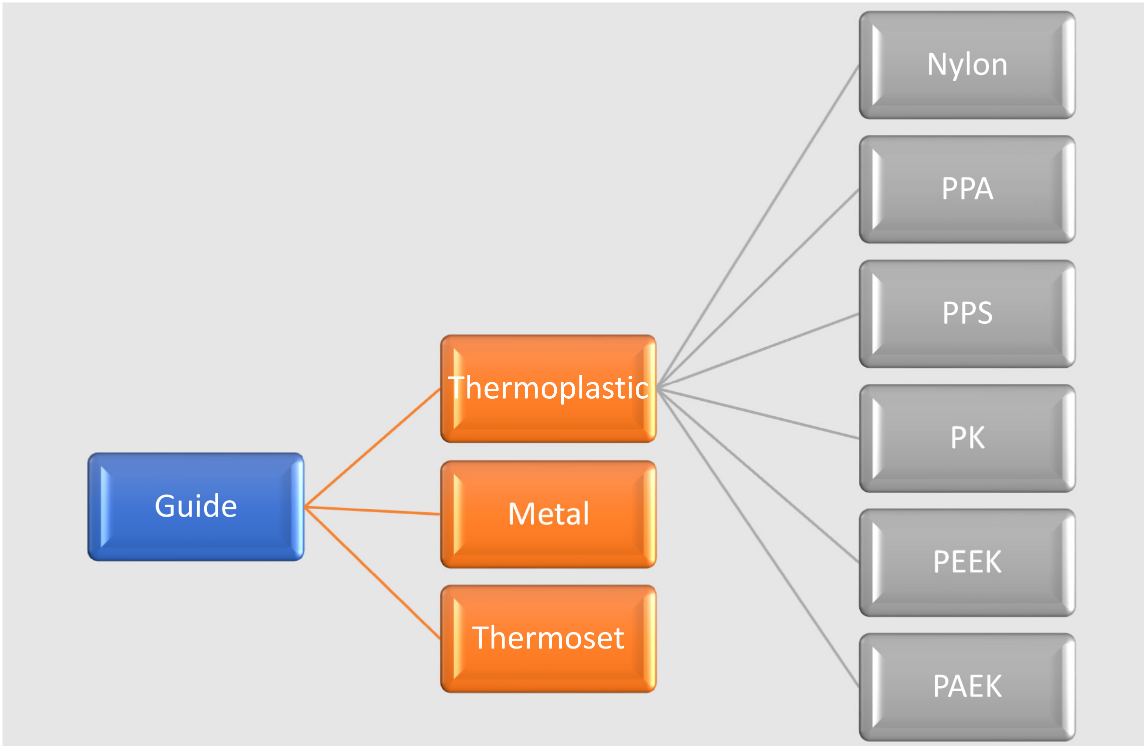

Fig. 1—Common materials used for sucker rod guides.

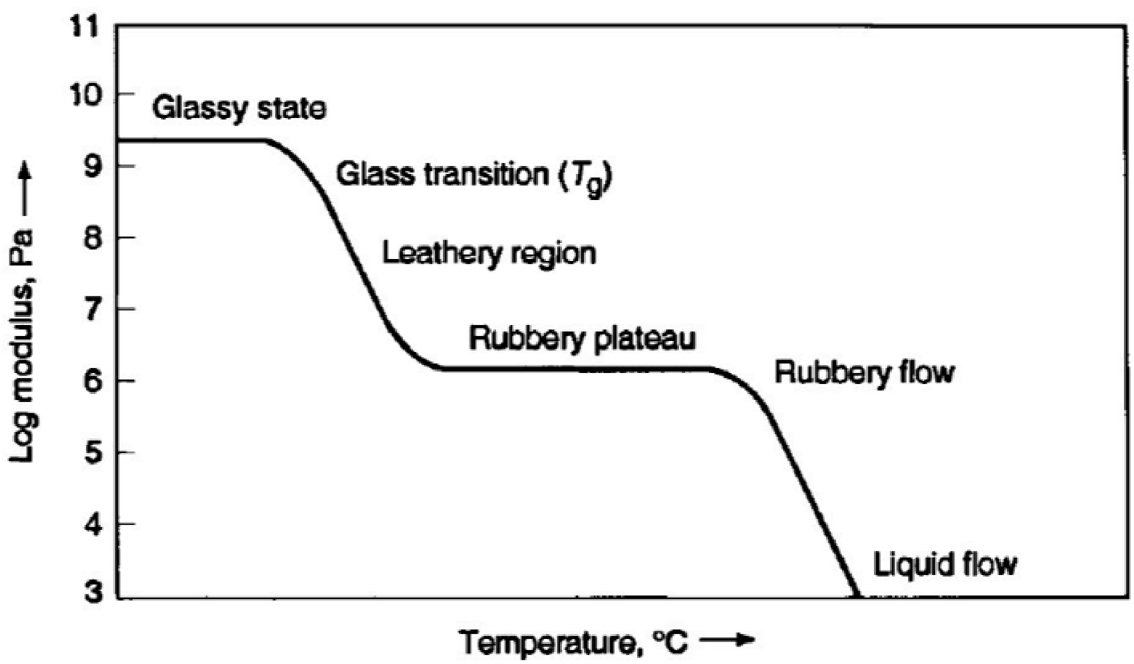

Fig. 2—Thermoplastic state transitions showing the glass transition (T_g).

Property		Impact on application	
Yield Strength	Yield strength is the maximum engineering stress in psi (or Pa) before a permanent non-elastic deformation of the thermoplastic material begins.[1]	The main property that ensures the guide remains integral and withstands the loads applied on it.	
Tensile Modulus or Young's Modulus - E	Tensile modulus or Young's Modulus is the ratio of stress to strain within the elastic region of the stress-strain curve before the yield point.[1]	Analogous to steel, it helps engineer the deformation expected in the guide under the predicted loads and ensure it won't break.	
Flexural Strength	The flexural strength of a material is defined as its ability to resist deformation under load. For materials that deform significantly but do not break, the load at yield, typically measured at 5% deformation/strain of the outer surface, is reported as the flexural strength or flexural yield strength. The test beam is under compressive stress at the concave surface and tensile stress at the convex surface. ASTM D790, ISO178.[2]	Measure of how the guide will behave under side loads applied by the rod.	These values are a measure of stiffness.
Flexural Modulus	The ratio of stress to strain in a flexural deformation.[2]		

Table 1—Other important properties of thermoplastics.

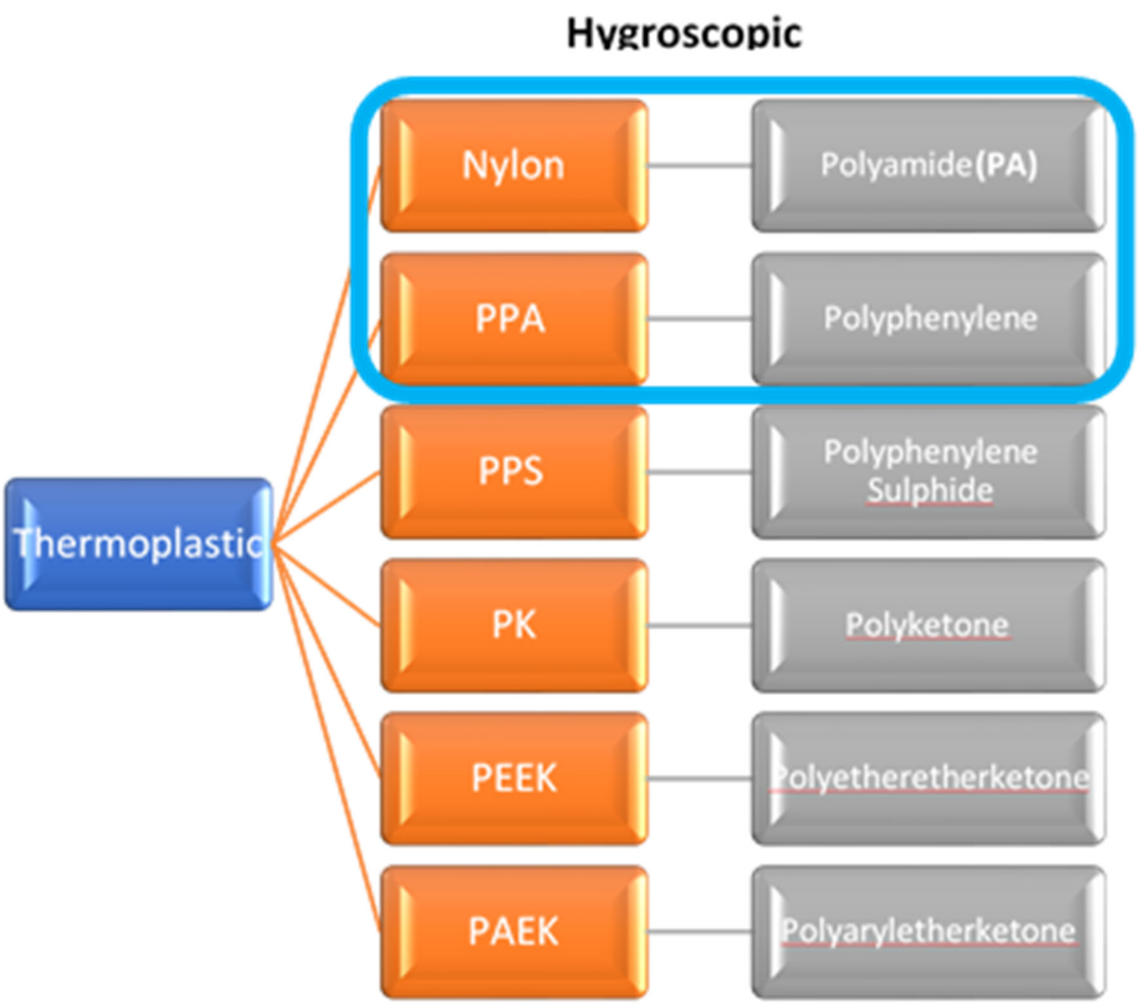

Fig. 3—Most hygroscopic thermoplastics.

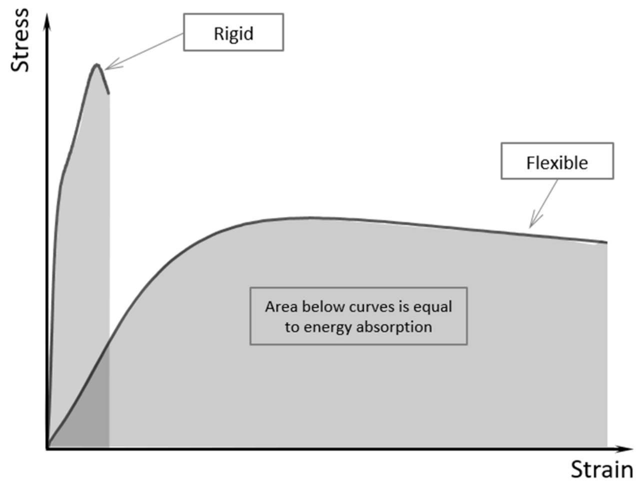

Fig. 4—Typical stress/strain curves of polymers under tension.

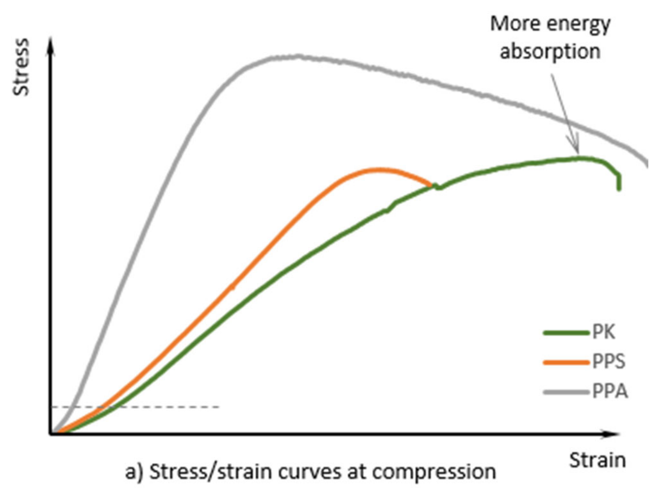

Fig. 5—Typical stress/strain curves of polymers under compression.

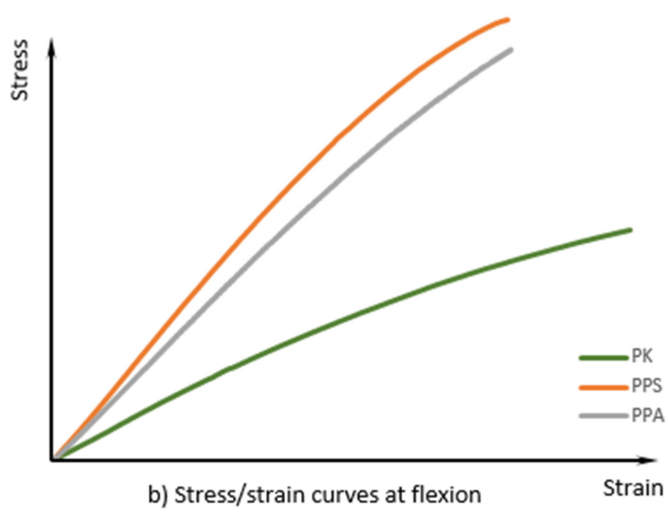

Fig. 6—Typical stress/strain curves of polymers under flexion.

PROPERTIES & AVERAGE VALUES OF INJECTION MOLDED SPECIMENS

PERMANENCE	English	SI Metric	ASTM TEST
Primary Additive	20 %	20 %	
Specific Gravity	1.37	1.37	D 792
Molding Shrinkage			
1/8 in (3.2 mm) section	0.0030 - 0.0080 in/in	0.30 - 0.80 %	D 955
MECHANICAL			
Impact Strength, Izod			
notched 1/8 in (3.2 mm) section	3.0 ft-lbs/in	160 J/m	D 256
unnotched 1/8 in (3.2 mm) section	22.0 ft-lbs/in	1175 J/m	D 4812
Tensile Strength	15000 psi	103 MPa	D 638
Tensile Elongation	5.0 - 7.0 %	5.0 - 7.0 %	D 638
Tensile Modulus	0.65 x 10^6 psi	4482 MPa	D 638
Flexural Strength	21000 psi	145 MPa	D 790
Flexural Modulus	0.60 x 10^6 psi	4137 MPa	D 790

Fig. 7—Preliminary datasheet for aliphatic polyketone glass fiber, silicone-lubricated, UV-stabilized (source: RTP Company).

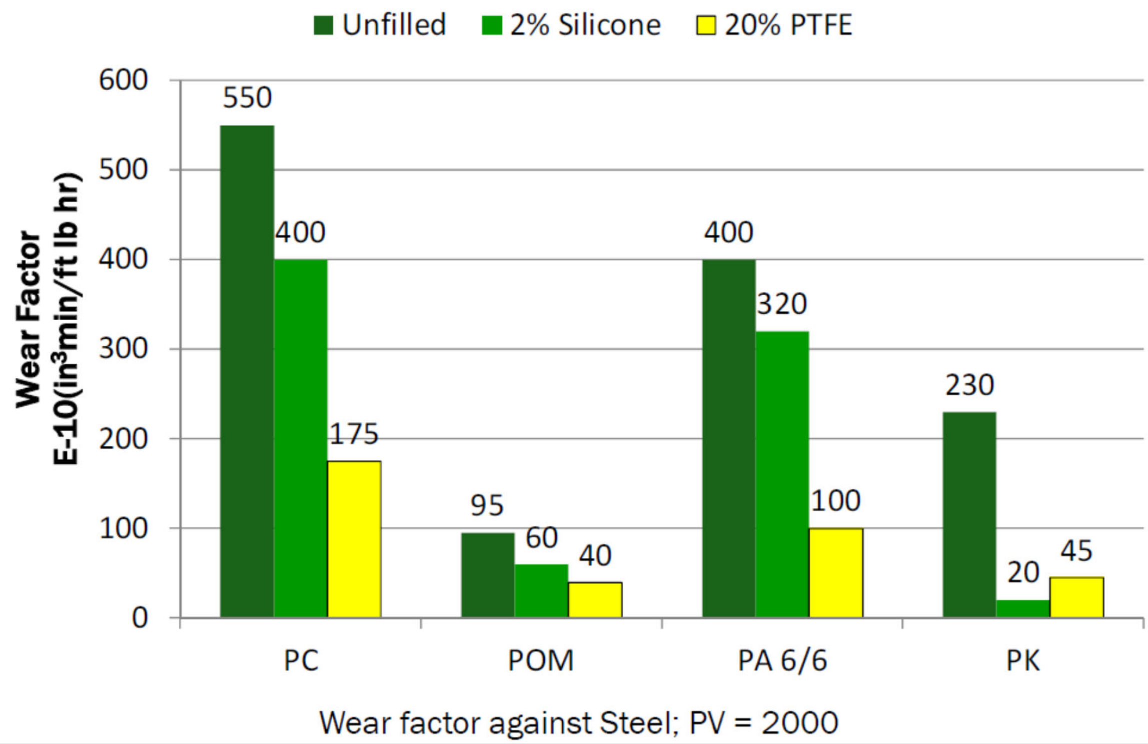

Fig. 8—Wear testing results (source: RTP Company).

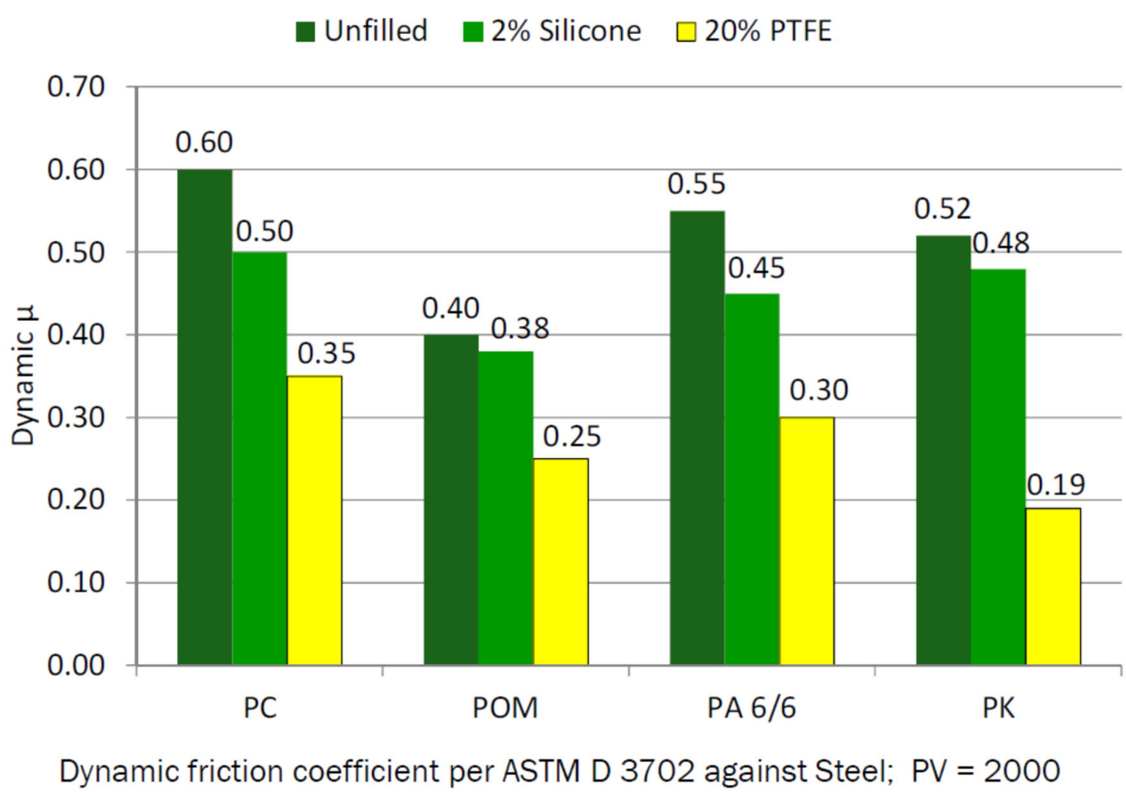

Fig. 9—Friction comparison (source: RTP Company).

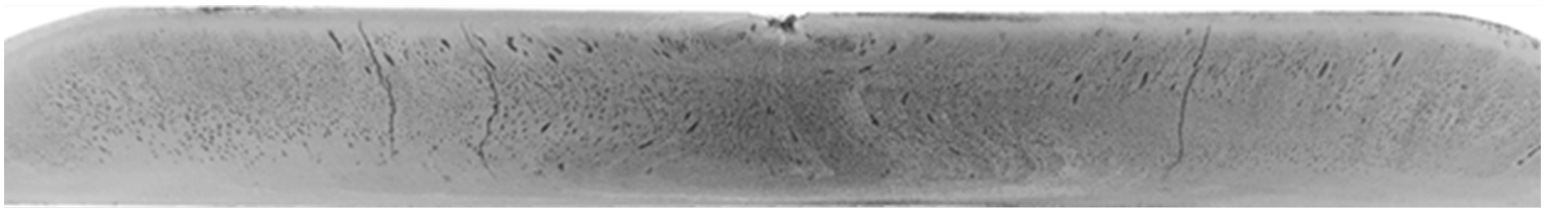

Fig. 10—Typical cracks after exposure to freezing temperatures.

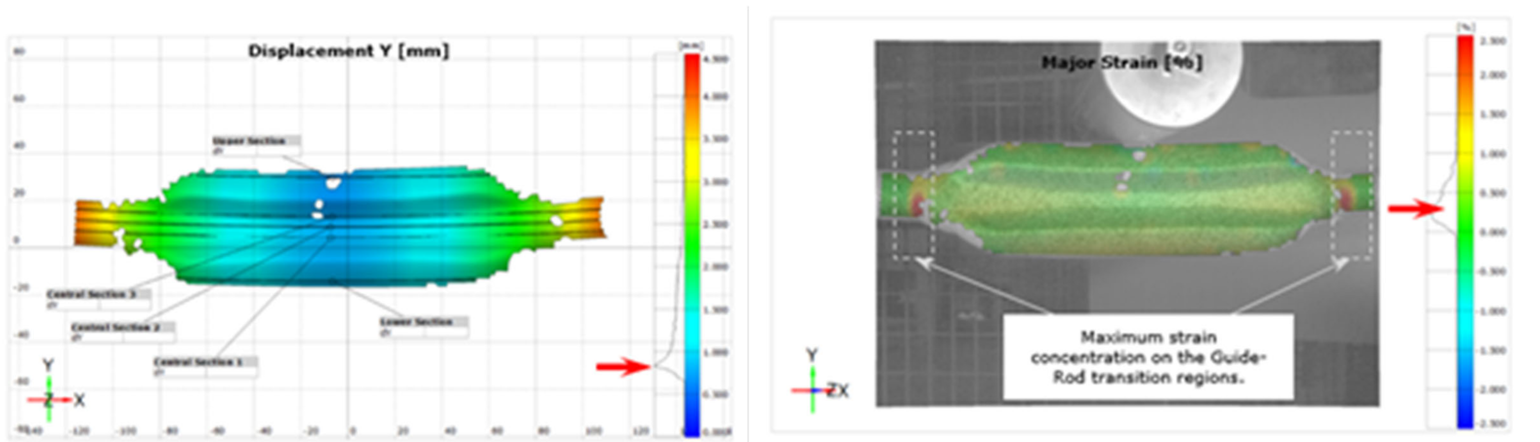

Fig. 11—Strain correlation on flexed guide

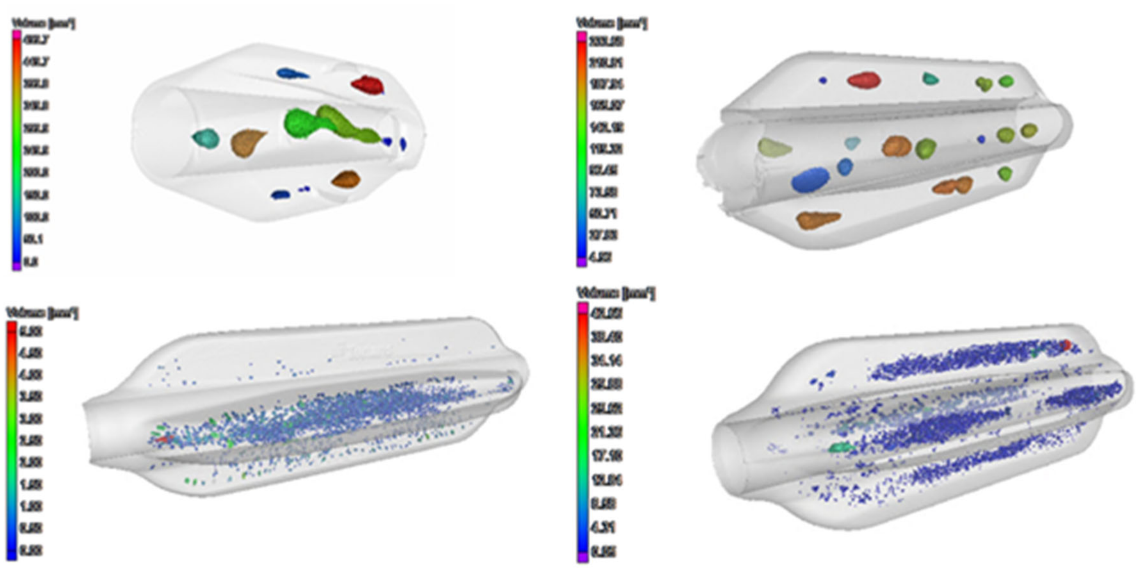

Fig. 12—Images from internal voids showing their size and distribution with different materials.

Fig. 13—Excessive porosity.

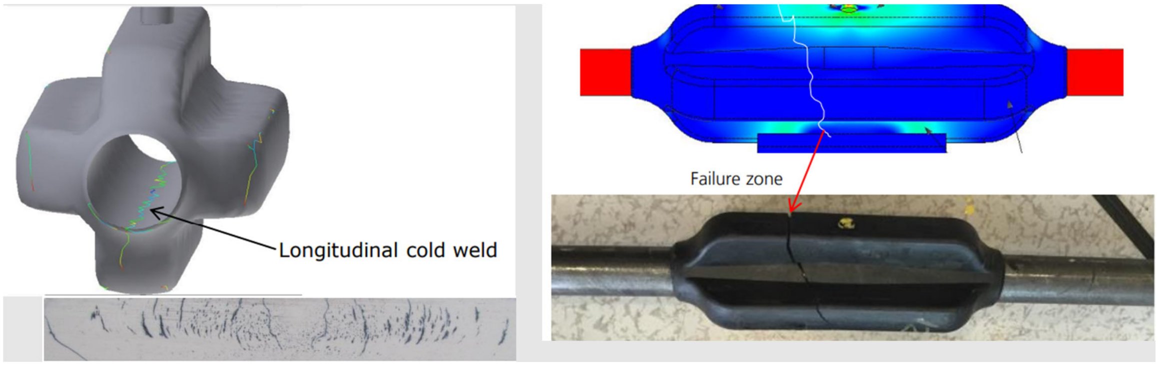

Fig. 14—Internal cold welds developing cracking.

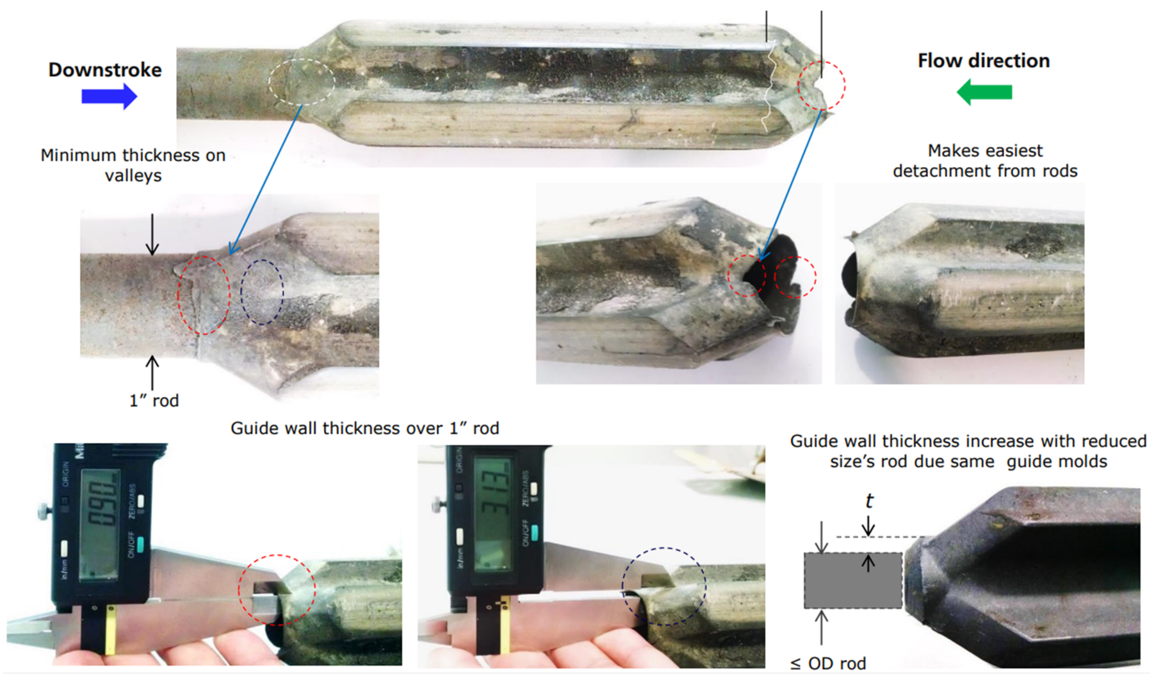

Fig. 15—Flow erosion/corrosion caused by transition from guide to rod body.