Wear-Resistant Elastomer Improves Performance of Telescopic Joint Packers

WHITE PAPER

C.R. DENISON, C.J. FIORE, F.J. KRAKOWSKI | LORD CORPORATION

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Wear-Resistant Elastomer Improves Performance of Telescopic Joint Packers

Deepwater drilling contractors have always faced extensive downtime for the replacement of elastomeric seals on their floating rigs. This has translated into lost time, lost profits, and the potential for environmental damage. LORD Corporation's wear-resistant elastomers can improve the performance of seals, resulting in improved uptimes and reduced rig maintenance.

INTRODUCTION

Deepwater rigs use telescopic joints, also called slip joints, to connect to a drilling riser and accommodate vertical motion from vessel heave. Elastomeric seals, or packers, interface between the inner and outer barrels of the joint and are pneumatically or hydraulically actuated to contain drilling mud within the riser. These seals experience a great deal of friction as the barrels move relative to one another and the seals therefore need to demonstrate high abrasion resistance to minimize material loss from this friction.

Historically, standard nitriles or urethanes have been used to manufacture packers. However, standard nitriles wear quickly in high-friction applications, requiring prolonged downtime to replace seals when a leak develops. Urethanes provide improved wear-resistance compared to standard nitriles, but are typically stiffer than nitriles and therefore require higher actuation pressures to seal. Actuation pressures that exceed rig air supply capacity instead use hydraulics for actuation. Regulating the hydraulic actuation pressure is difficult without performing costly rig upgrades to improve low-pressure hydraulic control. Urethanes are also susceptible to hydrolysis when exposed to water, which results in a loss of mechanical properties.

LORD has developed nitriles that exhibit much less wear than other nitriles in abrasive environments. The new wear-resistant nitrile and soft wear-resistant nitrile demonstrated superior abrasion resistance during material specimen testing and out-performed traditional nitrile packers in two initial field tests. Packers made of the wear-resistant nitrile are no stiffer than traditional nitriles and require lower actuation pressure to seal than packers made from urethane. The soft wear-resistant nitrile is a lower durometer version of the wear-resistant nitrile and is used in applications with a lower targeted stiffness.

MATERIAL TESTING

Rotary Platform Abrasion Testing

During the elastomer formulation process, LORD tested samples using a Rotary Platform Abrasion Tester as shown in Figure 1. The tester measures how much mass a material sample loses as it wears against abrader wheels. Testing was conducted in accordance with ASTM D3389, Standard Test Method for Coated Fabrics Abrasion Resistance (Rotary Platform Abrader), as described by the following excerpt:

> "Abrasion resistance… is measured by subjecting the specimen to the rotary rubbing action of two abrasive wheels under controlled conditions of pressure using the rotary platform abrader. The test specimen, mounted on a turntable platform, turns on a vertical axis against the sliding rotation of two abrading wheels. One abrading wheel rubs the specimen outward toward the periphery and the other, inward toward the center. The resulting abrasion marks form a circular pattern of crossed arcs over an area of approximately 30 cm^2. Resistance to abrasion is evaluated by average mass loss, wear index (average mass loss per revolution) or cycles required to wear through the coating to expose the yarn in the base fabric." (ASTM International 2016).

ASTM D3389 test conditions were modified slightly to accommodate test samples that were extracted from actual molded parts as opposed to samples made of rubber-coated fabric. Polymer scientists used an H22 grinding wheel composed of abrasives in a matrix of vitrified clay, which approximates the abrasion level the elastomer is expected to experience in real-world conditions (CCSi-inc.com. 2006). The machine is equipped with a built-in vacuum to remove crumbs from the surface of the sample throughout the tests. Test results were reported in terms of the Wear Index, which is calculated by measuring the loss in weight (in milligrams) per thousand cycles of abrasion. The lower the Wear Index, the better the abrasion resistance (Taberindustries.com. 2016).

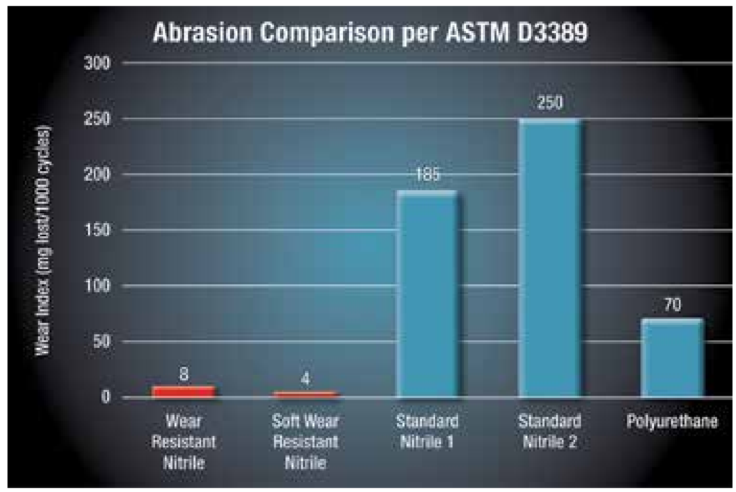
Figure 1: Rotary Platform Abrasion Tester used to perform comparative abrasion testing on two elastomer specimens at a time

In all abrasion tests, specimen loading was 500 grams per wheel. The working surfaces of the wheels were refaced by using a 150 grit silicon carbide abrasion resurfacer for 50 cycles after every 1000 cycles of testing to remove accumulated rubber debris. Materials tested included the wear-resistant nitrile, soft wear-resistant nitrile, white polyurethane, and two standard nitriles that are commonly used in packers today. Figure 2 shows an example of the abrasion test specimens used to perform this testing. The standard nitrile specimens were excised from molded packers, while the wear-resistant nitrile, soft wear-resistant nitrile, and polyurethane specimens were taken from molded tensile pads. All samples were preconditioned on the Rotary Platform Abrasion Tester until a uniform starting surface finish was achieved.

Figure 2: Examples of Abrasion Test Samples with indicated abrasion area

The rotary platform abrasion test results are shown in Figure 3. All data points are calculated from the average value of three tested samples. During abrasion testing, only 8 milligrams of the wear-resistant elastomer were lost per 1000 cycles, and 4 milligrams of soft wear-resistant elastomer per 1000 cycles. Standard Nitrile samples 1 and 2 lost 185 milligrams and 250 milligrams of material respectively and the polyurethane lost 70 milligrams. The Standard Nitrile 1 and 2 materials are representative of what is commonly used in most packers today. The wear-resistant nitrile experienced 8 times less wear than polyurethane, 23 times less wear than Standard Nitrile 1 and 31 times less wear than Standard Nitrile 2. This suggests a longer overall service life, which was corroborated in the field testing results.

Figure 3: Material Specimen Rotary Platform Abrasion Testing Results



Swell Testing

Polyurethane, the wear-resistant nitrile, and the soft wear-resistant nitrile samples were tested in accordance with ASTM D471, Standard Test Method for Rubber Property—Effect of Liquids. Water was used as the test fluid to evaluate the propensity of the materials to swell.

ASTM D471 "provides procedures for exposing test specimens to the influence of liquids under definite conditions of temperature and time. The resulting deterioration is determined by measuring the changes in physical properties, such as stress/strain properties, hardness, and changes in mass, volume, and dimension, before and after immersion in the test liquid" (ASTM International. 2012). Polyurethane and the soft wear-resistant nitrile were tested at 212°F for 168 hours. Both the polyurethane and soft wear-resistant nitrile samples were excised from molded packers. Additionally, a commercially available castable polyurethane was tested against the wear-resistant nitrile and soft wear-resistant nitrile in water exposure at 212°F for 70 and 168 hours.

The soft wear-resistant nitrile sample was excised from a packer that had not been in service, and the polyurethane sample was excised from a packer that had been in service. This may have caused the polyurethane sample to swell less than a fresh sample. The soft wear-resistant nitrile sample experienced a decrease in volume of 0.5 percent, and the polyurethane sample experienced an increase in volume of 3.1 percent.

Since polyurethane elastomers are susceptible to hydrolysis, durometer and tensile testing were conducted to compare a commercially available castable polyurethane, not the polyurethane excised from a packer as mentioned above, to the wear-resistant nitrile and the soft wear resistant nitrile after water immersion at 212°F. It is important to remember that most elastomers are not susceptible to hydrolysis, but polyurethane is. Figure 4 through Figure 7 show the results. The immersion was conducted at 212°F to increase the hydrolysis reaction rate, effectively creating an accelerated aging condition. The polyurethane durometer drops significantly, as shown in Figure 4. Tensile property retention for both the wear-resistant nitrile and the soft wear-resistant nitrile are superior to the polyurethane, shown in Figure 5 and Figure 6. Even in short-term exposure of 70 hours the polyurethane loses almost 90 percent of its original strength, as shown in Figure 5. The polyurethane's elongation goes up in the first 70 hours of exposure before dropping, as shown in Figure 6. This is likely because the swelling initially softens the material via chain scission before causing more complete degradation. The elongation and tensile drop for the wear-resistant nitrile and soft wear-resistant nitrile is small compared to that of the polyurethane and it is difficult to separate the purely thermal degradation from hydrolytic degradation. Despite the changes in mechanical properties, the volume increase is relatively small for all elastomers, as shown in Figure 7.

Figure 4: Water Immersion Durometer, Shore A change at 212°F

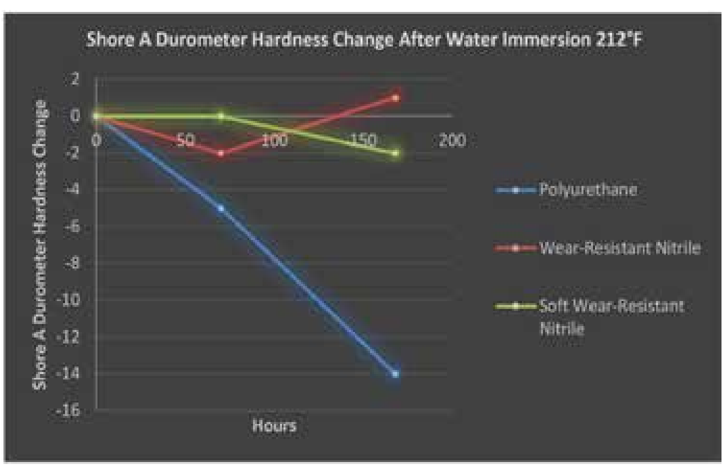


Figure 5: Percent Tensile Retention after Water Immersion at 212°F

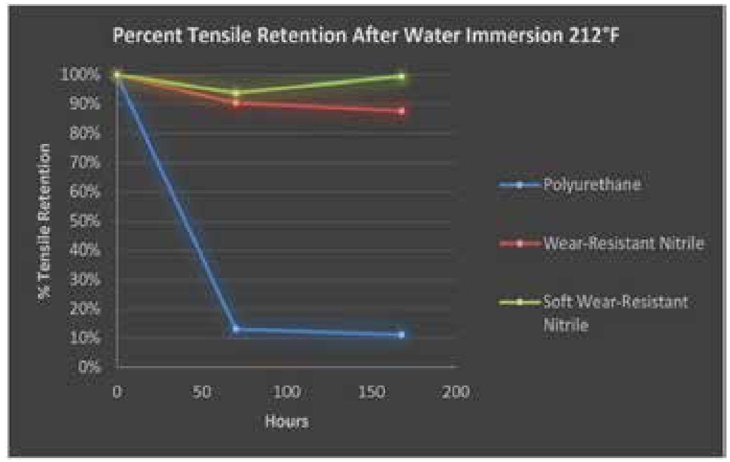


Figure 6: Percent Elongation Retention after Water Immersion at 212°F

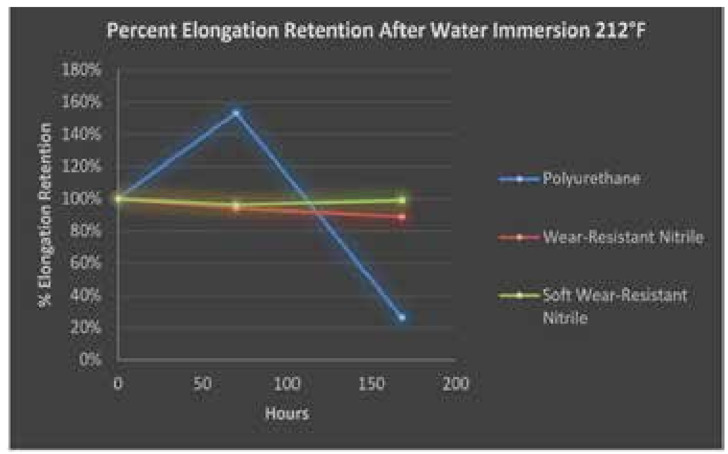
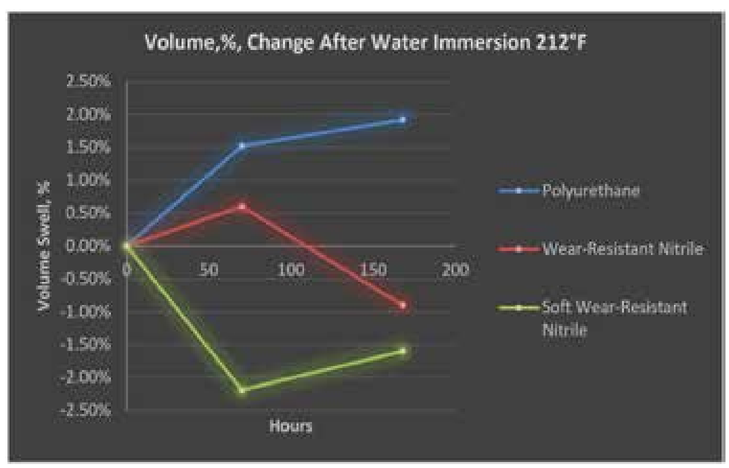


Figure 7: Volume Percent Change after Water Immersion at 212°F



LABORATORY SIMULATION TESTING OF TJ PACKERS

LORD designed and built an American Petroleum Institute (API) 16F telescopic joint packer test machine to act as a full-scale simulator of a telescopic joint assembly, as shown in Figure 8. The packer test machine is used to conduct comparative wear testing between packers molded from wear-resistant nitrile and standard nitrile, as well as to qualify packers to the API Standard 16F Specification. The packer test machine is comprised of a telescopic joint pressure housing and a section of 21-inch outside diameter riser pipe used as the inner barrel. Figure 9 shows a schematic of the telescopic joint housing with two sets of nested packers installed. The housing is easily customizable and is designed to accommodate both split and solid inner packers as well as TJ packers that operate without an outer packer.

Figure 8: API 16F Telescopic Joint Packer Test Machine used to conduct laboratory testing on full-scale packer elements

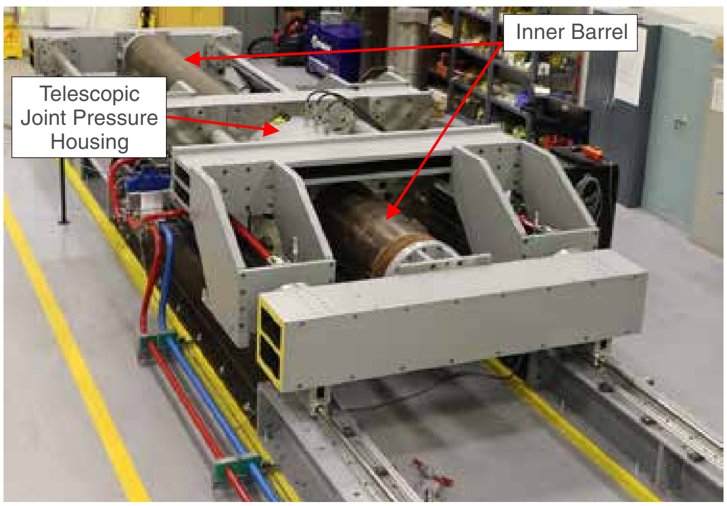
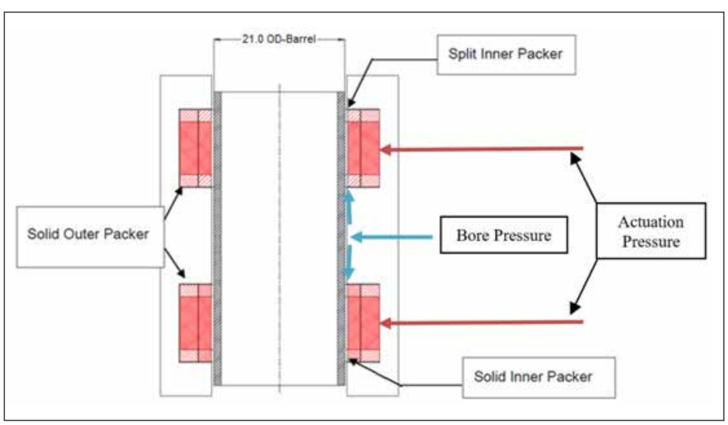


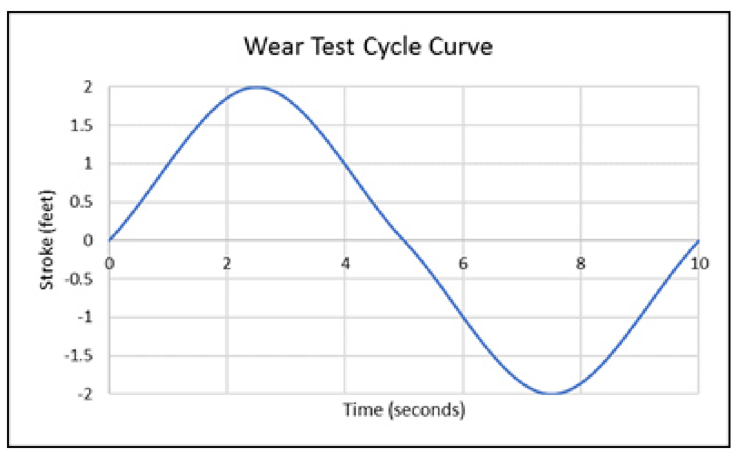
Figure 9: API 16F Telescopic Joint Packer Test Machine housing schematic with two sets of nested packers installed



A hydraulic pump uses water to apply an actuation pressure to the outer diameter of the two outer packers, which creates a seal between the inner packer and the inner barrel. Once the seal is established, the bore pressure is applied to the annulus between inner packers and the inner barrel using the hydraulic pump to simulate pressurized drilling mud. The machine is designed such that the telescopic joint housing remains stationary while the inner barrel is reciprocated using two hydraulic cylinders. The bore and actuation pressures are measured using pressure transducers and recorded. To accommodate the maximum twenty-foot stroke specified in the API Standard 16F Specification, the movement of the riser is measured and recorded using appropriately sized position sensors. The force required to displace the riser is calculated from the hydraulic pressure applied to the cylinders.

Both the standard nitrile and soft wear-resistant nitrile packers were tested to 6,300 wear cycles. A cycle, depicted in Figure 10, consists of a two-foot dynamic amplitude stroke and has a maximum cycle time of 10 seconds as defined in the Wear Test as specified in API Standard 16F. Due to time constraints, the full 50,000 cycle test was not performed for the comparison tests. The bore pressure was set to 25 psi, and an actuation pressure sufficient to prevent leaking was applied. In addition to visual checks, the actuation pressure and bore pressure were monitored throughout the duration of the test to ensure the packers did not leak. ALCO-EP-73 grease was used as a lubricant and applied to the packer inner diameters and inner barrel in all test cases. Packers were weighed and 3D scanned before and after testing to calculate the total amount of wear. The 3D scans not only quantify the wear across the surface of the packer, but also provide the ability to highlight uneven wear.

Figure 10: Wear Test Cycle Curve



The full-scale test results in the API 16F telescopic joint packer test machine demonstrated that the soft wear-resistant nitrile achieves better abrasion resistance than standard nitriles. Two split packers molded with wear-resistant nitrile and one split packer molded with standard nitrile were subjected to 6,300 abrasion cycles. The soft wear-resistant nitrile packers were subjected to a bore pressure of 25 psi and an actuation pressure of 125 psi. No wear was visually evident on the inner diameter surface of the elastomer, as shown in Figure 15. This was confirmed with 3D scans as shown in Figure 11 and Figure 12. There was no measurable change in weight between the pre-test and post-test packers, and there was no visible evidence of elastomer crumbing when the packers were removed from the packer test machine.

Figure 11: Wear-Resistant Nitrile Packer Pre-test 3D Scan

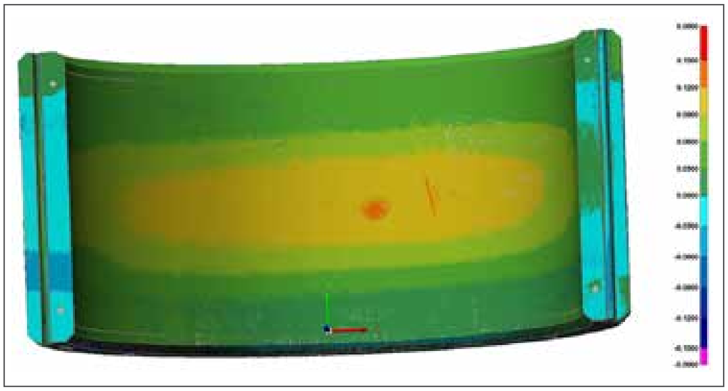
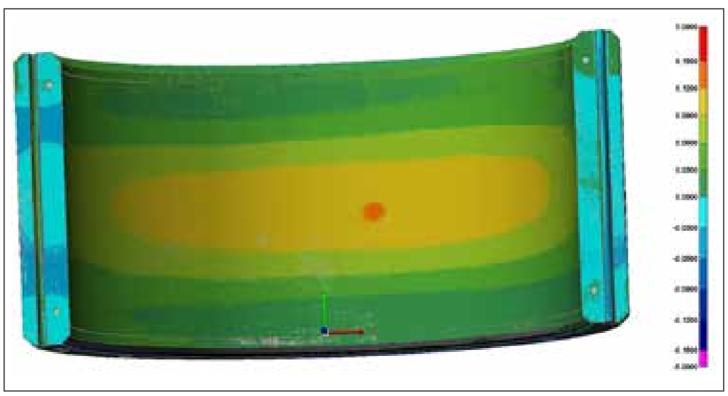


Figure 12: Wear-Resistant Nitrile Packer Post-test 3D Scan



The standard nitrile split packer was also subjected to 6,300 abrasion cycles, but due to delamination between the elastomer and metal rings of one of the solid outer packers provided by an external source, bore pressure could not be applied during the test without leaking. The intact standard nitrile packer was subsequently subjected to an actuation pressure of 125 psi to enable continued testing without the availability of bore pressure due to the delaminated outer packer. Wear was evident throughout the inner diameter surface of the elastomer, and was confirmed with the 3D scan. The 3D scans recorded a maximum decrease in thickness of about 7 percent in the standard nitrile packer, shown in Figure 13 and Figure 14. The standard nitrile packer lost approximately 0.46 pounds after being subjected to the 6,300 abrasion cycles. Figure 15 shows a visual comparison between the standard nitrile packer tested for 6,300 cycles and an untested standard nitrile packer. Figure 16 shows the standard nitrile packer's significant elastomer crumbing due to abrasion observed during disassembly of the test.

Figure 13: Standard Nitrile Packer Pretest 3D Scan

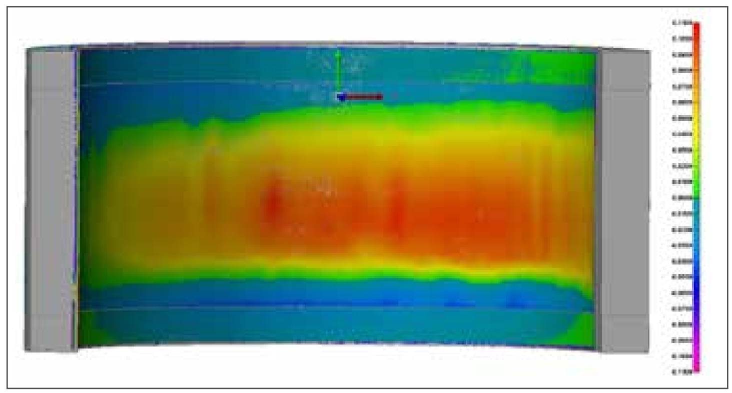


Figure 14: Standard Nitrile Packer Posttest 3D Scan

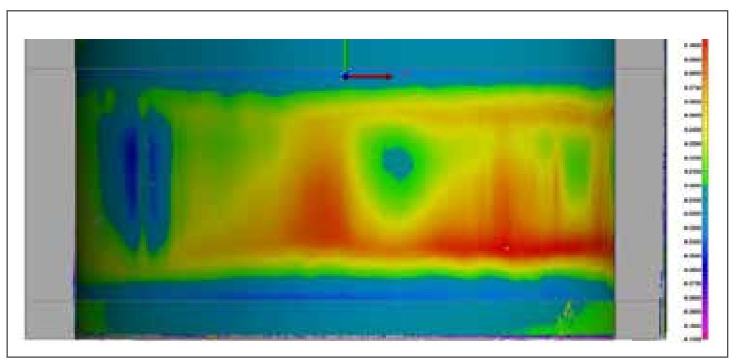


Figure 15: The packer on the left is a post-test standard nitrile packer. The packer on the right is a post-test wear-resistant nitrile packer. The standard nitrile packer displays evidence of wear across the inner diameter elastomer surface, while the wear-resistant nitrile displays no evidence of wear.

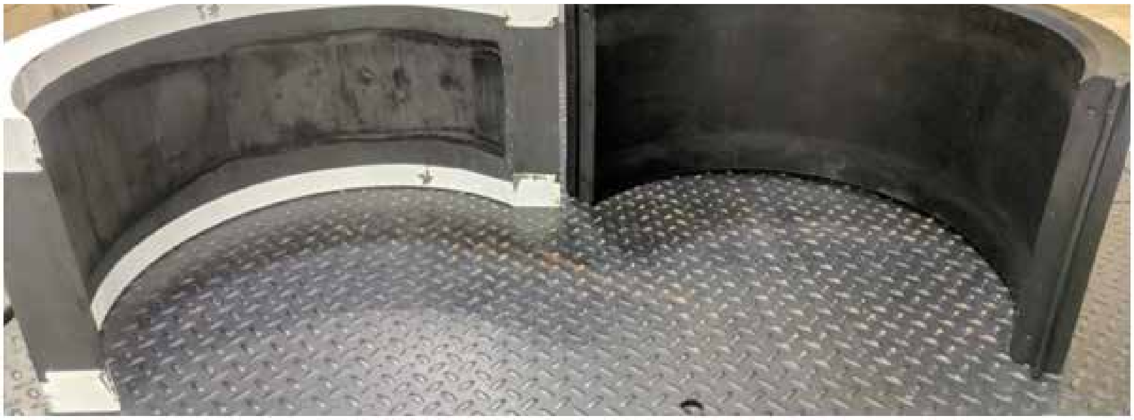


Figure 16: Standard Nitrile Packer elastomer crumbing due to abrasion

Table 1 presents a summary of the full-scale test data. The soft wear-resistant packers experienced no decrease in thickness while the standard nitrile packers were subjected to a maximum decrease in thickness of 7 percent. The standard nitrile packers lost approximately 0.46 pounds of elastomer while the wear-resistant packers' results showed no measurable loss of elastomer. The inferior performance of the standard nitrile packer was further evidenced by the significant elastomer crumbing, which only this packer displayed.

Table 1: Summary of Full-Scale Laboratory Test Results

Test Specimen	Soft Wear-Resistant Nitrile Packer 1	Soft Wear-Resistant Nitrile Packer 2	Standard Nitrile Packer 1
Change in Weight (lbs)	-*	-*	0.46
Maximum Decrease in Thickness (%)	-*	-*	7%

*The difference between the pre-test and post-test condition was not large enough to determine the change in thickness or weight.

FIELD TESTING OF THE TELESCOPIC JOINT PACKERS

Field testing of the wear-resistant elastomer was performed on two packer seals for six months at separate locations. One was located in the North Sea (installed in March 2016) and the other was in Brazil (installed April 2016).

The North Sea packer was actuated at approximately 35 psi the entire operational time. The riser contained oil-based mud (drilling fluid) for 99 percent of the time, and completion fluid (brine) on the remaining days.

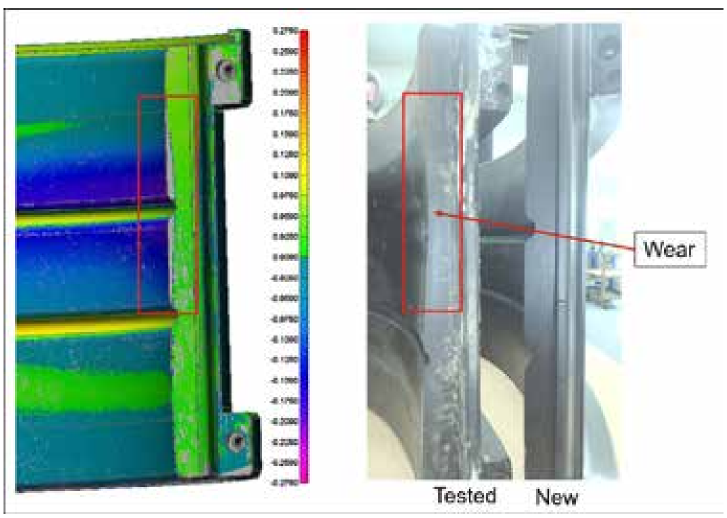
The wear-resistant nitrile packer tested in Brazil replaced a standard nitrile packer, which had a history of leakage. During its in-service time, the wear-resistant packer was energized at 45 psi and had an average stroke length of 0.73 meters. Water depth at this location was approximately 900 meters. Throughout its operation the riser contained water-based mud, sea water and oil-based mud.

When the packer seals were returned to the lab, 3D imaging was conducted in addition to visual inspection. The 3D scans provide dimensional details, thereby quantifying the extent of wear on a fielded packer and allowing for more accurate comparisons between one packer and another.

North Sea Packer Results

The wear-resistant packer tested in the North Sea environment was in operation for 190 days. After the field test was completed in late September 2016, 3D scans demonstrated that the packer had experienced 18 percent maximum wear through its cross section, as shown in Figure 17. Wear was uniform throughout the midsection of the packer, which suggests that the packer was properly installed and aligned during operation.

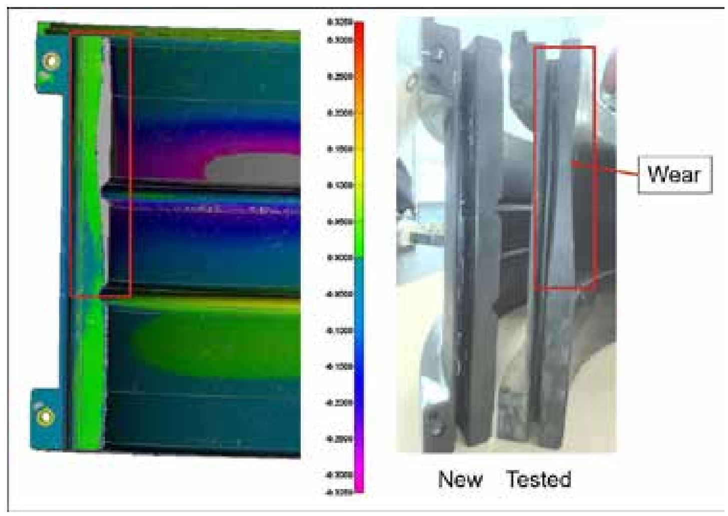
Figure 17: The left image is a 3D Scan of the packer tested in the North Sea. The grey area of the 3D scan represents the material that was worn away; this is used to calculate the maximum wear through the packer. The field-tested part along with an untested part are shown on the right.



Brazil Packer Results

The wear-resistant packer field tested in Brazil saw a total of 83 days in service. After the packer's first 21 days of service, the telescopic joint was shipped onshore for maintenance for unrelated issues. When removed from the TJ, the wear-resistant packer showed no signs of wear or damage and was flown back to the rig. During the maintenance period, a second telescopic joint had been put into service on the rig with a new standard nitrile packer. This packer only lasted four days before requiring replacement. The wear-resistant packer with 21 days of previous service was then re-installed. This packer was in service for an additional 62 days. The wear-resistant nitrile packer lasted over 20 times longer than the standard nitrile packer. The 3D scan in Figure 18 shows it lost 25 percent of its thickness. Wear was uneven across the midsection, with greater wear occurring toward the seam between the two split halves of the packer. Multiple variables from the installation and operation influence the wear pattern on the packers. Based on the remaining elastomer thickness the wear-resistant packer could have been returned to service again.

Figure 18: The left image is a 3D Scan of the packer tested in the Brazil. The field-tested part along with an untested part are shown on the right.



CONCLUSION

Material level abrasion test sample results demonstrate the wear-resistant nitrile lost 23 to 31 times less material than a standard nitrile when subjected to the same test conditions. The full-scale laboratory results showed the wear-resistant nitrile packer did not lose any mass or thickness, while the standard nitrile packer lost 0.46 pounds and had a maximum decrease in thickness of 7 percent. (The test was run to just over 10% of the full 50,000 cycles due to time constraints.) The performance advantage of the wear-resistant nitrile was corroborated by the field test results, which demonstrated the wear-resistant nitrile packer lasted 20 times longer than a standard nitrile packer. Laboratory testing confirmed that polyurethane is susceptible to significant hydrolytic degradation when exposed to water at 212°F, resulting in significant deterioration of mechanical properties. The commercial castable polyurethane retained only about 10-15 percent of its original tensile strength after aging at 212°F for 168 hours, while the wear-resistant nitrile and the soft wear-resistant nitrile retained about 90 percent of their tensile strength.

Because LORD's wear-resistant nitrile and soft wear-resistant nitrile exhibit much less wear than other nitriles in abrasive environments—and because their material properties are better suited to application on TJ packers—deepwater operators and rig contractors can experience improved uptime and reduced maintenance by using packers manufactured from the new nitriles. For more information, visit www.lord.com.

Portions of this paper are selected from "Paper 28918: Application of Wear-Resistant Elastomer to Significantly Improve Service Life of Telescopic Joint Packers"

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LORD Corporation
World Headquarters
111 Lord Drive
Cary, NC 27511-7923
USA

Customer Support Center (in United States & Canada)
+1 877 ASK LORD (275 5673)

www.lord.com

For a listing of our worldwide locations, visit LORD.com.

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