TECHNICAL BULLETIN

PROGRESSING CAVITY PUMPS | LS-TB-O30

LIFTING SOLUTIONS

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BACKROUND

It is understood by most of the progressing cavity (PC) pump community that one of the most important determinants to success of a PC pump is the selection of a suitable stator elastomer. The importance of the stator bond system, that keeps the elastomer securely attached to the tube under various application conditions, is less well understood - unless of course one has come across a premature and sometimes catastrophic stator-bond failure (often by the elastomer coming loose from the tube, known as debonding). Further, the reasons and causes that lend themselves to pump failure and underperformance from stator bonding often appear mysterious to PC pump users. As with stator elastomer and its performance, factors central to reliable and robust stator bond system include bond systems with excellent performance characteristics, a comprehensive understanding of the limitations of the bond systems to different environments and a carefully designed stator manufacturing process and stator bond quality control program. This bulletin aims to bridge the knowledge gap with PC pump users on stator bonding and provides an overview of the detailed process Lifting Solutions (LS) employs to develop, evaluate, rate, manufacture and assess quality of stator-bond systems.

DEVELOPMENT & EVALUATION

Stator bonding is achieved by application of chemicals called bonding agents (or adhesives) to the tube internal surface. Like elastomer, bonding agents also contain thermosetting polymers and therefore they need to undergo cross-linking (or curing or vulcanization) to achieve the final or desired properties. While LS develops its own elastomer formulation, bonding agents are bought off-the-shelf from leading companies specialized in rubber-metal bonding agents – approach used by almost all rubber-metal bonded part manufacturers.

LS integrates the selection of bonding agent into its elastomer development process due to the very intertwined nature of bond system performance to certain key elastomer ingredients and the elastomer vulcanization process. As an example, the desire to achieve good bond performance can conflict with achieving low elastomer swell. The process of bond system selection and development often starts with a laboratory screening test of a variety of bond systems with a few preliminary elastomer formulations. This then allows a few (2-3) bond systems to be shortlisted for full stator evaluation with the shortlisted 2-3 elastomer formulations. This process is often iterative in that elastomers may require further customization (ingredients & their levels) to achieve the desired bonding as well as elastomer properties.

In terms of the nature of the LS bond system evaluation, the laboratory screening test referenced above involves molding small bond coated coupons with elastomer, aging the coupons in fluids, peeling the elastomer in a tensile machine, and assessing the separated interface and the pull load. While this test is good for screening purpose, it is not suitable for a thorough evaluation of stator bonding since the preparation of coupons doesn't capture the stator manufacturing process, which has a large influence on the formation of the bonding layer and subsequently bonding strength & durability. Therefore, to do the more detailed evaluation, LS produces actual stators with the shortlisted bonding agents and elastomers. 5/8" thick stator cross-sections (called bond sample) are cut from different locations of the stators and subjected to a mechanical bond push-out test, both in their as-manufactured (unaged) condition and after aging in various fluid environments.

The bond push-out test subjects the bond layer to high stresses through the use of a fixture to hold the tube while the rubber is pushed out by a die with narrow clearance to the tube internal diameter. The push-out die fixture is shown in image below, along with two bond samples that were put through the bond push-out testing:

Figure 1: Bond Push-out Fixture & Pushed-out Bond Samples

The assessment of the result involves a close examination of the separated interface, where a separation within the rubber matrix indicates a strong bond layer and is therefore the desired result. The assessment assigns a failure mode in terms of the % area of regions exposed at the bond interface. The most desired result is 100R meaning 100% rubber tear, while other results included an estimate of the non-rubber areas (ex. 80R 10RC 10M means 80% rubber tear and 10% each of rubber-coat interface and metal tube surface). The push-out load is also a criterion used for bonding assessment. LS uses the protocol defined in ISO 15136-1:2009(E) International Standard for Progressing Cavity Pumps: Annex A for the bond push test method, tooling dimension and failure definition.

The downhole fluid and temperature environment play a significant role in chemically deteriorating and physically weakening the bond layer and therefore any evaluation of stator bond system must test them in the expected exposure environments and beyond. This is accomplished by a bond immersion test, where the bond samples are immersed in representative fluids at the desired temperature for durations of up to 30 days. Considering the direct exposure of fluid to bond interface (in stators, the fluid contact is indirect as it occurs after the fluid penetrates through the elastomer other than at ends), the test accelerates bond degradation and provides a quicker way to assess bonding in various fluid/temperature environment. After exposure, the bond samples are subjected to a push-out test and the bond failure mode and load are characterized for the level of degradation by comparison to their unaged result.

In the LS bond system evaluation, bond samples are exposed to standard reference fluids such as IRM 903, diesel, fuel B and water but also to produced fluids such as crude oils and chemicals. It is our experience (as well as that of the general rubber-metal bonding industry) that water at elevated temperatures is more detrimental to bond layer compared to the other fluids mentioned that are typically used to assess elastomer swell and physical property changes. Hence, in addition to evaluation of all fluids, LSI puts special emphasis on water immersion at various temperatures and durations to assess bond systems.

To illustrate the extensive nature of the bond evaluation LS undergoes, a small portion of the bond results from its second-generation high nitrile elastomer (HN2) development program is shown below:

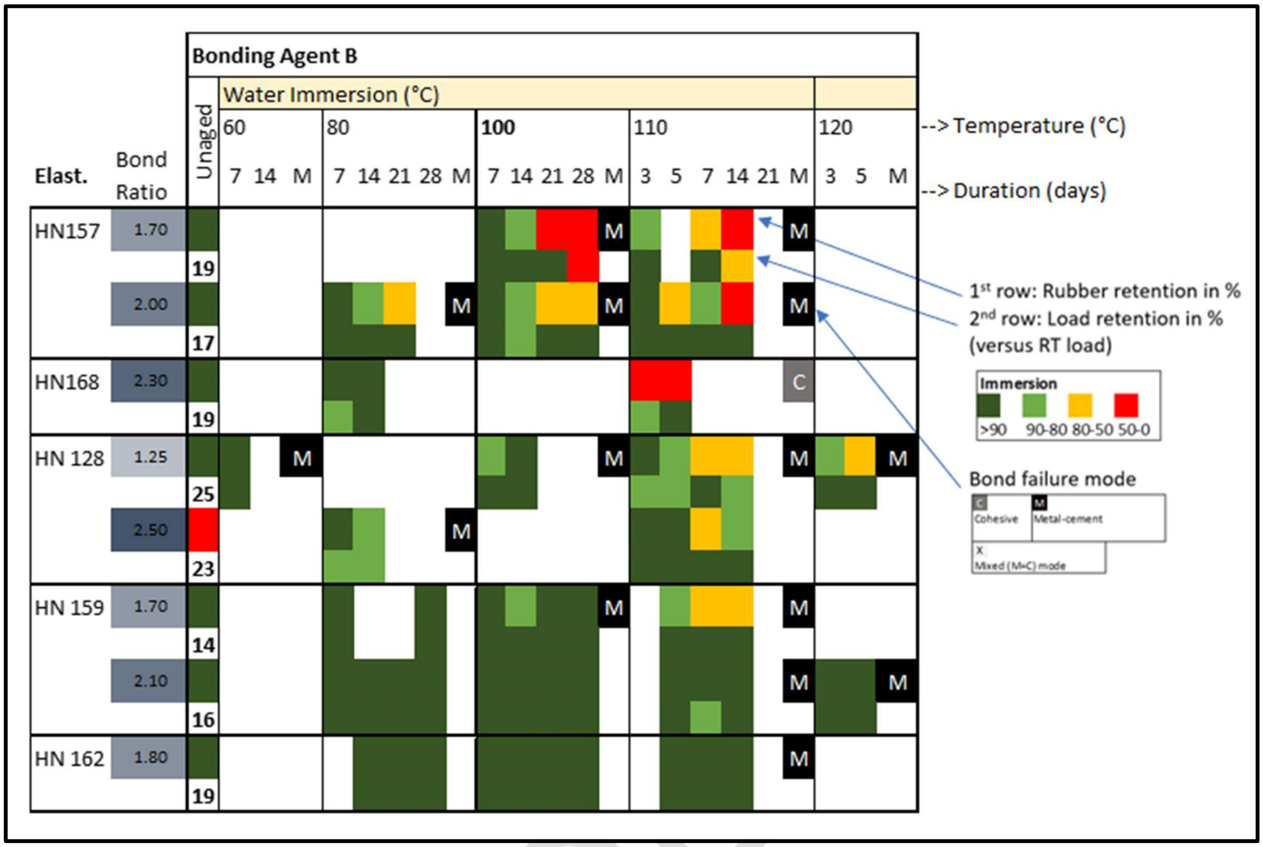

Figure 2: LSI HN2 Development – Select Bond Immersion Results

LS's HN2 development included making about 29 stator prototypes with 10 different elastomer formulations, 3 different bonding agents and different manufacturing parameters to arrive at a few combinations of elastomer, bonding agent, and manufacturing conditions that show the best results.

Final validation is done in a durability bench test, also in compliance with ISO 15136-1:2009(E) standard, where the stator must successfully complete the target 25 million revolutions at 500 rpm and 125% of pressure rating with minimal loss of efficiency. Additionally, the tested stator is destructively inspected, again using the bond push-out test, to confirm minimal or no loss of bond integrity. This extensive evaluation process – starting from lab screening test, then stator bond evaluation in unaged and aged conditions, and finally durability validation – ensures that the bond system selected has the desired bond integrity and environmental resistance but also helps sets forth the manufacturing process parameters. The bond system thus selected is paired permanently with the elastomer. The only instances where a change to bonding agent may occur is when a new bonding agent is found that improves bonding performance significantly or when a supply chain disruption occurs – in both cases, the complete validation process outlined is conducted to confirm similar or improved bonding integrity. In fact, LS's approach is to conduct the same validation process for any meaningful change to manufacturing process parameters that may be identified through our ongoing continuous improvement efforts. This approach ensures that the product bonding performance is not in any way altered once an elastomer is developed and commercialized.

ENVIRONMENTAL RESISTANCE & RATING

As explained in earlier section, resistance to different fluid & temperature environments is the most important criteria in bond system development and is thus mostly established as part of the development process. This section presents select bond environmental resistance results of all commercial LS elastomers. The LS ISO elastomer datasheet, prepared in compliance with ISO 15136-1:2009(E) standard, contains bond results after exposure to various environments. This forms a good portion of the information presented in this section.

LS's acceptance criteria for all elastomers is 100R result in the unaged push-out test. After fluid immersion, a criterion of >90R is considered a good result as some level of failure in the sample is unavoidable and often that doesn't represent a deterioration in bond integrity. The table below summarizes some of the laboratory testing results under various fluids, temperatures, and durations:

Fluid Category	Fluid	Temp. (°C)	Duration (days)	Medium Nitrile		High Nitrile		
				SN1	MN1	HN1	HN2	HNED
Unaged				*100R*	*100R*	*100R*	*100R*	*100R*
Water-Based	Water	80	7	100R	100R	100R	100R	100R
			14	100R	100R	100R	100R	100R
			21	100R	100R	100R	100R	100R
		100	7	100R	100R	50R, 50MC	100R	100R
			14	100R	98R, 2MC	Not tested	95R, 5MC	99R, 1MC
			21	100R	98R, 2MC	Not tested	95R, 5M	99R, 1MC
	3% NaCl Brine	100	7	100R	100R	20R, 80MC	100R	Not tested
Med API Oil	IRM 903	80	7	100R	100R	100R	100R	100R
		100	7	100R	100R	100R	100R	100R
Light Oil /Condensate	Diesel	60	14	Not tested	100R	100R	100R	Not tested
Solvents / Downhole Chemical	Fuel B	30	7	100R	100R	100R	100R	100R
		60	7	100R	100R	98R, 2MC	100R	Not tested

Figure 3: LSI Elastomer-Bond System Results in Various Environments

The fluid immersion tests cover a wide range of downhole scenarios. It is quite clear that in IRM 903 - a substitute for medium API oil - bond integrity is uncompromised even up to 100°C in a 7-day test. Though results of only 7-days are presented here, longer durations tests conducted have shown the same result. The more aggressive fluids - diesel and Fuel B - are tested up to 60°C with similar results. Generally, these fluids are very aggressive to elastomer and lead to significant softening of elastomer, which will increase the likelihood of a rubber tear failure due to lower stresses on the elastomer and less of it being passed on to bond layer. Considering the same mechanism will also transpire with a stator downhole, testing at higher temperatures does not normally add any new information in these aggressive fluids. As alluded to in the earlier section, it can be concluded that bond integrity of all LSI elastomers is not a concern in oil and most chemical environments.

When it comes to water immersion, all of the LS elastomers show excellent results at 80°C and all but HN1 elastomer show excellent results at 100°C up to 21 days of immersion. Preventing water-induced bond degradation is inherently more difficult in high nitrile elastomers, which is evident in HN1's result. This was overcome with HN2 elastomer through the extensive focus on attaining on excellent bond results (as touched on in the earlier section), with the same knowledge extended to HNED elastomer. Overall, the superior hot water bond immersion results of LS elastomers are uncommon in the industry.

It can be concluded from the bond evaluation results that the bond systems of LS elastomers pose no risk to the PCP downhole conditions encountered including warm/hot water producing wells (ex. CSG/CBM wells), warm/hot oil wells with a wide range of API gravities and water-cuts, and wells with downhole chemical injection programs.

In certain cases, free gas produced through the pump can work its way through the elastomer to the bond interface and lead to bond deterioration and bond failure. This is often more prominent in bonding systems that are brittle in nature and possess weak mechanical integrity. LS has considered this as a criterion to bond system selection mitigating the risk of gas-induced bond damages.

LS's approach is to consider the limitations of both elastomer and bond system to assign the temperature rating of its products, which is reflected in the LS's elastomer brochure and ISO elastomer datasheet. As is evident from the bond results in the table above, most LS elastomers have bond systems that are robust up to 100°C. However, since the temperature ratings consider elastomer suitability as well as other factors, only HN2 is rated at 100°C whereas other elastomers are rated at lower temperatures: SN1 at 60°C, MN1 and HN1 at 80°C. Consequently, this approach reduces the need to assess suitability of bond systems to a new application environment as the bond system will be suitable to almost all environments where the elastomer is deemed suitable. Still, when doubts arise on bond integrity risk, a bond immersion test with produced fluid can be conducted to obtain the needed confidence before offering an elastomer/bond system recommendation.

MANUFACTURING & QUALITY CONTROL

Pump debond failures can be an outcome of an inconsistent manufacturing process combined with inadequate quality control procedures. LSI devotes at least as much attention to manufacturing and quality as it does to develop elastomer-bond systems. A multi-pronged approach is employed to ensure that every manufactured stator does not deviate from its design specifications.

Raw Material & Process Controls

The main raw materials that impact stator bonding – bonding agents and elastomers - are tested in-house to meet internally established specifications. The processes that affect bonding encompass the entire stator manufacturing process including the bond coating steps (thermal degreasing, grit blasting, bond mixing, bond coating) and elastomer associated process steps (preheat, extrusion, vulcanization). Multiple process controls exist for each of the individual process steps with stringent specifications. Operators are aided and supported by advanced digital information recording and tracking system, and automation of process steps to eliminate the human variability inherent in some of the process steps. The information collected in the digital information system is routinely used for statistical process control exercises, to monitor and mitigate material and process variables, and for ease of trouble-shooting non-conformances.

Product Quality Control

With an emphasis on process controls and in-process verifications, stator non-conformances are significantly minimized. The bond push-out test, employed by LS as the quality inspection for stator bonding, is performed at both ends of every manufactured stator of elastomers MN1, HN1, HN2 and HNED. LS performs the test on a predetermined frequency for the SN1 elastomer, which is primarily used in cold heavy oil applications, where the bonding requirement is low. Test acceptance criteria is a 100R failure, indicating no amount of bond failure is accepted. Additionally, hot water bond immersion tests are periodically conducted on randomly selected stators to monitor bond integrity. Bond immersion testing serves as a great tool to detect minor deviations in bond integrity and therefore allows LS to maintain high consistency in stator bonding.

FAILURE ANALYSIS FEEDBACK

As a last but important measure to maintain robustness of stator bond integrity, stators that are selected for detailed field inspections are destructively evaluated for bond integrity with the bond push-out test. The bond inspection is performed on all stators selected for detailed inspection irrespective of the cause for pump inspection. Multiple bond samples are cut across the entire length of the stators (every 1-2 feet) for the bond test. The bond inspection allows LS to understand the degradation mechanism of bonding system from field operation and to identify any manufacturing process variability. This knowledge is applied to improve bonding on existing and new products and refinement of manufacturing processes - thus closing an important feedback loop in the continuous product improvement and development cycle.