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THE EVOLUTION OF POLYMER BEARING PROCESSING FOR SCROLL COMPRESSOR PERFORMANCE AND LIFE ENHANCEMENT

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Abstract

Polymer bearings with a PTFE-based running surface were first introduced as a breakthrough in scroll ompressor performance approximately 30 years ago. These bearings consisted of the polymer surface, porous bronze interlayer and steel supporting layer. That construction has become widespread in compressor applications, as the bearing composition and performance have advanced, with improved environmental impact. Since that introduction, polymer application to the bronze bearing interlayer has typically relied on the deposition of a composite slurry to produce the low-friction, wear resistant surface. While that deposition method has served the compressor application well, bearing life was basically limited by the polymer integrity and layer thickness due to the inherent nature of the slurry-based process.

A new material technology is now available for use in scroll compressor bearing manufacture to provide notably improved performance both in durability and seizure resistance in comparison to the historical slurrybased deposition method. These performance improvements have been documented through wide-ranging tribological testing in general tribological testing conditions as well as methods relevant to scroll compressor conditions.

A comparison of the bearing materials manufactured by multiple process technologies is provided as well as tribological results documenting the performance enhancement. Test data presented include results from the bearing development and manufacture and also qualification tests by a prominent compressor manufacturer, documenting improvements in both durability and seizure resistance.

1. Introduction

Multilayer PTFE-lined bearing materials have been adopted successfully across a broad application base, primarily because the filled-PTFE running surface provides superior self-lubricating properties. The inherent low friction associated with this polymer has been used to increase efficiency in applications impacted by sliding friction, and to reduce bearing wear in systems that are susceptible to adhesive wear.

The classic three-layer configuration for this bearing type is shown in Figures 1 and 2 (next page). This structure consists of a porous bronze innerlayer sintered to a steel backing, and impregnated with a filled-PTFE compound to purposely leave a film of the same composition remaining on top. This upper layer, or "overlay" is fundamental to bearing operation. Figure 1 shows the bearing with a PTFE and lead composition, the original multilayer polymer bearing innovation in scroll compressors. Figure 2 shows a lead-free alternative that has replaced the former in recent years for some applications to comply with increasing environmental requirements.

A longstanding manufacturing approach for this class of materials (1, 2) has been to co-coagulate a PTFE based aqueous dispersion with desired particulate fillers, creating a slurry-based compound that could be impregnated into the porous bronze structure. Subsequent incremental developments around this process led to a dry powder process that together with compositional improvements improved properties such as cavitation resistance and fatigue resistance (3).

Size adjustment after installation for both slurry-based and powder-based liner systems is limited to burnishing for both materials. It was demonstrated that the powder-based liner was able to undergo significant modification through burnishing while maintaining tribological performance. But resizing via machining for both types resulted in a significant life reduction and higher friction through increased exposure of the bronze interlayer.

The latest innovation in the manufacture of PTFE-based tribological layers has been through the impregnation of higher-integrity polymer films (5,6). These films provide the ability to build a thicker polymer overlay that delivers increased resistance to key tribological conditions including sliding wear and cavitation erosion. The historical overlay thickness was typically in the range of 5 to 25 µm thickness, with Figure 3 showing such an example with a layer of 17 µm. The enhanced overlay version is nominally over 100 µm thickness, with Figure 4 showing a thickness of 126 µm. This thicker overlay overcame the sizing limitations of its predecessors, permitting machining after bearing installation to a precision equivalent to metallic materials. Additionally, it has also provided favorable tribological improvements in a number of conditions relevant to scroll compressor operation.

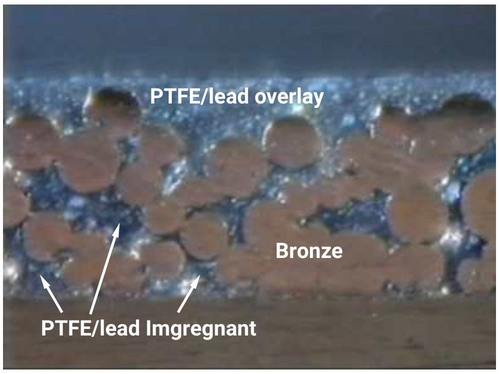


Figure 1: Cross-sectional image showing the multi-layered bearing construction. Image shows a bearing of PTFE/lead composition, the original bearing of this type utilized in scroll compressors.

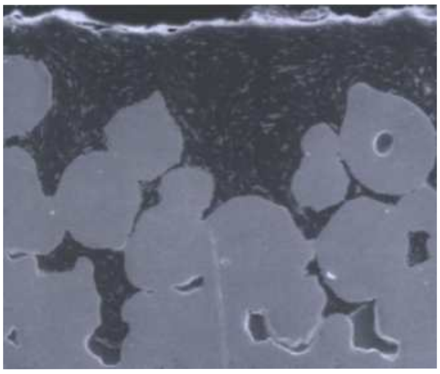


Figure 2: Cross-sectional image of a lead-free composition with MoS_2 filler

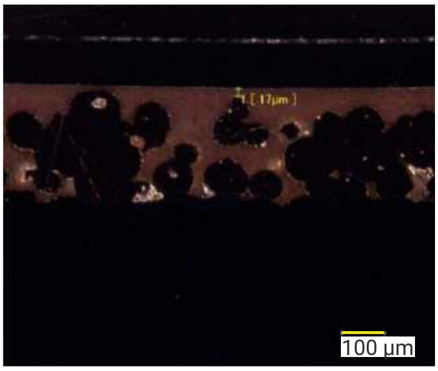


Figure 3: Cross-sectional of historical bearing construction showing limited polymer overlay thickness, in this case 17µm

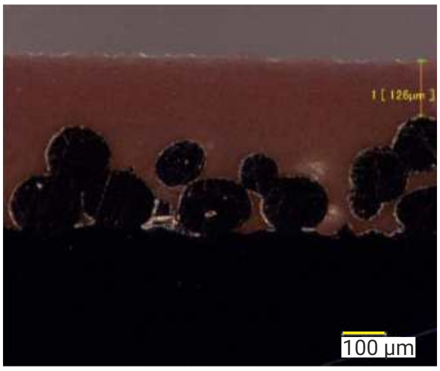


Figure 4: Bearing construction showing machineable polymer overlay, in this case 126µm

2. Experimental Procedure

2.1 Materials Tested:

Each material consisted of a classic metal / polymer composite structure. That is, a steel backing, porous bronze interlayer and a PTFE-based polymer impregnant, within the porous structure with a polymer overlay as the initial running surface. Three individual materials were tested:

- Slurry-based PTFE layer: MoS2 particulate filler, balance PTFE; cross-section shown in Figure 2 [product DP10TM]
- Powder-based PTFE layer: CaF2, a second fluoropolymer addition and colloidal Al2O3 particulate addition, balance PTFE (3); cross-section shown in Figure 3 [product DP31TM]
- Film-based PTFE layer: CaF2, balance PTFE; cross-section shown in Figure 4 (5,6) [product DTS10^{TM}]

Note that the slurry and powder-based polymer layers were produced with a polymer overlay of approximately 25um, designed to be used in the as-impregnated state. By comparison, the film-based PTFE layer was designed to have the capability to be machined, thus containing a polymer layer of 100 µm or greater. These overlay differences are visible in the cross-sectional images of the various materials. All performance data are presented in the asformed bearing condition, without secondary sizing operations.

2.2 Test Methods

Two sets of tribological evaluations were conducted. One series was conducted by the bearing manufacturer, GGB Bearing Technologies. A second set was run by compressor manufacturer Daikin Industries, Ltd. As a result, the test descriptions, and results presentation are identified as being by the bearing manufacturer or by the compressor manufacturer.

2.2.1 Bearing Manufacturer Test Conditions

2.2.1.1 Cavitation Erosion:
Testing was conducted on flat samples of composite, polymer-lined discs. The cavitation test rig is shown in Figure 5. Samples were held magnetically in place 1mm below a high frequency sonic horn as shown, immersed in room temperature water. The horn operated at 26 kHz for a pre-determined duration that was determined by the material under test. Material loss was quantified by weighing samples before and after the test. Data are presented as an erosion rate, mg/min.

2.2.1.2 Boundary Lubricated Wear Testing:
Wear testing was performed on the rig shown in Figure 6. These tests also used flat samples of the polymer-lined discs as test samples. The test head shown in Figure 2 consists of three hemispherical counterbodies (“shoes”) held in a rotating fixture and forced to slide against the flat test specimen. The lubrication regime was altered from boundary lubrication (material / material contact) to a hydrodynamic film (no material contact) based upon speed, load, temperature and oil type. Individual conditions are listed in Table 1.

Wear Test Conditions				
Test Regime	**Load**	**Speed**	**Lubrication**	**Oil**
Boundary Lubrication	14.5 MPa	0.163 m/s	95 °C	Type F

Table 1: Wear Test Conditions

Note that the oil type (Type F transmission fluid) was chosen primarily because of the viscosity and tendency to form a specific type of lubrication regime; not to simulate a specific application.

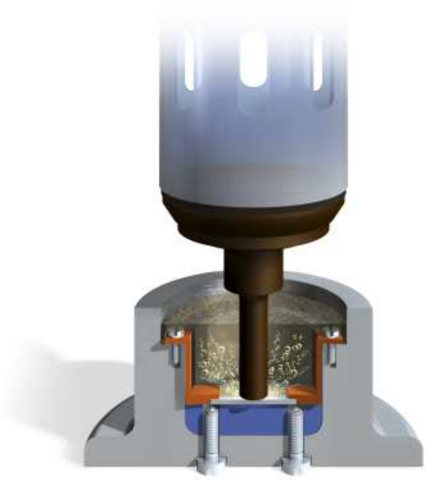


Figure 5: Cavitation erosion rig

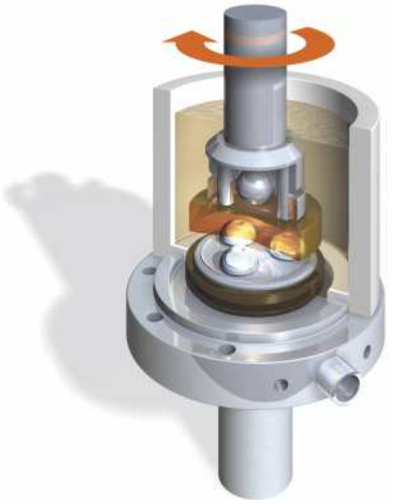


Figure 6: Wear test rig showing the three „shoe“ test configuration

2.2.2 Compressor Manufacturer Analysis

The same three materials were also evaluated by using test conditions considered relevant to those in a scroll compressor. The conditions reported here evaluated seizure resistance and general wear resistance. Both seizure and wear tests utilize a bushing configuration of 30 mm ID x 20 mm length.

Test Parameters	Seizure Resistance*	Wear Resistance
Load	step load to 31 MPa	5.9 MPa
Speed	11.3 m/s	0 m/s (10 s) - 2.8 m/s (10 s)
Lubricant	24% FVC68D oil w/ R410A	24% FVC68D oil w/ R410A

Table 2: Test Parameters **Seizure resistance test was stopped at friction coefficient >0.2; temperature >200°C*

3. Results

3.1 Tribological Data: Bearing Manufacturer

3.1.1 Cavitation Results

Cavitation testing was conducted on the three materials, and weight loss calculated for each sample grouping. Data are reported in Figure 10 as wear rate (mg / minute) for each of three materials. The greatest level of erosion loss was measured on the slurry-based liner, followed by the powder-based material. The lowest level of erosion loss was measured on the film based liner. Surface images are also shown in Figures 7 through 9 for examples of each of the three materials at equivalent test duration (6 minutes). Removal of pieces of the overlay may be observed for the slurry-based material in Figure 7. The underlying bronze structure may be seen to have been exposed during the cavitation process. The powder-based liner shown in Figure 8 exhibited reduced exposure of the underlying bronze structure in comparison to Figure 7, and reduced weight loss rate as indicated in Figure 10. The superior cavitation performance of the film-based liner quantified in Figure 10 and supported by the surface image shown in Figure 9. The underlying bronze structure was not exposed, as a result of both the reduced weight loss rate, and the thicker polymer overlay.

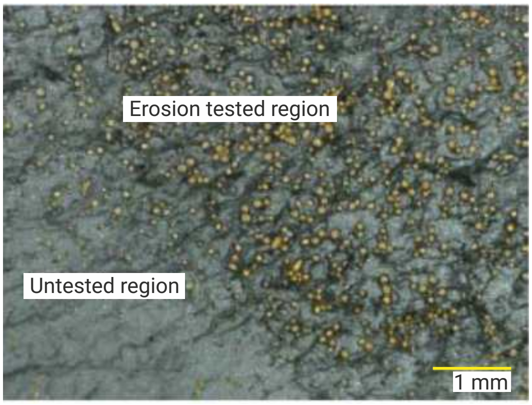


Figure 7: Cavitation erosion test sample, slurry-based liner

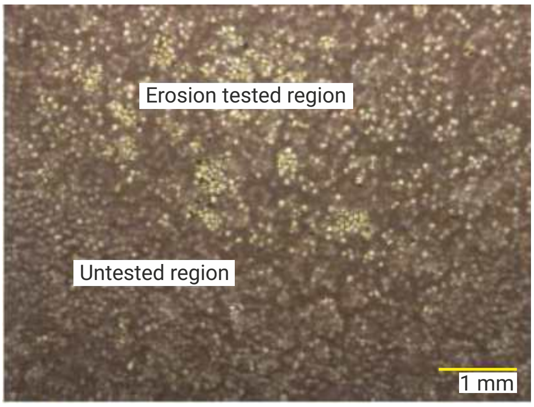


Figure 8: Cavitation erosion test sample, powder-based liner

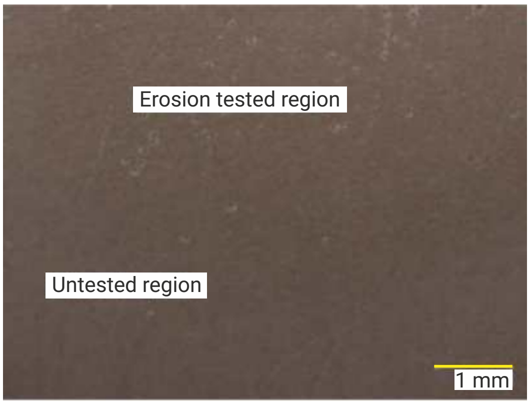


Figure 9: Cavitation erosion test sample, film-based liner

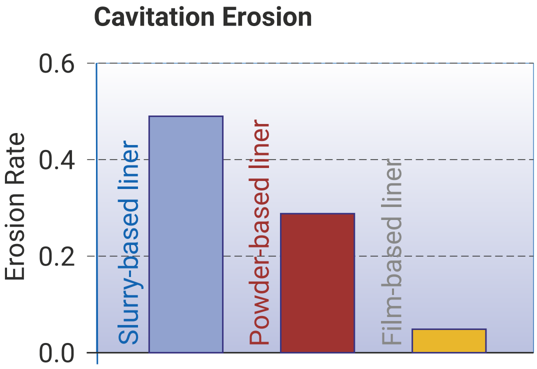


Figure 10: Cavitation erosion data

3.1.2 Boundary Lubricated Surface Wear

Lubricated wear testing was performed on the three sample materials using the three “shoe” test rig shown in Figure 6. Data are shown in Figure 14, presented as wear rate, that is, wear depth (µm) as a function of sliding distance (km). Surface images of the three materials are shown in Figures 11 through 13 indicating the representative surface appearance after a wear test. The overall wear depth for the sample shown is noted in each figure. The slurry-based material experienced the greatest wear rate at 1.9 µm/km. The powder-based product had the next level at 0.66 µm/km with the lowest from the film-based liner at 0.46 µm/km. This lowest wear rate was in addition to having overlay thickness of >100 µm, which was significantly greater than either of the other materials (< 25 µm). This wear resistance translates directly into extended bearing life in a compressor, with the added advantage of a thicker overlay (even after machining) contributing further to durability.

Surface imagery followed the quantitative wear results in that the material with the greatest wear also showed the greatest disruption of the wear surface. The surface of a tested slurry-based liner in Figure 11 exhibited exposure of the underlying bronze layer. The powder-based liner, shown in Figure 12, exhibited less disruption through wear indicated by only a slight change in bronze exposure between the untested region and the wear track. The film-based product in Figure 13 appeared smooth by comparison with verylittle disruption following wear testing.

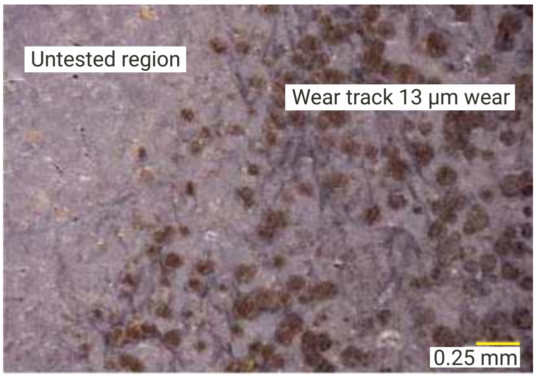


Figure 11: Boundary wear tested sample, slurry-based liner

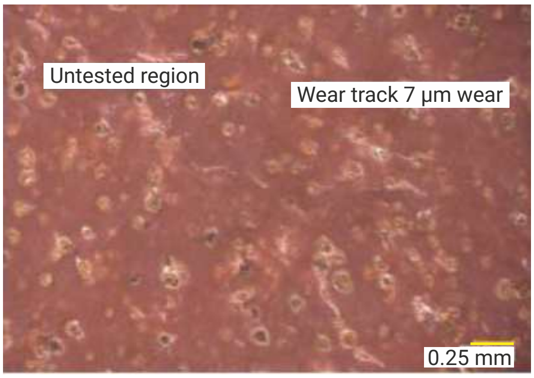


Figure 12: Boundary wear tested sample, powder-based liner

Figure 13: Boundary wear tested sample, film-based liner

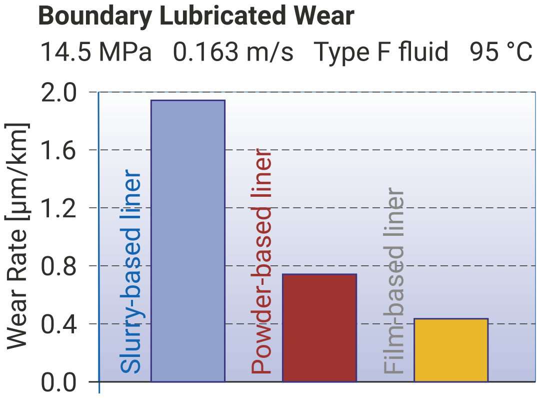


Figure 14: Boundary wear data

3.1.3 Boundary Lubricated Friction Data

Representative friction curves are shown in Figure 15 for the three materials. The powder-based and film-based materials show one curve each, as those materials typically exhibit minimal wear at the conditions shown. The slurry-based material, by comparison, shows two friction curves, representing different test responses. The friction curves for the powder-based and filmbased materials show that friction was higher initially for those in comparison to the slurry-based liner, but experienced low wear and thus consistent friction. The low wear rate resulted in minimal exposure of the bronze interlayer at the test completion. Figures 12 and 13 show final sample conditions for the powder and film-based samples. In the case of one slurrybased sample higher wear and resulting bronze exposure caused increased friction late in the test. Figures 16 and 17 represent the final condition for two slurry-based samples, with varied levels of bronze exposure. This difference demonstrated the friction increase resulting from bronze exposure compared to the friction of a surface consisting primarily of PTFE.

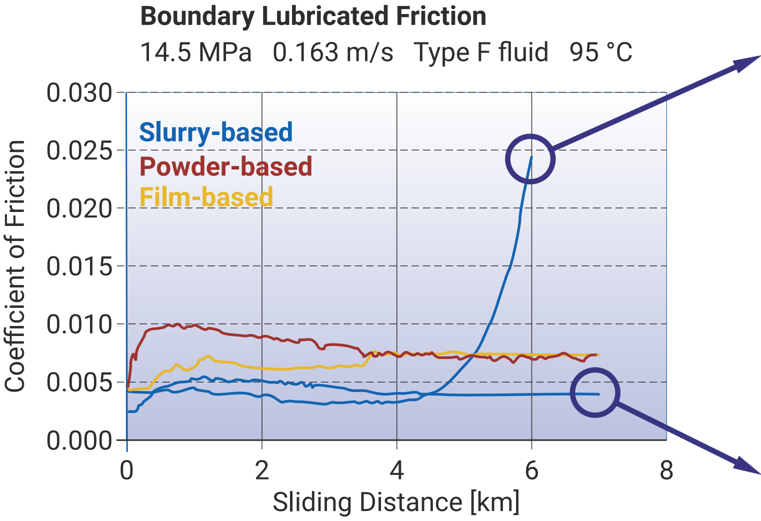
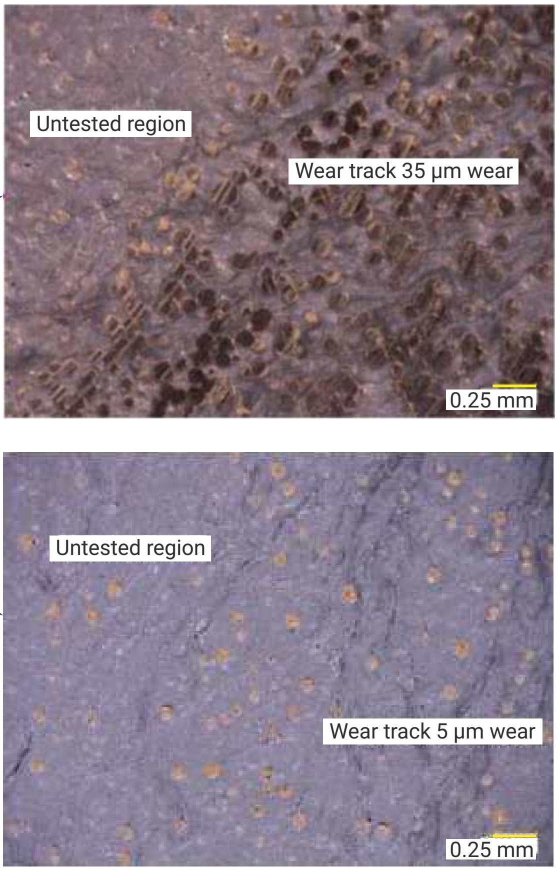


Figure 15: Friction curves from boundary lubricated wear testing



Figures 16 (top) and 17 (bottom) showing surface condition after wear testing for a range of bronze interlayer exposure and varied friction results

3.2 Tribological Data

Compressor Manufacturer: Testing was conducted to evaluate both wear resistance and seizure resistance of the three bearing materials listed in Section 2.1. The wear data in Figure 18 generated by compressor manufacturer showed the same order and relative scale of the wear data in Figure 14 by bearing manufcaturer, despite being tested under notably different conditions. Again, the slurry-based material had the highest wear depth and the film-based material the lowest.

Seizure resistance data are shown in Figure 19, presented as the load at which the friction exceeded 0.2 or the temperature exceeded 200°C. The data showed a similar trend as wear and cavitation data with the film-based material exhibiting the most favorable performance.

These data helped to validate test results discussed above, with the film-based liner exhibiting the highest wear resistance. It is also believed that the low and consistent friction over an extended test duration provided the favorable seizure resistance, especially for the film-based bearing material.

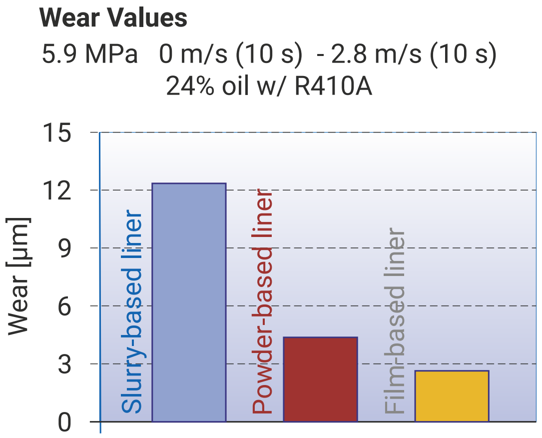


Figure 18: Wear data for compressor manufacturer testing presented as overall wear depth

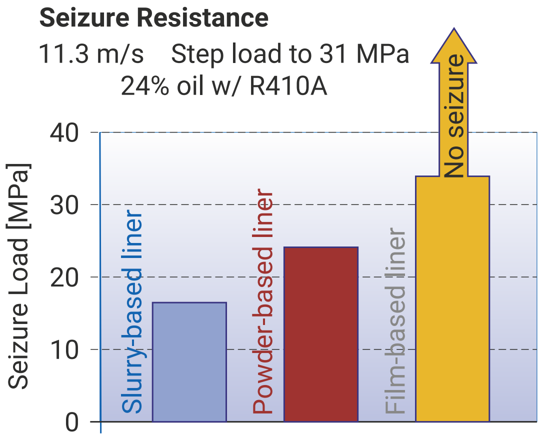


Figure 19: Seizure resistance presented as seizure load . Note that the film-based liner did not seize at the maximum test load.

3.3 Performance Summary

Tribological data were presented comparing bearing materials with differences including manufacturing method, composition and thickness of the polymer wear layer. Wear rate differences were documented, including highly-correlated relative differences between the testing performed in different test locations using varied test methods. Wear rate was lowest for the film-based material, which also had the greatest wear layer thickness. The cavitation erosion rate was also lowest for the film-based material. Seizure resistance was also most favorable for the film-based material. The performance of the powder-based material was favorable to the slurry-based material in each data set and test regime, although wear layer was nominally identical for those two materials.

It is proposed that the manufacturing method by which the polymer layer was produced and applied played a significant role in bearing performance. This enhanced performance would ultimately relate to increased bearing life in scroll compressor applications.

3. Conclusions

- Three PTFE-lined bearing materials distinguished by their polymer processing methods were tested in wear, cavitation and seizure resistance. The processing method differences concerned the means by which a self-lubricating polymer layer was applied to a supporting porous bronze interlayer. The methods were slurry-based processing, a powder-based process and a film-based method.
- The film-based material had a thicker polymer overlay than the other materials, proving the opportunity for precision machining after installation and/or increased wear life as a result of a greater thickness of the self-lubricating polymer layer.
- Separate tribological evaluations were conducted by both the bearing manufacturer and by a compressor manufacturer. Both sets of results demonstrated the most favorable wear performance for the film-based liner, followed by the powder-based material.
- The film-based polymer liner system exhibited the highest level of wear resistance, cavitation resistance and seizure resistance. The slurry-based material demonstrated the lowest level of resistance to each of the conditions.

4. References

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