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EVALUATION OF NON-ASBESTOS SHEET GASKET FOR MOBILE REFRIGERATION COMPRESSORS

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ABSTRACT

Maintaining a high level of gasket performance with current non-asbestos materials can be difficult. The replacement of previous asbestos containing sheet gaskets with other types of fiber reinforced sheet gaskets required a thorough evaluation using a simulated service testing procedure. In this paper we will discuss the details of the fabrication of a test fixture which simulates the temperature, refrigerant pressure and load bearing conditions often observed in mobile refrigeration compressors and evaluation of the load changes and refrigerant leakage over a large number of temperature and pressure cycles. Highlights of the results obtained in this study will be presented.

INTRODUCTION

Due to the health hazards in the use of asbestos, both the manufacturing and availability of asbestos gaskets became difficult a few years ago. The refrigeration industry has successfully used asbestos reinforced nitrile-butadiene rubber gaskets in sealing various component in the compressor. The replacement of these sheet gaskets with other types of fiber reinforced sheet gaskets required a thorough evaluation. Traditional screening tests, such as tensile strength, elongation, compression set under various loads, permanent set and stress-relaxation are good tools for screening. But for actual performance of the gasket under service conditions required fabrication of a special simulated service test equipment which was capable of temperature and refrigerant pressure cycling the gasket and simultaneously determining the refrigerant leak rate and gasket load changes. Screening test results and simulated service test results obtained in this study are presented.

EXPERIMENTAL

Screening Study

To aid in the screening of sheet gaskets, accelerated aging conditions were used. The dog bone samples (for tensile strength) and discs (for compression and recovery) were exposed to alkylbenzene and R-22 at 347°F for 32 days. Standard tensile dog bone bars and 1 1/8 in. diameter compression buttons were cut from the flat sheets using suitable dies. These test samples were clamped in test fixtures that prevented curling of the sample during high temperature environmental exposure.
After exposure to the refrigerant/lubricant environment, test samples were withdrawn and scrutinized for physical conditions. The following tests on aged and unaged samples were performed.

**Compressibility and Recovery**

Gasket compressibility and recovery tests were conducted at room temperature in accordance with ASTM-F36, "Compressibility and Recovery of Gasket Materials". Procedure A was followed. In this procedure a minor compressive load of 5 lbf is applied to a 1 1/8 in. diameter test gasket using a 0.252 in. diameter hardened tool - the load is maintained for 15 sec. And then a major load of 450 lbf (500 lbf total) is applied uniformly within 10 sec. And maintained for 60 sec. During this procedure, load and gasket thickness under load are continuously recorded on an X-Y recorder.

Compressibility and recovery are calculated as follows:

\[
\% \text{Compressibility} = \left(\frac{P-M}{P}\right) \times 100
\]

\[
\% \text{Recovery} = \left(\frac{R-M}{P-M}\right) \times 100
\]

where P = final thickness under initial preload, M = final thickness under total load, and R = final recovered thickness under second pre-load.

**Tensile Strength**

Tensile tests were conducted at room temperature using as a guide, ASTM-F-152, "Tension of Nonmetallic Gasket Materials". Some exceptions were taken - samples were conditioned at 158°F and 50% relative humidity rather than 212°F (dry) and testing speed was 0.1 in./min rather than 12 in./min. Tensile strength is calculated as peak load divided by original cross-sectional area.

**Weight Changes**

The percentage weight gain by each specimen was calculated by measuring the weight before and after aging.

**Compatibility**

Compatibility evaluation of gasket samples, cut in a strip of 2 in. long and ¼ in. wide, immersed in R-22 and Zerol 15-0 was done at 347°F in high pressure tubes. The samples were rated based on the color of the oil/refrigerant, sediments and wall deposits.

**Stress Relaxation**

Relaxation was measured using fixtures patterned after ASTM-F38, "Creep Relaxation of a Gasket Material", Test Method A. The fixtures are similar to the "Relaxometer" described in F38 except for changes made to permit the tests to be run at elevated temperatures.

**Simulated Service Test (SST)**

A test fixture was designed and fabricated to evaluate gasket performance under cyclic conditions of temperature and refrigerant R-22 pressure. A schematic of the test apparatus is presented in Figure 1. The test specimen is a ring-shaped single thickness of the gasket material, nominally 3.4 inch outside diameter x 3.0 inch inside diameter. The specimen is moistened with 4 drops of alkylbenzene refrigeration oil just before installing between the loading surfaces of the aluminum test fixture. The initial clamping force on the gasket (equivalent to 4000 psi) is measured with a load cell in the fixture as the clamping bolts are tightened. A torque wrench is used to ensure uniform loading. The fixture and associated instrumentation are designed to measure the refrigerant pressure on the specimen inside diameter, the specimen temperature, the total clamping load on the specimen, and the leak detector output. These four parameters plus piston stroke and additional thermocouples are recorded continuously on a strip chart recorder. Leakage of refrigerant through or past the test gasket is measured continuously by a Balzer's Frigosniff (RXS-
which uses a quadrupole mass spectrometer for detection. Nitrogen is used as a carrier gas to transport the leaked refrigerant into the Frigosniff for detection.

Temperature and pressure are cycled during the test but at different frequencies - a temperature cycle is completed every two hours while a pressure cycle takes only two minutes. Temperature is controlled by a programmable temperature controller connected to electric resistance heaters and a solenoid valve in a cooling water line. Pressure is varied by compressing a volume of refrigerant in a piston. The refrigerant piston is driven by a hydraulic actuator. A pressure transducer in the refrigerant line is used for both recording and feedback to the hydraulic servo controls. A full test normally lasts 5700 pressure cycles (95 temperature cycles).

The test system is initially charged by first pulling a vacuum and then backfilling from a cylinder of refrigerant. To achieve an adequate charge, the refrigerant piston is chilled with blocks of dry ice to ensure that the piston contains both liquid and gaseous refrigerant. As testing progresses a portion of the liquid refrigerant vaporizes to make up for any leakage that may occur. A control option permits the R-22 pressures to be cycled continuously or to hold the pressure at 150 psi after the gasket temperature drops to 310°F (from a maximum of 350°F) and not resume pressure cycling until the gasket temperature rises above 170°F during the heat-up portion of the next temperature cycle. This option more closely simulates service conditions wherein the compressor pressure would not be cycling during cool down after the compressor was shut off, but would cycle as the compressor was restarted from a "cold" condition. This 150 psi hold is a less severe condition as far as the potential for gasket leakage is concerned because the gasket clamping pressure is lowest at the low end of the temperature cycle where, if coupled with a higher R-22 pressure of 400 psi, a leak would more likely occur. Eventually if the refrigerant does not leak through the gasket for approximately 95 thermal cycles, the R-22 pressure is cycled continuously to simulate the more stringent conditions.

RESULTS AND DISCUSSION

Screening Evaluation

Potential replacements were selected from the industry at large. These sheet gaskets were made of a variety of synthetic fibers and thermoplastic or thermoset binders. Most of these sheet gaskets were manufactured by a compressed process with a few exceptions in which a beater addition process was used. Product literature and material safety data sheets were reviewed against the engineering requirements. The candidates which met the engineering requirements were then evaluated for tensile strength, compression, recovery and weight changes after exposure to the refrigeration medium at 347°F for 32 days. Results of some selected sheet gaskets are summarized in Table 1. The most noticeable changes in percent compressibility and percent recovery occurred after aging of the samples containing graphite (Sample TK10). In the presence of alkylated benzene lubricant and R-22 refrigerant at 347°F, the graphite-containing sample lost its resistance to compression. The same sample swelled to maximum as determined by the weight change after aging. Sample TK37 made with Aramid fiber and thermoset binder, became very brittle and broke during aging. Further inspection of the sample showed blistering and delamination. Additionally, compatibility of all the sheet gaskets was carried out by immersing the small pieces of gasket in the refrigeration media in a sealed glass tube and aging at 347°F for 20 weeks.

Stress relaxation testing was performed at 400°F and 600°F as described previously in the experimental section. The results of the stress-relaxation tests on a few selected candidate gasket samples are shown in Figures 2 through 5. In general, the tests were performed for more than 5000 hours, but the testing was discontinued in some cases where the stress dropped significantly in a short period of time. A large reduction in stress with time was observed for synthetic fiber/SBR/NBR (S. No. TK34) and PTFE/filler (S. No. TK33) at 600°F. The comparison of stress
relaxation rates (experimental data) of several gasket materials is shown in Table 2. Based on these screening tests, each candidate material was rated. Each test was given a weighted value dependent on Thermo King's requirements. It is important to note that these weights may or may not represent the needs of a different application and should be re-evaluated and reviewed before conclusion can be made. Based on the weighted averages of the screening evaluations, the selected candidates were further tested under simulated service test conditions.

Simulated Service Testing (SST) Results

The SST was custom designed to closely simulate operating compressor conditions in a laboratory. This test was considered the final laboratory proof that an asbestos-free gasket material would perform adequately during service in the refrigerant lubricant environment. It was followed by additional functional compressor endurance and field testing. Our initial experiments on SST were carried out using a gas chromatograph, a batch analysis of refrigerant. This was replaced with a hydrocarbon analyzer, which allowed us to measure the refrigerant R-22 leakage continuously throughout the SST duration. This hydrocarbon analyzer was not very sensitive to the refrigerants. Therefore, finally, a quadrupole mass spectrometer (Frigosniff from Balzer’s) was used to quantitatively measure the refrigerant leak continuously through the SST duration. It was also noted early on that rate of cooling from 350°F to 160°F during temperature cycling had a profound effect on the refrigerant leakage and load changes. In the initial testing, cold water was circulated through the coils in the aluminum blocks, causing the temperature, especially near the bolts, to decrease unevenly with sudden spikes. This decrease in temperature, especially the thermocouple 8 in Figure 1 has a direct impact on the bolt loads. After carrying out several experiments initially, a flow meter was added in the cooling water line and warm water was circulated instead of cold water to more uniformly regulate the temperatures during the cool-down cycle. Figure 6 clearly shows the relationship between the rate of cooling and the lowest temperature of thermocouple 8 to the bolt loads and refrigerant leakage. This figure shows the 20th temperature cycles in three different SST experiments carried out on Aramid/synthetic fiber (TK38) gasket. Experiments 1 and 2 were carried out using cold water for cooling cycle whereas Experiment 3 was carried out by regulating the flow of warm water for cooling cycle. The loads, temperatures and refrigerant leak rate for these three sets of experiments are shown in Table 3. This reduction in bolt load is caused by the mismatch in coefficient of thermal expansion (CTE) between the aluminum head and body (CTE = 13 x 10⁻⁶ in./in.°F) and the steel bolts (CTE = 6 x 10⁻⁶ in./in.°F) as well as creep and relaxation. Following these experiments, all the remaining simulated service tests were carried out using a flow meter and warm water during cool cycle.

Typical SST results on Aramid/synthetic binder are shown in Figure 7. These results suggest the suitability of this gasket and assembly for Thermo King application. After 95 thermal cycles, continuous pressure cycling was started making conditions more harsh. This particular gasket performed well even after the continuous pressure cycling was started. Figure 8 shows the SST results of a Kevlar/NBR gasket which did not perform well. It exhibited loss of clamping load as well as heavy refrigerant leak.

CONCLUSION

Custom designed simulated service equipment for qualifying the gasket use in the refrigeration environment has been developed. This equipment has been successfully used to test the asbestos-free replacement sheet gaskets and its assembly to determine the refrigerant leak rates and clamping load changes during various temperature and pressure cycles. The gaskets selected after the simulated service testing have been implemented in the Thermo King compressors. Four years field data has supported the efficacy of the SST.
Table 1 - Mechanical Properties of Some Selected Sheet Gaskets Before and After Aging in R-22/Alkylbenzene at 175°C (347°F) for 32 Days

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Material Composition</th>
<th>As-Received Tensile Strength (psi)</th>
<th>As-Received Compressibility %</th>
<th>As-Received Recovery %</th>
<th>As-Recovery Tensile Strength (psi)</th>
<th>As-Recovery Compressibility %</th>
<th>As-Recovery Recovery %</th>
<th>After Aging in R-22/Alkylbenzene Tensile Strength (psi)</th>
<th>After Aging in R-22/Alkylbenzene Compressibility %</th>
<th>After Aging in R-22/Alkylbenzene Recovery %</th>
<th>Weight Change %</th>
</tr>
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<tbody>
<tr>
<td>TK5</td>
<td>Aramid-Cellulose/NBR</td>
<td>1423</td>
<td>15.5</td>
<td>69.3</td>
<td>704</td>
<td>7.3</td>
<td>50.2</td>
<td>65.2</td>
<td>10.4</td>
<td>10.4</td>
<td>4.9</td>
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<tr>
<td>TK6</td>
<td>Aramid-Cellulose/SBR</td>
<td>1384</td>
<td>19.7</td>
<td>47.7</td>
<td>533</td>
<td>10.7</td>
<td>54.8</td>
<td>85.5</td>
<td>17.5</td>
<td>17.5</td>
<td></td>
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<tr>
<td>TK7</td>
<td>Compressed Mica/Binder</td>
<td>843</td>
<td>19.6</td>
<td>47.7</td>
<td>19.8</td>
<td>19.8</td>
<td>85.5</td>
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<td>17.5</td>
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<tr>
<td>TK9</td>
<td>Kevlar/NBR</td>
<td>981</td>
<td>10.1</td>
<td>55.6</td>
<td>391</td>
<td>6.7</td>
<td>60.4</td>
<td>8.4</td>
<td>8.4</td>
<td>8.4</td>
<td></td>
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<tr>
<td>TK10</td>
<td>Graphite/Metal</td>
<td>301</td>
<td>17.3</td>
<td>21.3</td>
<td>503</td>
<td>100.8</td>
<td>1.2</td>
<td>28.8</td>
<td>28.8</td>
<td>28.8</td>
<td></td>
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<tr>
<td>TK18</td>
<td>Asbestos/NBR</td>
<td>2999</td>
<td>10.5</td>
<td>53.0</td>
<td>3895</td>
<td>8.4</td>
<td>73.4</td>
<td>6.7</td>
<td>6.7</td>
<td>6.7</td>
<td></td>
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<tr>
<td>TK20</td>
<td>Synth. Fiber/BR</td>
<td>561</td>
<td>14.2</td>
<td>49.6</td>
<td>1125</td>
<td>10.5</td>
<td>56.0</td>
<td>6.7</td>
<td>6.7</td>
<td>6.7</td>
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<tr>
<td>TK33</td>
<td>PTFE/Filler</td>
<td>2254</td>
<td>4.5</td>
<td>65.4</td>
<td>2275</td>
<td>6.8</td>
<td>57.8</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>TK34</td>
<td>Synth. Fiber/SBR/NBR</td>
<td>6058</td>
<td>10.4</td>
<td>67.1</td>
<td>3086</td>
<td>9.1</td>
<td>53.2</td>
<td>11.9</td>
<td>11.9</td>
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<td></td>
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<tr>
<td>TK37</td>
<td>Aramid/Thermoset</td>
<td>1400</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>16.0</td>
</tr>
<tr>
<td>TK38</td>
<td>Aramid/Synth. Binder</td>
<td>4967</td>
<td>9.3</td>
<td>54.4</td>
<td>4047</td>
<td>8.3</td>
<td>32.9</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td>TK40</td>
<td>Aramid/Synth. Binder/Wire Mesh</td>
<td>5133</td>
<td>5.1</td>
<td>51.5</td>
<td>3850</td>
<td>4.2</td>
<td>42.2</td>
<td>3.7</td>
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<td></td>
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</tbody>
</table>

Table 2 - Comparison of Stress Relaxation Rates (Experimental Data) of Several Gasket Materials

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Material Composition</th>
<th>Test Temp. °F</th>
<th>Relaxation Rate Log Stress/Log Time</th>
<th>Intercept Log Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>TK18</td>
<td>Asbestos/NBR</td>
<td>600</td>
<td>-0.0284</td>
<td>3.501</td>
</tr>
<tr>
<td>TK33</td>
<td>PTFE/Filler</td>
<td>400</td>
<td>-0.0344</td>
<td>3.403</td>
</tr>
<tr>
<td>TK34</td>
<td>SBR/NBR/Synth. Fibres</td>
<td>600</td>
<td>-0.1147</td>
<td>3.430</td>
</tr>
<tr>
<td>TK37</td>
<td>Aramid/Thermoset Resin</td>
<td>400</td>
<td>-0.1134</td>
<td>3.430</td>
</tr>
<tr>
<td>TK38</td>
<td>Aramid/Synthetic Binder</td>
<td>400</td>
<td>-0.032</td>
<td>3.5358</td>
</tr>
<tr>
<td>TK40</td>
<td>Aramid/Synthetic Binder/Wire Mesh</td>
<td>400</td>
<td>-0.0243</td>
<td>3.551</td>
</tr>
</tbody>
</table>

Table 3 - SST Results on Aramid/Synthetic Binder (TK36) From Three Different Experiments at Temperature Cycle 20

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>Lowest Temperature on TC °F</th>
<th>Maximum Load (lbs)</th>
<th>Minimum Load (lbs)</th>
<th>Balzers R-22 Leak Rate (g/year)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65</td>
<td>16,500</td>
<td>1,600</td>
<td>&gt;140</td>
<td>No Pressure Cycling From 310°F to 170°F During the Temp. Cycling</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>17,100</td>
<td>2,000</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>110</td>
<td>17,400</td>
<td>3,000</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1 - Schematic representation of the Simulated Service Test (SST), fixture and control

Figure 2 - Stress relaxation of Aramid/Synthetic binder gasket at 400°F (TK 38)

Figure 3 - Stress relaxation of Aramid/Synthetic binder gasket at 600°F (TK 38)

Figure 4 - Stress relaxation of SBR/NBR/Synthetic fiber gasket at 600°F (TK34)

Figure 5 - Stress relaxation of PTFE/Filler gasket at 600°F (TK33)
Figure 6 - Cycle 20 from SST strip chart record for Aramid/Synthetic binder (0.019 in.) from three different experiments

Figure 7 - Selected cycles from simulated service test chart strip record for 0.019 in thick Aramid/synthetic binder gasket

Figure 8 - Selected cycles from simulated service test strip chart record for Kevlar/NBR gasket