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Performance Evaluation of Schauenburg Industries Ltd. Fiberglass Ventilation Ducting – Leakage Assessment

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EXECUTIVE SUMMARY

CanmetMINING developed a research project to evaluate the leakage of fibreglass ventilation ducting manufactured by Schauenburg Industries Ltd., North Bay, Ontario. Recently, the company had introduced innovative changes in their manufacturing process of fibreglass ventilation ducting with a view to reducing the internal surface roughness and thereby its resistance to airflow. Consequently, the company was interested in determining if the new process improved the energy efficiency of their product and were supported in this evaluation by the National Research Council of Canada's Business Innovation Access Program (BIAP) as administered through their Industrial Research Assistance Program (IRAP). Industry end-users were also interested in obtaining definitive expert derived resistance values under controlled circumstances to help them choose between the varieties of ventilation duct products available.

Considering both resistance and leakage control play a significant role in system selection and relative economics, both of these factors need to be defined. Having already ascertained a resistance value for the duct, the work presented herein aimed to assess leakage for this new ventilation ducting product.

Testing was conducted at CanmetMINING on Schauenburg Industries fibreglass ventilation ducting to assess air losses at the joints between duct segments that could be confidently measured. This test involved using 0.6 m (24 inch) diameter ducting, comprised of 3 to 6 sections where the end pieces were sealed. This laboratory condition could be considered as representative of an ideal installation. The system was pressurized with compressed air and the amount of air required to maintain a constant pressure was measured. Conversely, a second method was used to determine the leakage at the joints by measuring the pressure decay in the system over time. The tests allowed the measurement of leakage at different pressures that could be representative of actual auxiliary ventilation systems.

It was determined that the leakage per joint for the fibreglass bell and spigot duct was 0.0009 to 0.0019 m^3/s (1.9 to 4 cfm) for pressures ranging from 0.5 to 5+ kPa (2 to 20" w.g.). It was also shown that although there was potential for reducing the amount of air loss at the joints with a redesigned gasket, the leakage from the original gasket was not significant. Testing was conducted to assess whether the duct segments could be installed with slight misalignment. Leakage did not significantly increase at an angle of 5 degrees however, when adjoining segments were installed at angles of 8 degrees, leakage could be considered significant thus the use of elbows is recommended in these cases to minimize air loss at the joints.

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UNITS

The primary units used in this report are metric. However, as some mines still use imperial units in describing ventilation parameters, where appropriate, both units are given.

INTRODUCTION

CanmetMINING were asked to evaluate the leakage at the joints between segments of a fibreglass ventilation duct manufactured by Schauenburg Industries Ltd. of North Bay, Ontario. This request arose out of the interest of the manufacturer and mining companies to have performance data namely a joint leakage value relating to this product. The need for an expert assessment from CanmetMINING was financially supported by the National Research Council of Canada's Business Innovation Access Program (BIAP) as administered through their Industrial Research Assistance Program (IRAP).

Test Installation

The system consisted of 0.6 m (24 inch) diameter duct segments connected to two sealed end pieces using cam buckle straps (same as those typically supplied for installation underground). Holes were drilled into the end pieces to install fittings whereby the air supply and instruments could be connected. Rubber gaskets and silicone were used to ensure that there was no leakage at the fittings.

The length of the unit where the duct segments were tested individually, with 2 joints was 2.3 m (90 inches) whereas the complete assembly with 5 joints was 4.5 m (178 inches). The system with one individual duct segment and 2 sealed ends is shown in Figure 1 whereas the assembly with all 4 duct segments is in Figure 2.

Air was introduced into the system via a tube connected to a compressed air supply and the flowrate was controlled with a needle valve located at the outlet of the rotameter which measured the airflow. Pressure inside the duct was measured with a barometer via a tube connected to a tapping on the other sealed end of the system.

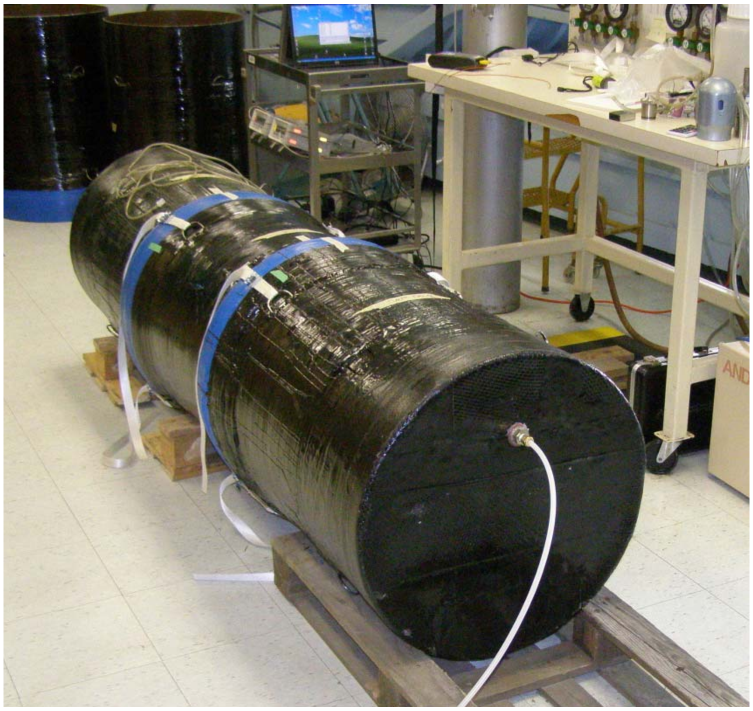

Figure 1 System with 2 joints

Figure 2 System with 5 joints

Procedures

Two procedures were used to assess the leakage at the joints and are described in the following.

<u>Method 1 – Flowrate measurement</u>

The flowrate measurement method for leakage testing consists of measuring the amount of gas or air leaking from a sealed system (McMaster, 1982). The sensitivity of leakage rate measurement from this method depends on the instrument used for measuring the compressed air flowrate.

During this test, the compressed air supply valve was opened and the flowrate was controlled with a needle valve. Two barometers were used to determine the gauge pressure in the unit by taking the difference between the pressure inside the system and the atmospheric pressure. Pressure measurements from both barometers were logged for the duration of the test using a computer. The air flowrate was kept constant until the gauge pressure was stable; this essentially measured the amount of air leaking from the system at a given pressure.

Subsequently, the air flowrate was increased by further opening the needle valve, where pressure and corresponding flowrate values were recorded. Temperature measurements inside the system, as well as ambient were recorded and logged. The testing was conducted at various gauge pressure values, up to 7 kPa (28” w.g.).

When a rotameter is operated at pressure and temperature that differ from those at which it was calibrated, corrections to flowrate measurements are required (Caplan, 1985; Okladek, 1988). Equation 1 illustrates the correction factor used to convert measured values to standard flowrate values (Caplan, 1985).

$$R_2 = R_1\sqrt{\frac{\rho_1}{\rho_2}} \qquad \text{Eqn (1)}$$

where: R_1 *and* ρ_1 correspond to the rotameter reading and air density at which the rotameter was calibrated, and

R_2 and ρ_2 are the rotameter reading and air density at which the rotameter was operated.

As density is proportional to pressure, the density values in (1) were replaced with pressures to determine the flowrate correction factor. Since the test was conducted at the same temperature as that which the rotameter was calibrated, no other corrections to the measured values were required.

Since the leakage from the individual joints in a given assembly could not be measured, the total leakage represented by the measured flowrate was divided by the number of joints, thus representing the average leakage per joint.

Method 2 – Pressure decay

Another procedure was used as a secondary method to verify the leakage of the system. This method applies to determination of leakage of a vessel subject to a positive pressure differential, where pressure decay measurements are used to calculate the change of mass within the vessel. Pressure decay is derived from the ideal gas equation, and measured pressures and time intervals are used to determine the amount of gas loss from the vessel. The leakage rate, ΔQ (m^3/s) is calculated from Equation 2 (Simode, 1976).

$$\boldsymbol{\Delta Q} = \frac{\boldsymbol{\Delta P}}{\boldsymbol{\Delta t}} \times \frac{\boldsymbol{V}}{\boldsymbol{P_a}} \qquad \text{Eqn (2)}$$

Where ΔP is the gauge pressure loss in the vessel between successive readings (kPa)

Δt is the time interval between successive readings (s)

V is the volume (m^3)

P_a is the atmospheric pressure (kPa).

In this test, once the maximum desired pressure was attained in the flowrate measurement method, the air to the system was turned off using a gate valve on the compressed air supply line. The pressure values, averaged at 10 second intervals, were recorded until the pressure inside the duct decayed to roughly atmospheric pressure.

The leakage rate was calculated from the pressure loss for each 10 second interval. Subsequently, the average leakage for discrete pressure ranges was calculated from those determined during the pressure decay test.

Apparatus

The following instrumentation and equipment was used for the leakage test:

- Two Paroscientific barometers (model number 745)
- Gilmont GF-4540 rotameter (2 - 45 LPM), accuracy: ± 2% of reading
- King rotameter (1.4 - 14.4 SCFM), accuracy: ± 2% of full scale
- Dwyer VFB66BV rotameter (1-10 LPM), accuracy: 3% of full scale
- Graywolf Advanced Sense Environmental Test Meter with thermocouple probe for temperature measurements
- Compressed air supply (80 psig)
- 2 duct segments sealed at one end (one bell type and one spigot type)
- 4 open duct segments
- 2 duct segments with redesigned gaskets (one sealed bell type and one open duct).

TEST RESULTS

The duct segments received from Schauenburg were labelled with numbers 1 through 8. The sealed end segments corresponded to 1 and 2, whereas the open ducts were labelled 3 to 6. The open duct with the redesigned gasket was numbered as 7 and the sealed end was number 8. The tests performed on the ventilation ducts were conducted as follows.

Original Gasket Design

Testing variability due to assembly

An assessment of the variability of leakage due to installation was conducted by assembling the end pieces (#1 and #2) with duct segment #3. A leakage measurement test was conducted then the system was disassembled. The same duct segments were then reassembled and the leakage test was repeated. This was reiterated a total of three times. The results illustrating the leakage per joint at various pressures for the three trials with segment #3 are presented in Figure 3. A leakage decay test was also attempted but the rate of pressure loss in the system was too quick to measure, thus results are not available for this test.

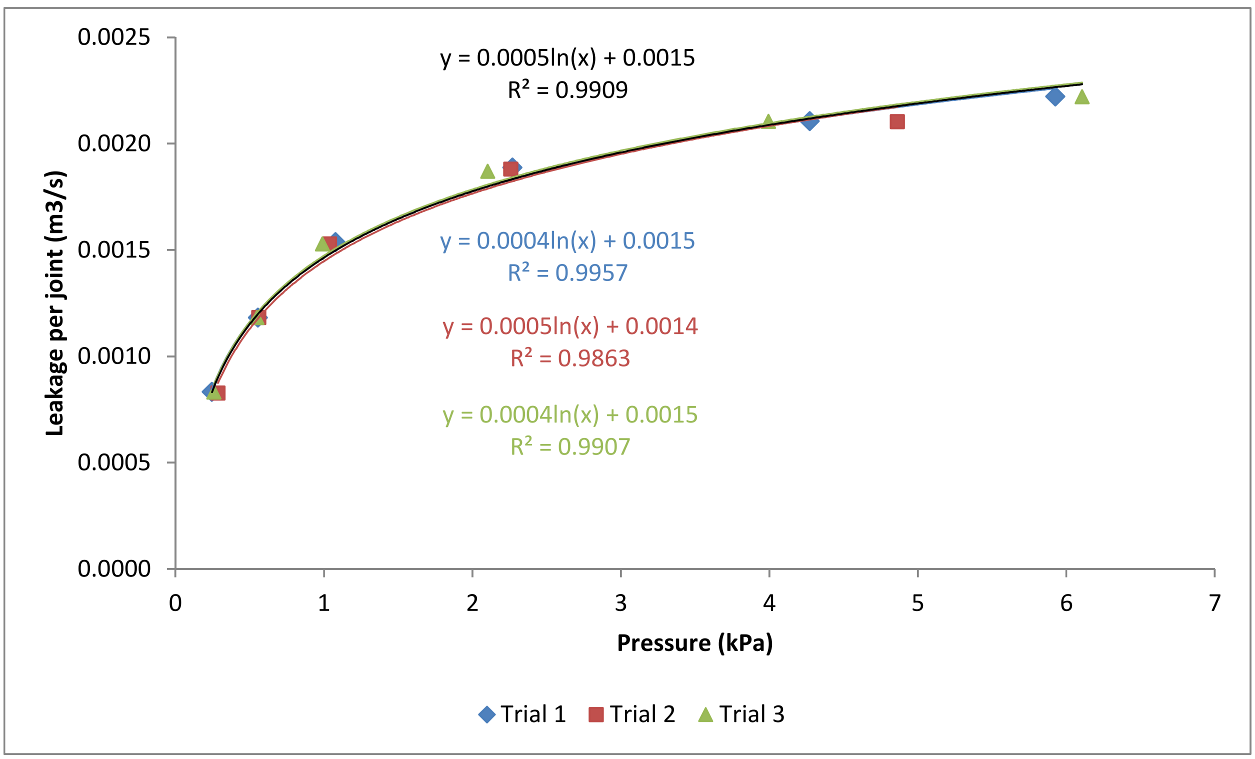

Figure 3 Leakage determined from flowrate measurement test from 3 trials conducted on same duct

It can be seen from Figure 3 that the results obtained from these tests are comparable which indicates that the variability due to installation was low. All the measurements from the three trials were within 10% of the leakage values predicted from the regression line based on the results from all three trials. Thus only one trial per test was conducted for the other assemblies.

Testing variability of individual segments

Each additional open duct segment (#4 to #6) was then tested individually with end pieces #1 and #2. However, only one trial for each segment was conducted since the previous test indicated that the results from individual tests were repeatable as shown in Figure 3. The results of the tests conducted with the individual segments are presented in Figure 4. A leakage decay test was also attempted but the rate of pressure loss in the system was too quick to measure, thus results are not available for this test.

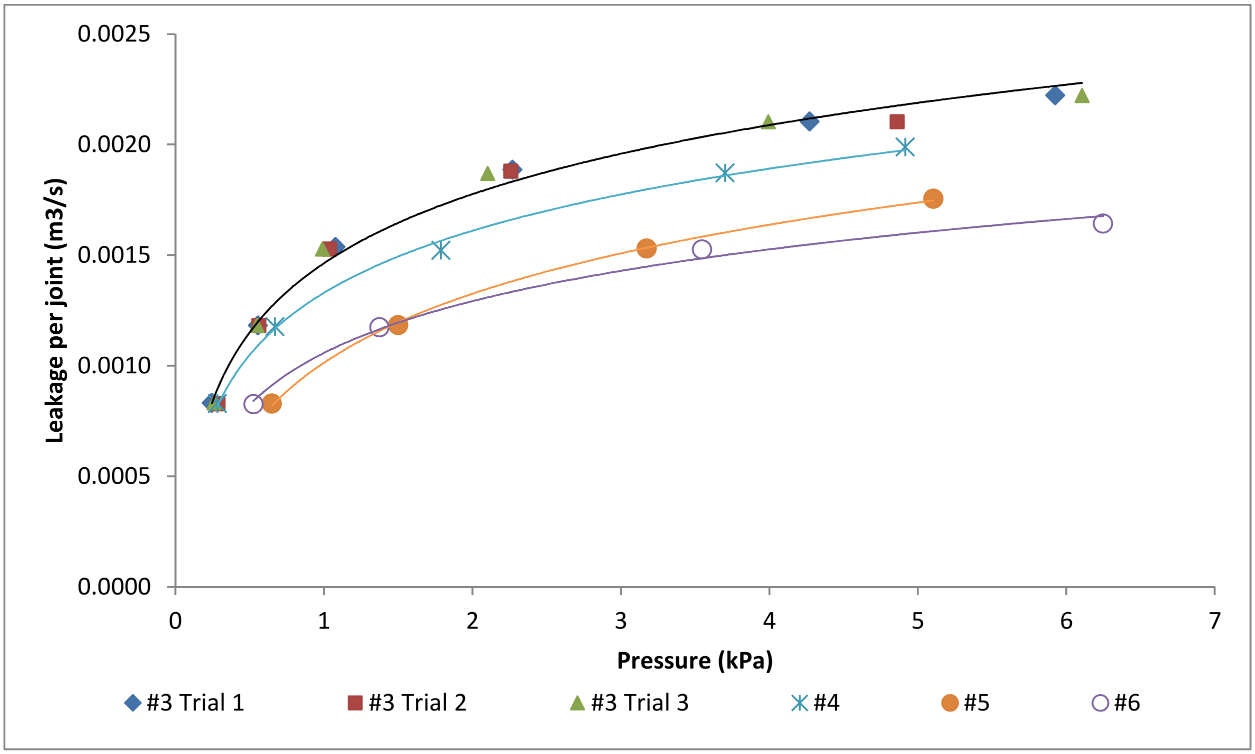

Figure 4 Leakage determined from flowrate measurement method from tests conducted on individual duct segments

It can be seen from Figure 4 that the leakage per joint varied for each segment, up to an average of 27% between the ducts with lowest and highest leakage (#6 and #3 respectively).

Testing all segments as one complete system with 5 joints

Subsequently, all segments from #1 to #6 were installed as a system with a total of five joints. The average leakage per joint as a function of pressure for this system is presented in Figure 5 along with the results from the individual tests for comparison. A leakage decay test was also attempted but again the rate of pressure loss in the system was too quick to measure, thus results are not available for this test.

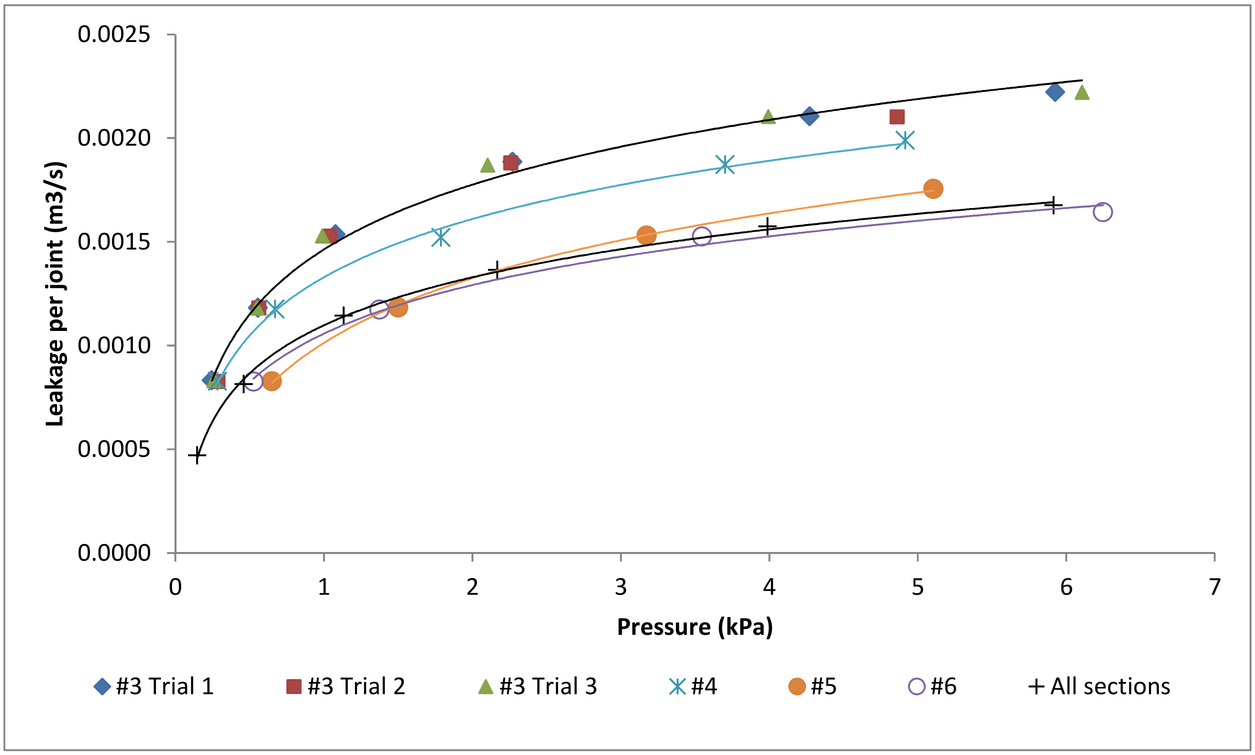

Figure 5 Leakage determined from flowrate measurement test for all segments with original gasket design

It can be seen from Figure 5 that the average leakage per joint from the test conducted with all segments compares well with that of the results from the individual segments.

Testing external gaskets

Preliminary tests were conducted to assess the effectiveness of Schauenburg's external gaskets at reducing leakage from the joints between duct segments. Due to the shape of the bell end of the duct it was not possible to obtain a good seal with the external gasket, thus it is not believed that leakage would be improved with this measure. Furthermore, it was observed after removal of the external gasket that the cam buckle straps that are used to secure adjoining duct segments together were loosened, likely due to pressure applied on them by the external gasket.

Patched Gasket

Testing leakage from individual and all segments with patched gasket

It was observed during the previous tests that leakage at the joints was concentrated where the rubber piece used as the gasket inside the duct overlapped onto itself which created a channel whereby air was flowing out of the duct. Thus a patch was fabricated for each duct with foam and secured with adhesive tape to smooth the step produced by the overlapping rubber. Figure 6 shows the original gasket on the left and the patched gasket on the right.

Figure 6 Photo of seal (**Left:** original gasket; **Right:** patched gasket)

Leakage testing was repeated on the individual segments as well as all ducts as a complete assembly with all the gaskets patched as shown in Figure 6 (right). The results are presented in Figure 7 along with those from duct #3 and all segments with the original gasket for comparison. Table 1 shows the results from the pressure decay test.

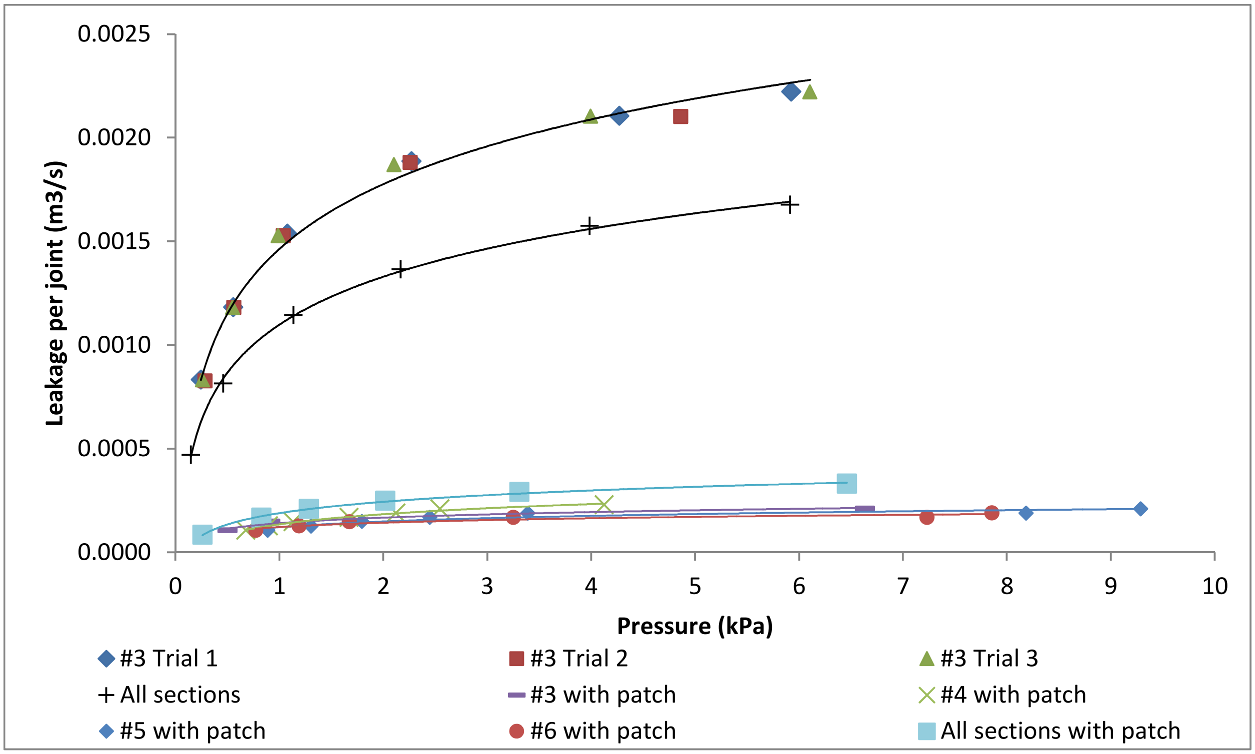

Figure 7 Leakage from flowrate measurement tests with patched gasket

Table 1 Leakage results with patched gasket from pressure decay testing

Duct segment	#3	#4	#5	#6	All
Pressure range (kPa)			**Leakage per joint (m^3/s)**		
0.5 - 1	0.0001	0.0001	0.0001	0.0000	0.0001
1 - 2	0.0001	0.0002	0.0001	0.0001	0.0002
2 - 3	0.0002	0.0002	0.0001	0.0001	0.0003
3 - 4	0.0002	0.0003	0.0002	0.0001	0.0004
4 - 5	0.0002	0.0003	0.0002	0.0002	0.0004

It can be seen from the results presented in Figure 7 and Table 1 that both methods used produced comparable leakage results. Furthermore, the system comprising all segments, with a total of five joints, showed slightly higher leakage than the ducts tested individually. This may be due to variability in the shape or dimensions of the bell and / or spigot of each duct, which could affect the seal. Figure 7 also shows that leakage was substantially reduced by sealing the gap in the gasket. Specifically, the leakage was reduced by an average of 89% for the individual segments and by 82% for the assembly with all duct segments compared to the respective test results from the original gasket.

Testing bends at the joints

Testing was then conducted to assess the amount of leakage that would result from installing the ducts with bends at the joint. A total of four open segments with two end pieces were used for this work. The patches that were tested to reduce leakage from the gasket were also used in this test.

One test was conducted with the joints installed at an angle of 5 degrees and a second test was conducted where the average angle between segments was 8 degrees. A photo of these setups is shown in Figure 8 whereas Figure 9 illustrates the results from the leakage measurement method. The results from the previous tests conducted without bends at the joints are also included for comparison and the results obtained from the pressure decay method are presented in Table 2.

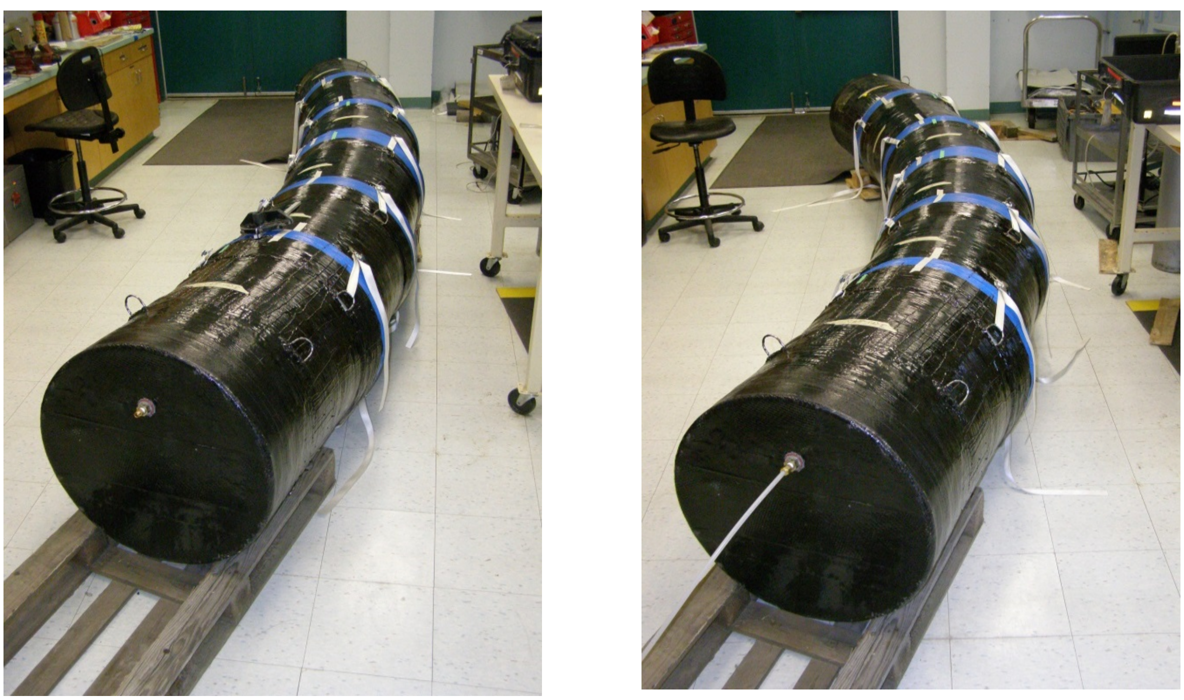

Figure 8 Test setup for leakage testing with joints at different angles (**Left:** 5 degrees; **Right:** 8 degrees)

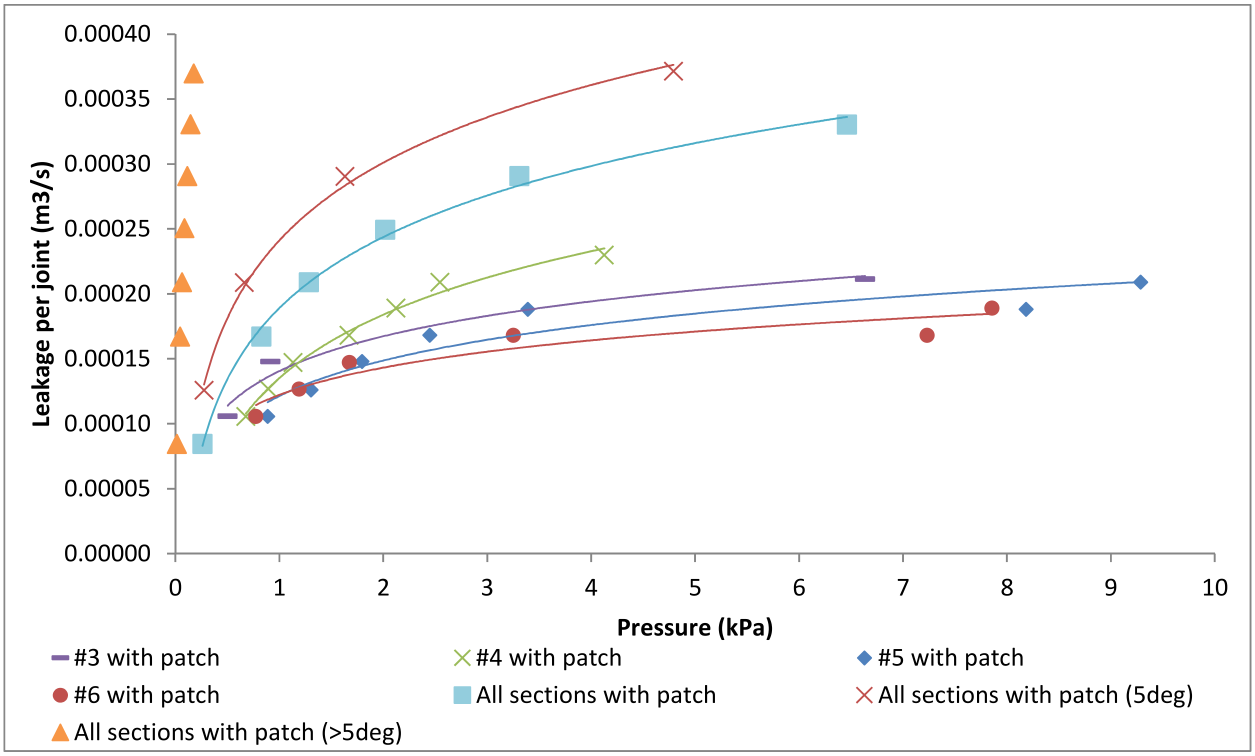

Figure 9 Test results from flowrate measurement method with the joints installed at 5 and 8 degree angles

Table 2 Leakage results from pressure decay test method with joints installed at 5 and 8 degree angles

Joint angle	**5 degrees**	**8 degrees**
Pressure range (kPa)	**Leakage per joint (m^3/s)**	
0.5 - 1	0.0002	N/A
1 - 2	N/A	N/A
2 - 3	0.0004	N/A
3 - 4	0.0004	N/A
4 - 5	N/A	N/A

It can be seen from the results presented in Figure 9 and Table 2 that although the leakage per joint for the test conducted with joints at an angle of 5 degrees were slightly higher for the pressure decay method than from the leakage measurement test, the values from both tests were similar. It can also be seen that leakage from the test conducted with the joints installed at angles of 8 degrees was higher thus measurements could not be obtained using the pressure decay method.

The results presented in Figure 9 also show that leakage at the joints increased when they were not aligned straight. On average, the leakage per joint increased by 25% for the assembly with the joints at 5 degrees compared to the straight installation, whereas at 8 degrees the leakage increased by 604%.

Schauenburg's Redesigned Gasket

Testing one segment with Schauenburg's redesigned gasket

Having recognized the potential for reducing leakage, Schauenburg developed a redesigned gasket and supplied an open duct segment as well as a sealed end for testing. Figure 10 shows a photo of the new gasket.

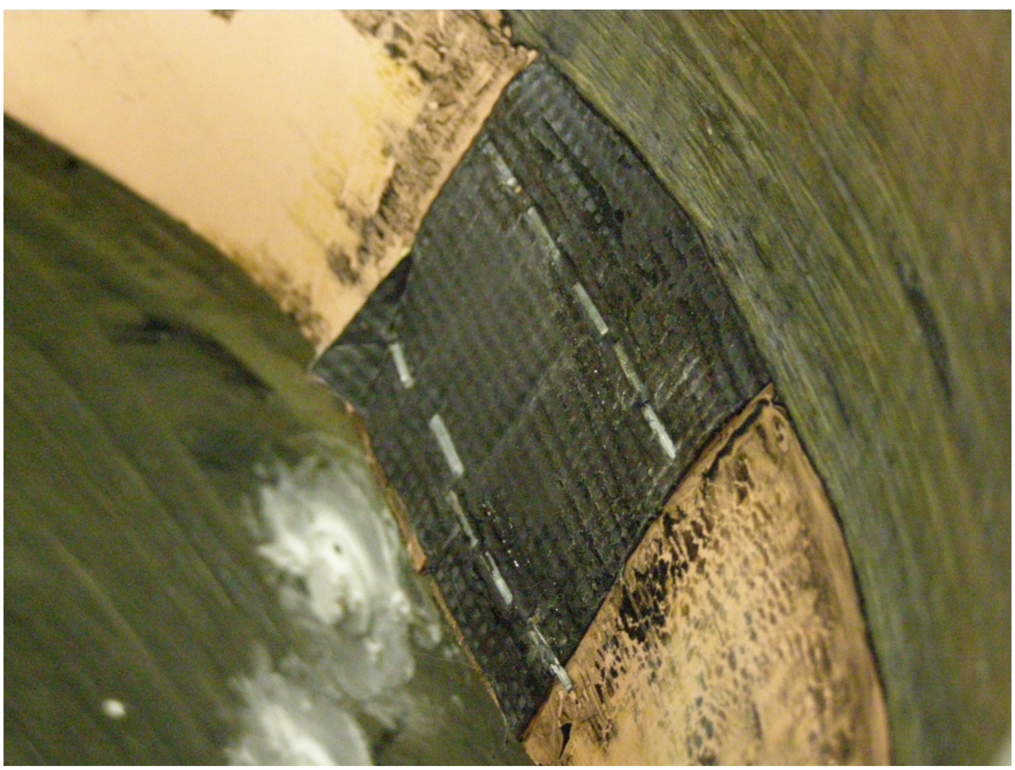

Figure 10 Photo of redesigned gasket

Leakage testing was conducted on these segments to determine the amount of leakage in a system with two joints. The third piece in this assembly was the original supplied spigot end which does not have a gasket, thus did not need to be replaced. It should be noted that the open segment with the redesigned gasket which was supplied was difficult to install into the bell side of the end piece. It appears that the spigot end may not be perfectly circular or that the diameter is slightly smaller than the other segment. It was difficult to keep the pieces aligned straight when tightening the cam buckle straps because the spigot end of the middle segment would slip beyond the bell of the next piece. Testing of the redesigned gasket was also conducted with an arrangement that included the end piece with the redesigned gasket, and segment #4 (original gasket) with the patch, which fit together better than both redesigned gasket pieces. The results of this testing is shown in Figure 11, which also includes the results from the testing conducted with the patched gasket for comparison.

It follows from the results presented in Figure 11 and Table 3 that the leakage determined from both methods is similar. Furthermore, although leakage from the redesigned gasket was lower than from the original design, it was slightly higher than from the tests conducted with the patched gasket. Specifically, the leakage from the joint was reduced by an average of 57% with the redesigned gasket compared to the original.

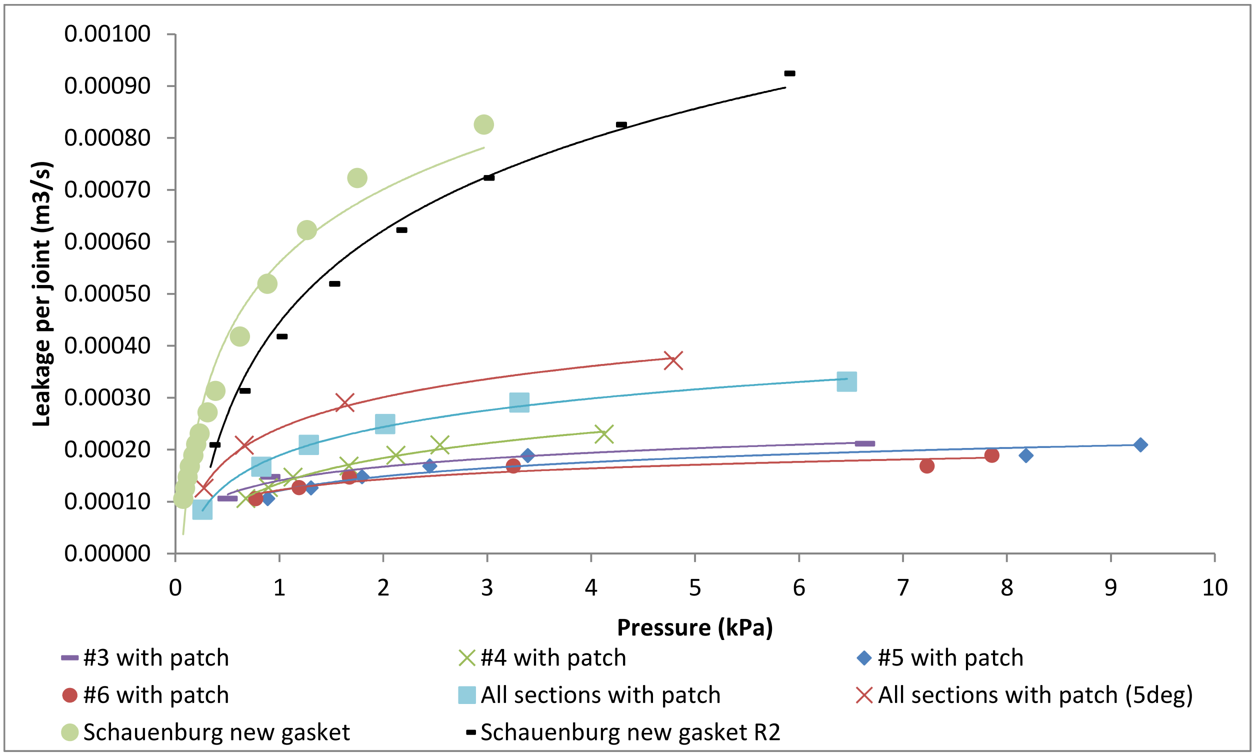

Figure 11 Leakage results from flowrate measurement testing with redesigned gasket

Table 3 Pressure decay results with redesigned gasket

Test	Schauenburg redesigned gasket	Schauenburg redesigned gasket R2
Pressure range (kPa)	**Leakage per joint (m^3/s)**	
0.5 - 1	N/A	N/A
1 - 2	N/A	0.0003
2 - 3	N/A	N/A
3 - 4	0.0007	0.0007
4 - 5	N/A	N/A

Estimate of Leakage in Auxiliary Mine Ventilation Systems

For comparison, a summary of all results is presented in Figure 12. Results show that the segments with the original gasket leaked the most, followed by those with the redesigned gasket, then those with the patched gasket. Also noted, is that installation of the segments with an angle of 5 degrees at the joints did not substantially increase leakage, however, at angles of 8 degrees the leakage was much greater. The information presented in Figure 12 and the previous figures showing results from the flowrate measurement test shows that the leakage at the joints does not increase linearly with pressure.

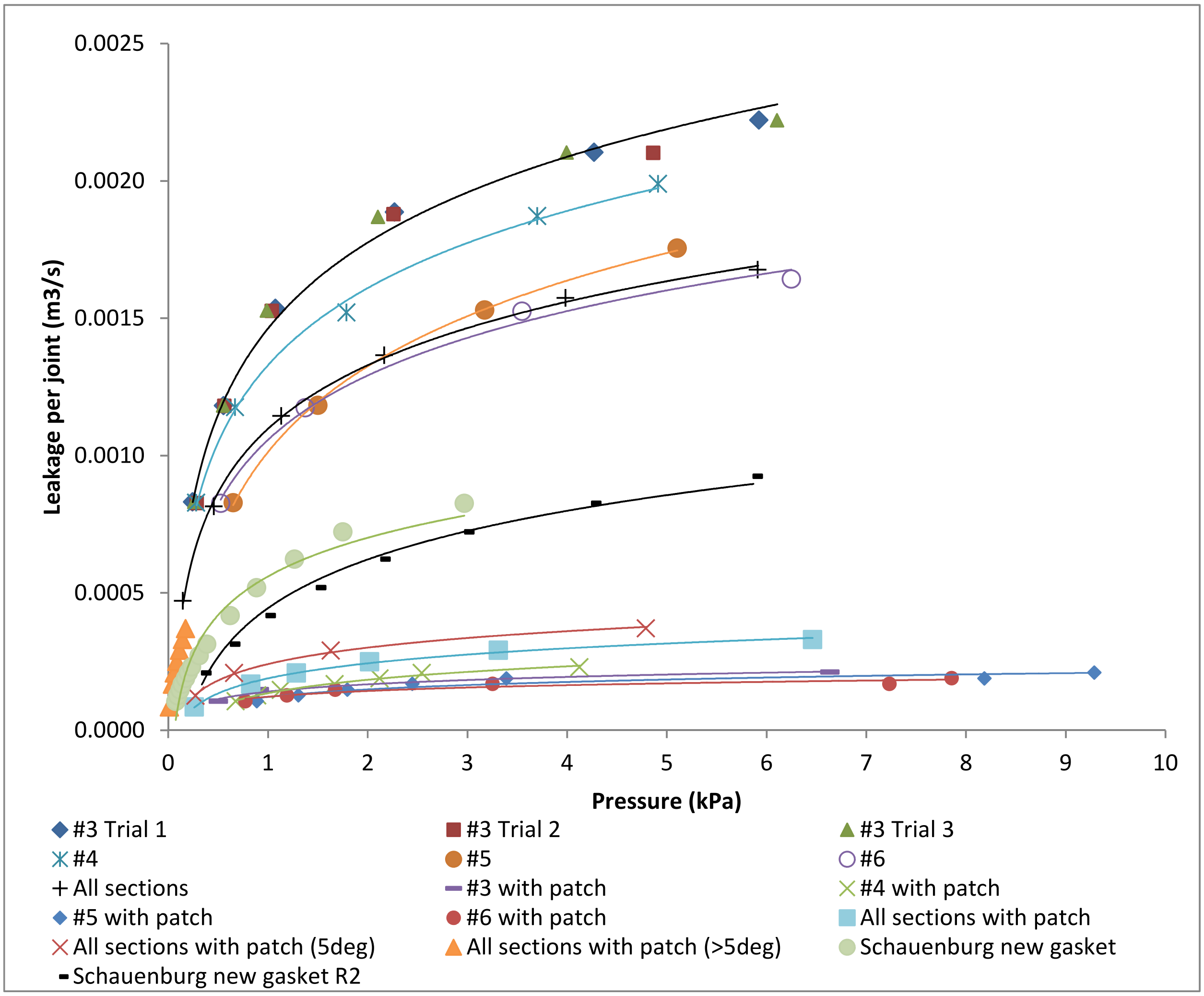

Figure 12 Summary of all test results obtained with flowrate measurement method

The results presented in Figure 12 illustrate that there is potential for reducing leakage from the joints of the original gasket. Thus an estimate of the significance of these results in the context of auxiliary mine ventilation systems was undertaken. The analysis was conducted using the average leakage per joint up to a pressure of 5 kPa (20”w.g.) as determined from the flowrate measurement tests. The delivered flowrate at the end of the duct was assumed to be 30 m^3/s (~64,000 cfm), and systems of various lengths ranging from 200 to 1000 m (~650 to 3300 feet) were examined, with each duct segment length corresponding to 3.1 meters (10 feet). Although leakage testing was not conducted with the original gasket installed at different angles, leakage for these scenarios was estimated from the tests undertaken with the patched gasket. The results from these hypothetical cases are presented in Table 4.

Thus from the information presented in Table 4, it can be seen that the percentage leakage increases with the number of joints, dictated by the length of a system. Furthermore, the only system where leakage could be considered significant is with the original gasket installed at an angle of 8 degrees.

Table 4 Estimate of leakage in auxiliary ventilation systems

Installation	Average leakage per joint (m^3/s)	Total length (m)	Total leakage (m^3/s)	Leakage (% of delivered flow)
Average original gasket	0.0015	200	0.09	0.3
		500	0.24	1
		1000	0.46	2
Joints at 5 degrees with original gasket	0.0016	200	0.10	0.3
		500	0.26	1
		1000	0.51	2
Joints at 8 degrees with original gasket	0.0097	200	0.61	2
		500	1.55	5
		1000	3.00	9
Average patched gasket	0.0002	200	0.01	0.1
		500	0.03	0.1
		1000	0.05	0.3
Joints at 5 degrees with patched gasket	0.0003	200	0.02	0.1
		500	0.05	0.2
		1000	0.09	0.3
Joints at 8 degrees with patched gasket	0.0018	200	0.11	0.4
		500	0.29	1
		1000	0.56	2
Redesigned gasket	0.0007	200	0.04	0.1
		500	0.11	0.4
		1000	0.22	1

DISCUSSION

Leakage testing was conducted on sealed sections of Schauenburg fibreglass duct using two methods; i) a flowrate measurement and ii) a pressure decay test. Although some of the results from these methods differed slightly, the leakage determined from both was similar. However, results using the decay method could not be obtained for tests where leakage was higher, such as with the original gasket because the pressure decrease rate was faster than the instrument could record. Thus the leakage measurement test appeared to produce results with a higher degree of confidence.

The average leakage per joint from the original gasket determined from the leakage measurement method corresponded to 0.0015 m^3/s (3.2 cfm) for pressures ranging from 0.5 to 5 kPa (2 to 20” w.g.). It was observed that most of the leakage occurred at the location where the rubber piece used for the gasket overlapped onto itself.

A patch installed on the gasket where most of the leakage occurred resulted in reducing the leakage by roughly 90%, to an average of 0.0002 m^3/s (0.4 cfm) per joint, representing an opportunity for improvement. A redesigned gasket was then assessed, where the leakage compared to the original design was reduced by over 50%, to 0.0007 m^3/s (1.5 cfm). However, only one segment and one end piece of this type were supplied and there appeared to be manufacturing issues which prevented a good seal with these segments. Nonetheless the redesigned gasket showed improvement with respect to leakage.

Testing was also conducted to assess the leakage from systems installed whereby the adjoining segments were installed at 5 degree and 8 degree angles. The results from these tests indicated that although leakage increased in the 5 degree installation compared to the test with the segments aligned straight, the impact was minimal. But, when the system was installed at 8 degrees the leakage at the joints was increased by about 600%.

A simple assessment was conducted to determine the significance of the leakage at the joints from the 0.6 m (24 inch) diameter Schauenburg fibreglass duct in auxiliary ventilation systems using hypothetical cases. It was determined that although there is potential to reduce leakage at the joints from the original gasket the amount of air loss is minimal compared to the volume delivered. The results also showed that leakage did not increase significantly when adjoining segments were installed at angles of 5 degrees, however a substantial amount of air leakage at the joints was observed when the angle was increased to 8 degrees. Thus, care should be taken in actual systems to ensure that segments are properly aligned to minimize the amount of air lost at the joints.

Results from the leakage measurement tests showed that the leakage per joint did not increase with pressure in a linear manner. It appears that the seal at the joints, between the duct and the gasket improved as the pressure increased.

The leakage from the joints of the Schauenburg 0.6 m (24 inch) diameter fibreglass ducting in this work was determined under controlled laboratory conditions whereby care was taken during the installation of the systems. Although leakage from actual systems was not assessed it is assumed that with proper installation and maintenance the same results should be achieved.

Recommendations for Further Work

Further leakage testing is recommended should the manufacturer adopt the redesigned gasket since only one segment of this type was assessed. As leakage could be influenced by the surface area of the joints it is also suggested that testing include an assessment of different duct sizes.

CONCLUSIONS

Leakage testing was conducted on 0.6 m (24 inch) diameter fibreglass ducting with bell and spigot joints whereby it was determined that the leakage per joint was 0.0009 to 0.0019 m^3/s (1.9 to 4 cfm) for pressures ranging from 0.5 to 5 kPa (2 to 20" w.g.). Although there is potential for improvement which was shown with the testing using the patched gasket and the redesigned gasket, the magnitude of the leakage may not be significant in auxiliary ventilation systems. The impact of leakage is more substantial in longer systems and where the segments with the original gasket are installed at angles greater than 5 degrees.

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