ROCKET LAB LTD

Explosive Fittings Testing

BFM Global Ltd.

May 2012

EXCELLENCE IS A MINIMUM REQUIREMENT

Contents

1. Summary

Rocket Lab Limited (RLL) was contracted to conduct explosive testing of various flexible duct coupling products (fittings) supplied by BFM Global Limited (BFM). The purpose of the testing was to subject the fittings to desired test pressures resulting from an explosion. This was achieved by placing designed explosive charges within a vented pressure vessel which integrated the fitting specimens, subjecting them to a relatively short pressure pulse by igniting the charges.

Five different fitting types were tested, made of various materials. Each fitting type was conditioned and tested at a target temperature range specified by BFM.

All five tests performed on the BFM SEEFLEX 040E fittings were successful, with 60kPa exceeded for all tests. All six tests performed on the BFM SEEFLEX fittings with WM12K cover were successful with an average pressure in excess of 100kPa observed.

The single test on the standard SEEFLEX specimen (with hose clamps) failed at an overpressure of 26.1kPa. Similarly, the single test on the standard Silicon specimen (with hose clamps) failed at an overpressure of 43.1kPa.

2. Description of Samples

Five different types of fitting were supplied by BFM for testing, made from various materials. Five specimens were tested of each fitting type. The types comprised of:

1. **SEEFLEX 040E – Transparent polyester based thermoplastic polyurethane alloy (with a minimum material thickness of 0.9mm) – 5 tests.**
2. **SEEFLEX with WM12K Cover – Transparent polyester based thermoplastic polyurethane alloy with an exterior Kevlar cover – 6 tests.**
3. **Standard SEEFLEX with Hose Clamps – Transparent polyester based thermoplastic polyurethane alloy fitted with hose clamps – 1 test.**
4. **Standard Silicon with Hose Clamps – White, 5mm thick Silicon fitted with hose clamps – 1 test.**

3. Equipment

The experimental setup consisted of:

- **Steel pressure vessel integrating BFM and 3rd party fittings, designed to contain explosive charge and pressure.**
- **Explosive charge, designed to produce minimum desired peak pressure**
- **Ballistic pressure sensor to measure pressure inside vessel**
- **Low-pass filter and amplifier to condition sensor signal**
- **Data acquisition system to record sensor data onto personal computer**
- **High frame rate (300fps) colour video cameras**

Pressure Vessel and Test Article

A steel pressure vessel supplied by BFM, which integrated the fitting and contained the explosive charge. A pop-off relief valve was located on top of the vessel to automatically vent all pressure after ignition.

Explosive Charge

An explosive charge manufactured by RLL, designed and tested to produce a minimum desired peak pressure. The propellant is low-explosive black powder, initiated by an electric-match igniter.

Pressure Sensor, Conditioning and Data Logging

A PCB 113A26 piezoelectric ballistic pressure sensor was used to record the pressure. This type was selected due to its extremely short rise and response time.

The sensor's output signal was conditioned using a PCB 483A02 Charge Amplifier and a Krohn-Hite Model 3321 Filter which further amplified increased the signal-to-noise ratio in the recorded signal.

A National Instruments USB-6009 14-bit data acquisition system was used to log the signal at a frequency of 1000Hz. All data from the DAQ system was directly recorded on a desktop computer.

Imaging Devices

A high-speed colour video camera was used to capture test footage at frames of 300 frames per second.

4. Test Plan and Methodology

4.1. TEST PLAN

A total of 13 tests were conducted. These comprised of the following:

- **5 x SEEFLEX 040E**
- **6 x SEEFLEX 040AS with WM12K Cover**
- **1 x Standard SEEFLEX with Hose Clamps**
- **1 x Standard Silicon with Hose Clamps**

BFM required the specimens to reach a peak temperature within a range during the explosive testing. The following table specifies the target temperatures for the different material types.

Material Type	Target Temperature (°C)
SEEFLEX 040E	40 – 50
SEEFLEX 040AS with WM12K Cover	40 – 50
Standard SEEFLEX with Hose Clamps	30
Standard Silicon with Hose Clamps	40 – 50

4.2. EXPERIMENTAL METHOD

Specimens were preconditioned in a temperature-controlled oven. To allow for cooling of the specimen between removal of the oven and ignition of the charge, conditioning temperatures were higher than the desired target temperature (typically 75-80°C). Specimen temperatures were recorded both prior to and after each explosive test.

Prior to mounting the specimens, the explosive device was placed in the test pressure vessel at a specified distance from the specimen fixture. The fittings were then mounted in place and the temperature recorded before proceeding with the ignition procedure.

Pressure data within the test vessel was recorded using a ballistic pressure transducer through a National Instruments DAQ system. A sampling rate of 1000Hz was used for all tests.

When the charge is ignited, the pressure climbs quickly and relatively linearly to a peak value before the pressure wave relieves through the valve. After the initial pressure wave, secondary pressure waves pass through the fitting. For the larger explosive charges (~100kPa overpressure), these secondary pressure waves can sometimes be greater than the initial pressure wave. These secondary pressure waves are due to internal reflections within the pressure vessel.

The entire duration of positive pressure due to the explosive charge is in the order of 600 – 800 milliseconds. The intensity of the explosive charge and an integrated relief valve at the top of the test vessel predominantly affects the amplitude and duration of the pressure trace.

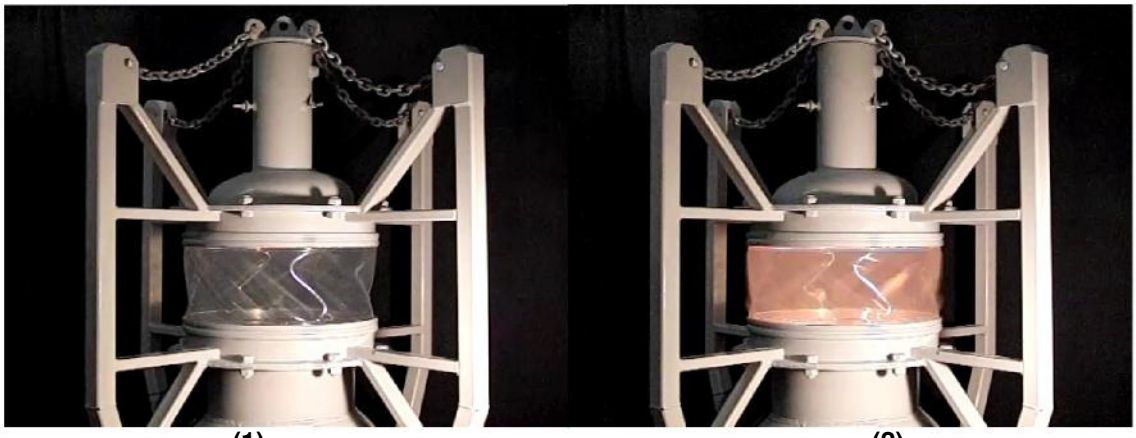
BFM also required high-speed footage of some testing. Colour videos with a frame rate of 300fps were captured.

5. Results

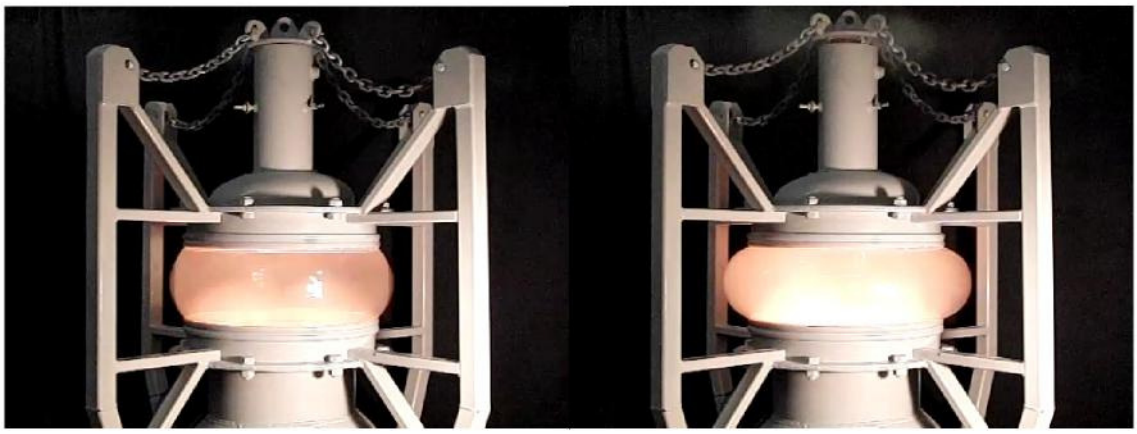
The following results were observed:

- **All five SEEFLEX 040E specimens tested successfully withstood peak overpressures of at least 60 kPa. The material temperature range for these tests was 44-50℃. All specimens tested had a thickness tolerance of 0.9mm or greater.**
- **The SEEFLEX 040AS with WM12K Cover specimens successfully withstood six tests with an average peak overpressure of 104.2kPa. The maximum and minimum peak pressures observed were 129.3kPa and 90.4kPa respectively. The material temperature range for these tests was 42-49℃.**
- **The single standard SEEFLEX specimen (with hose clamps) failed with a peak overpressure of 26.1kPa. The material temperature for this test was approximately 30℃. The failure was caused by the material pulling through the hose clamps, enabling the rapid decompression of the hot gases.**
- **The single standard Silicon specimen (with hose clamps) failed with a peak overpressure of 43.1kPa. The material temperature for this test was approximately 52℃. The failure was caused by the failure of one of the hose clamps, enabling the rapid decompression.**

The sequence of images below was captured from high-speed footage of a test of SEEFLEX 040E specimens. The images clearly show the expansion of the fitting due to the pressure from the explosion, and the venting of pressure from the relief valve.



(1) **(2)**



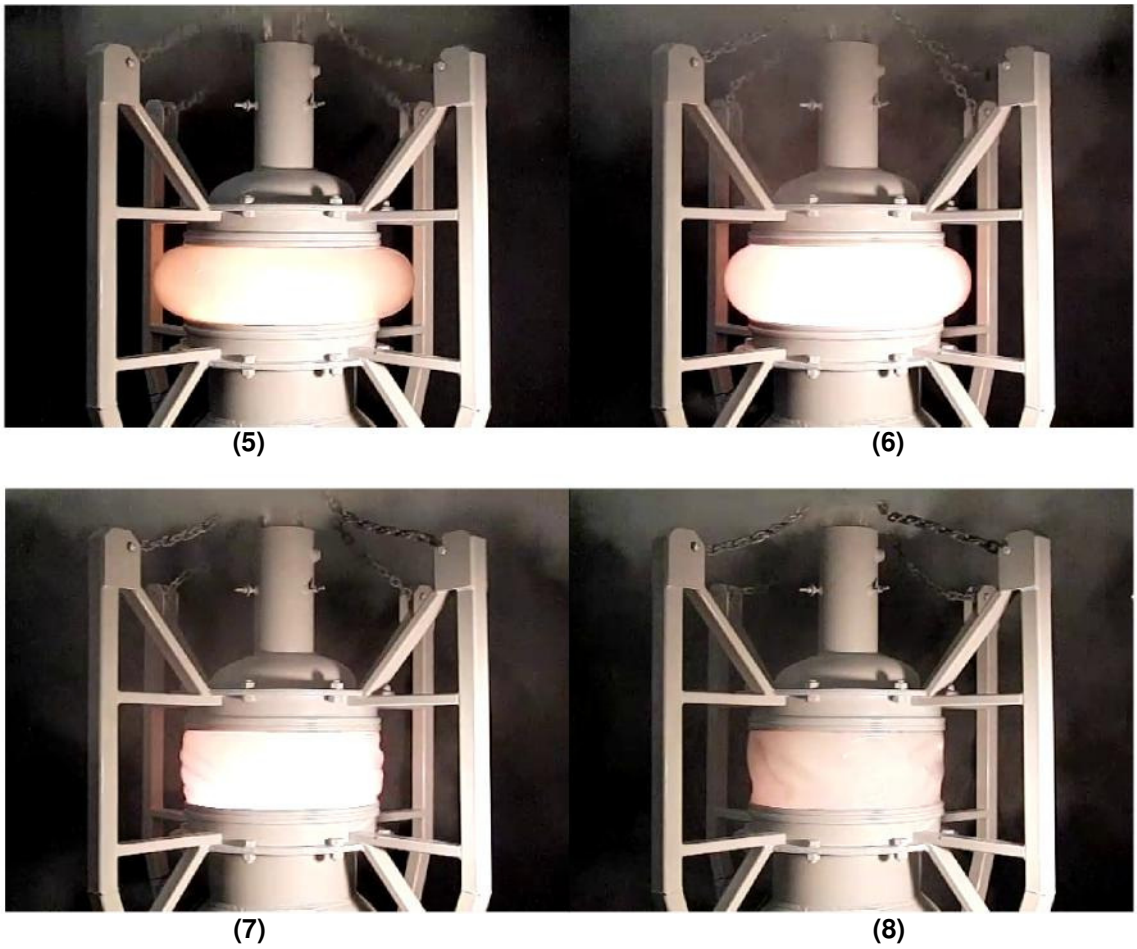
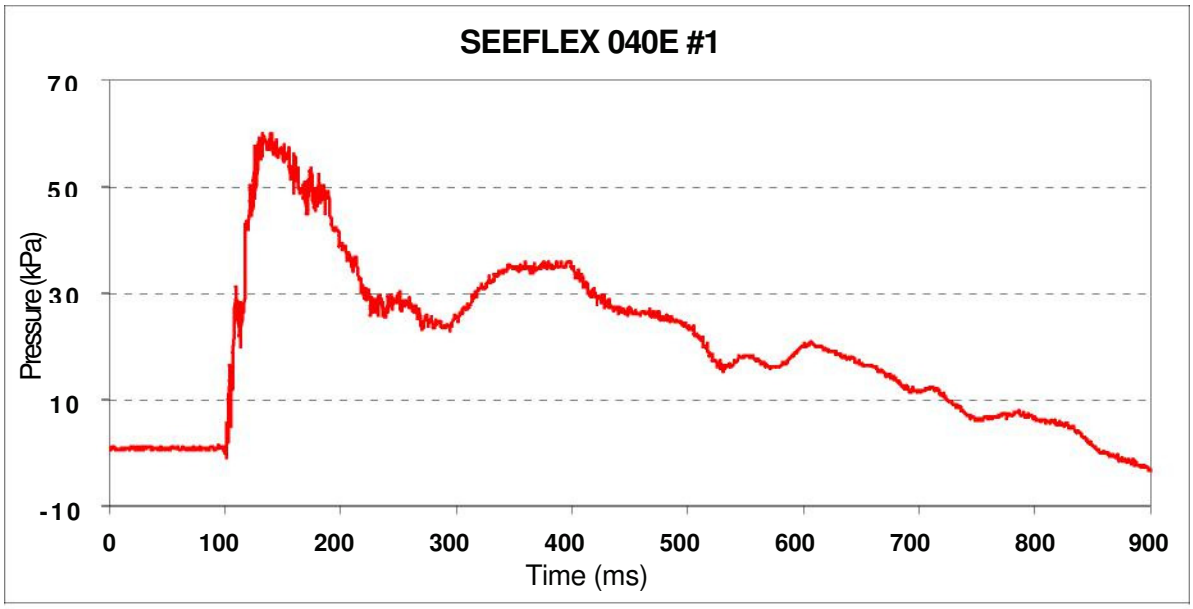
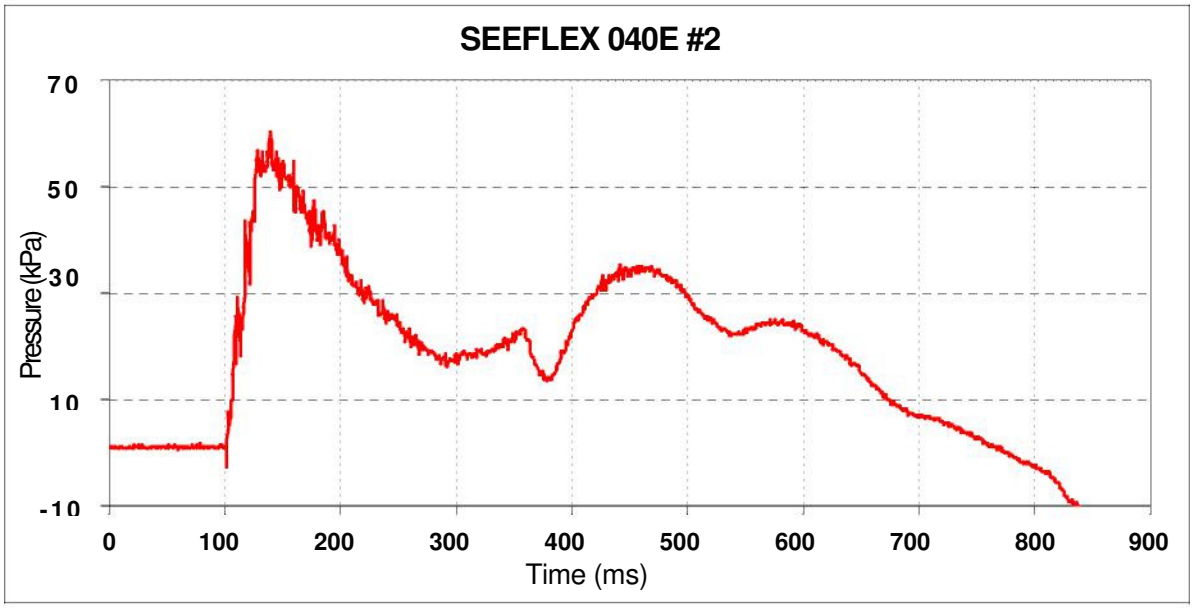


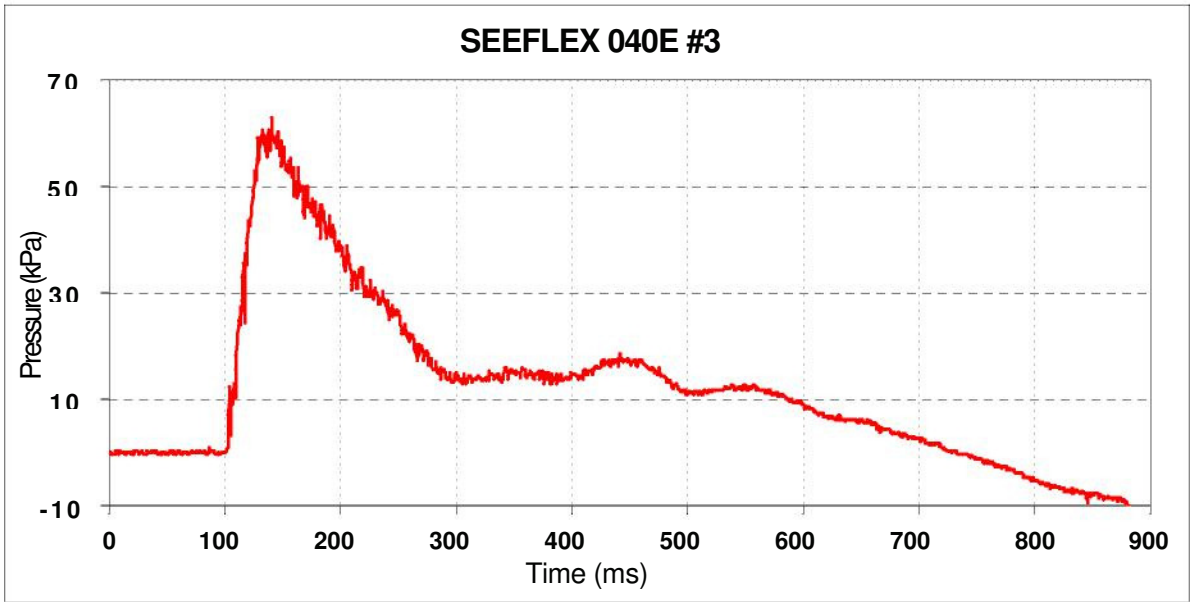
Figure 1: Sequence of images from high-speed footage of explosive test. Images numbered in chronological order

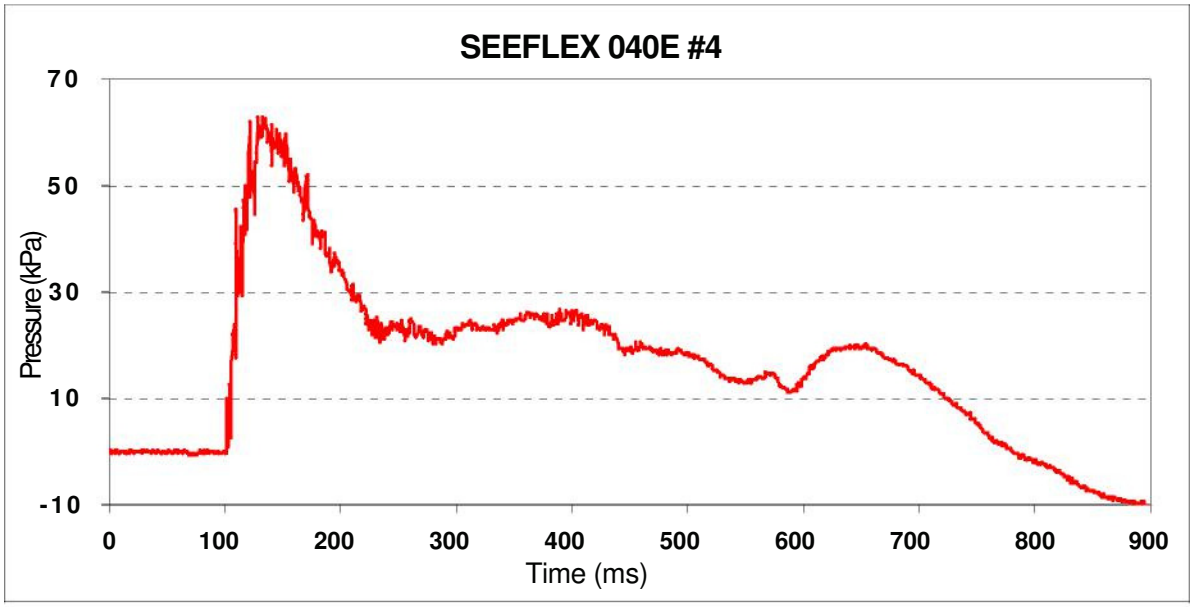
The results for all specimens are summarised in the table below. The figures on the following pages show pressure data from each of the individual tests.

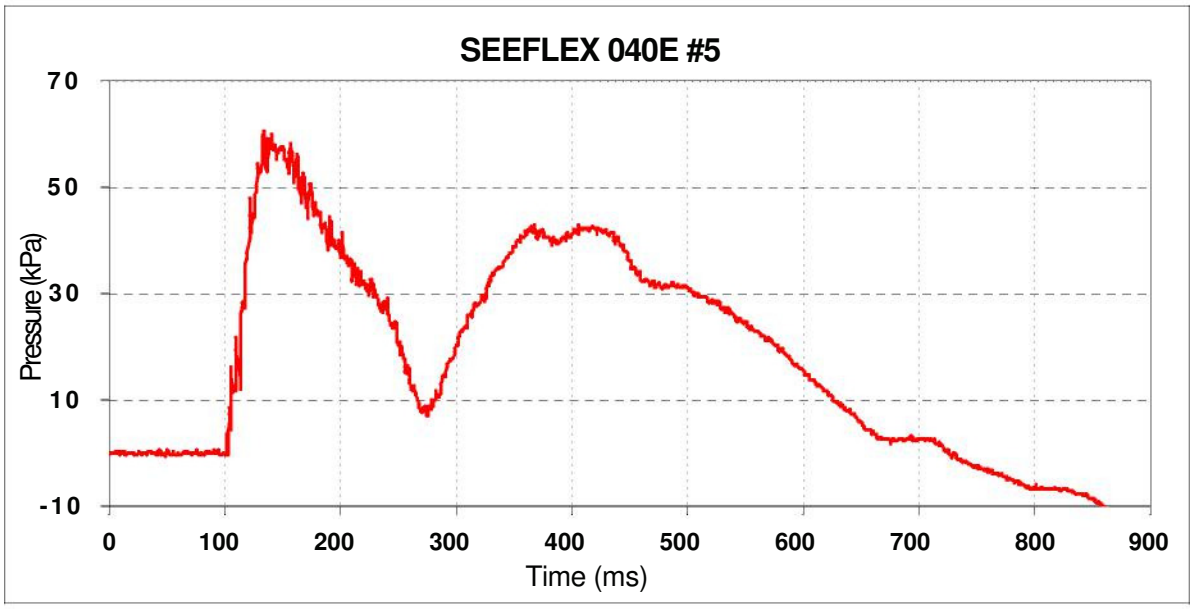
Specimen	Peak Pressure (kPa)	Positive Pressure Duration (ms)	Specimen Temperature (℃)		Peak Temp. (℃)	Result
			Pre-test	Post-test		
SEEFLEX_040E_1	60.1	632	42	44	44	PASS
SEEFLEX_040E_2	60.2	687	42	47	47	PASS
SEEFLEX_040E_3	62.8	642	42	47	47	PASS
SEEFLEX_040E_4	63.0	671	42	50	50	PASS
SEEFLEX_040E_5	60.3	761	42	46	46	PASS
SEEFLEX_040AS_WM12K_1	125.9	656	45	43	45	PASS
SEEFLEX_040AS_WM12K_2	90.5	687	43	42	43	PASS
SEEFLEX_040AS_WM12K_3	91.8	701	47	47	47	PASS
SEEFLEX_040AS_WM12K_4	95.2	620	49	47	49	PASS
SEEFLEX_040AS_WM12K_5	129.6	597	45	47	47	PASS
SEEFLEX_040AS_WM12K_6	92.2	677	45	43	45	PASS
STANDARD_SEEFLEX_1	26.1	36	28	30	30	FAIL
STANDARD_SILICON_1	43.1	52	52	46	52	FAIL

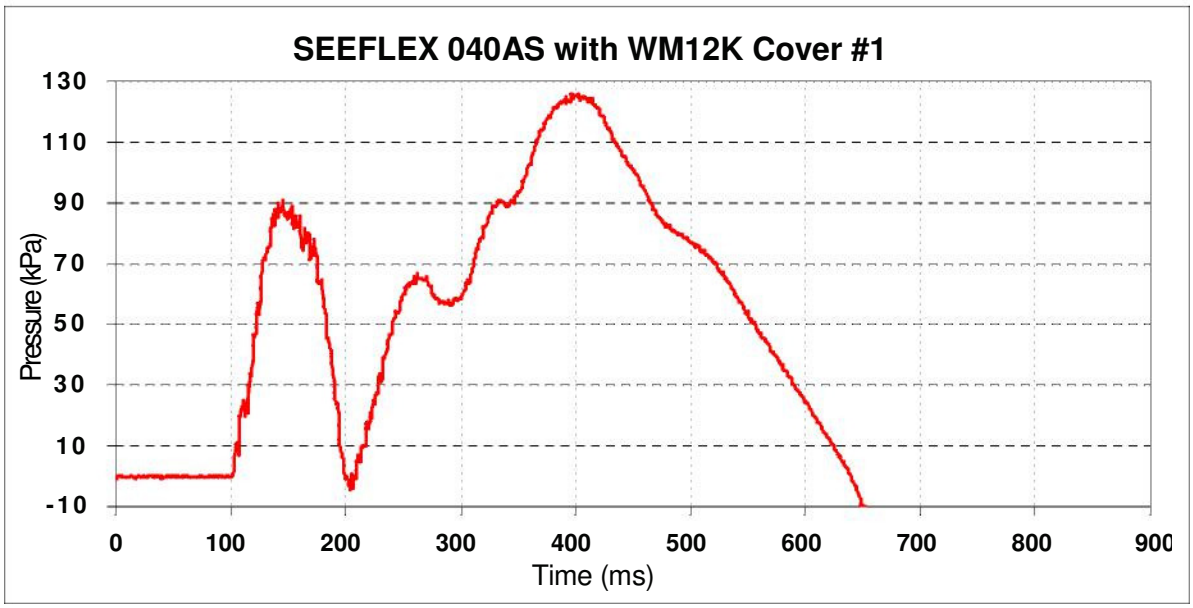

SEEFLEX 040E #1
Pressure (kPa)
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)

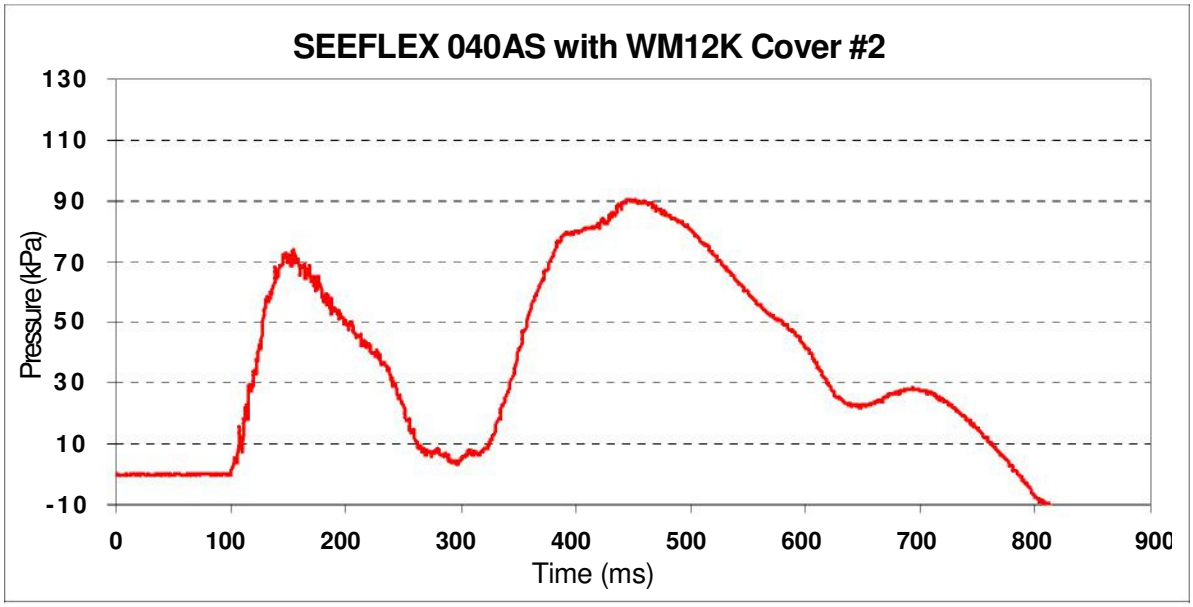

SEEFLEX 040E #2
Pressure (kPa)
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)

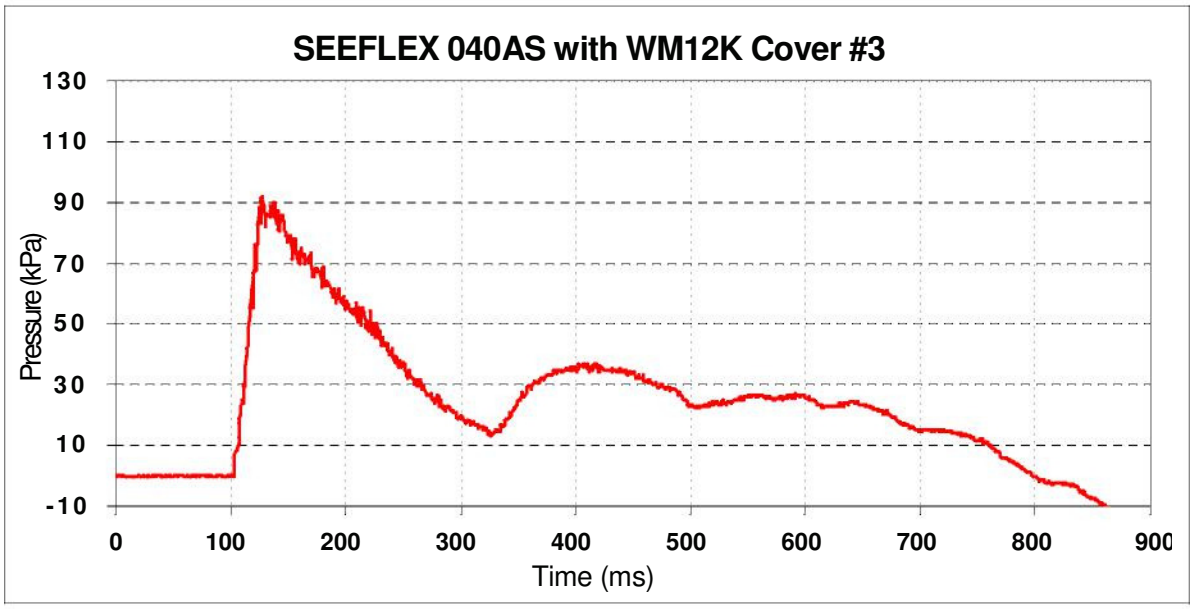

SEEFLEX 040E #3
Pressure (kPa)
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)

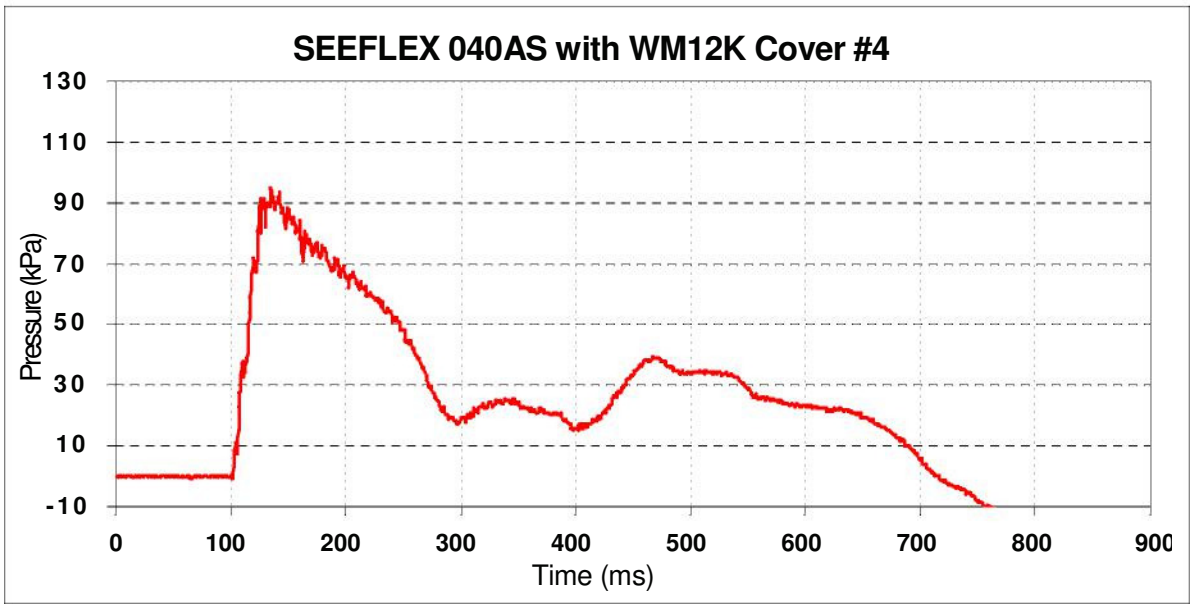

SEEFLEX 040E #4
Pressure (kPa)
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)

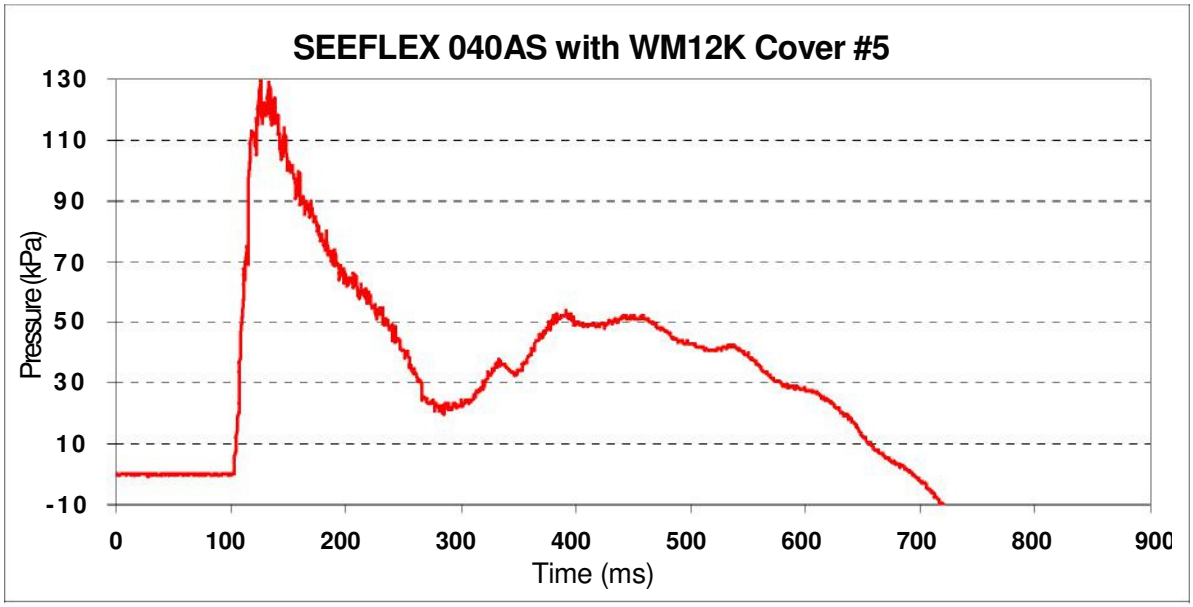

SEEFLEX 040E #5
Pressure (kPa)
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)

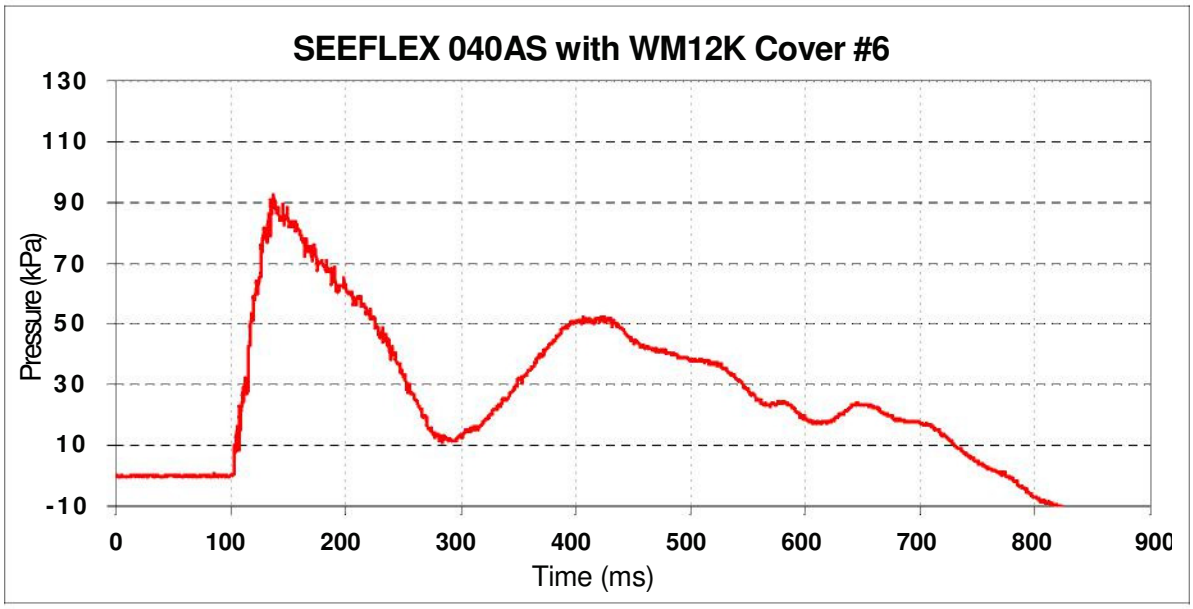

SEEFLEX 040AS with WM12K Cover #1
Pressure (kPa)
130
110
90
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)

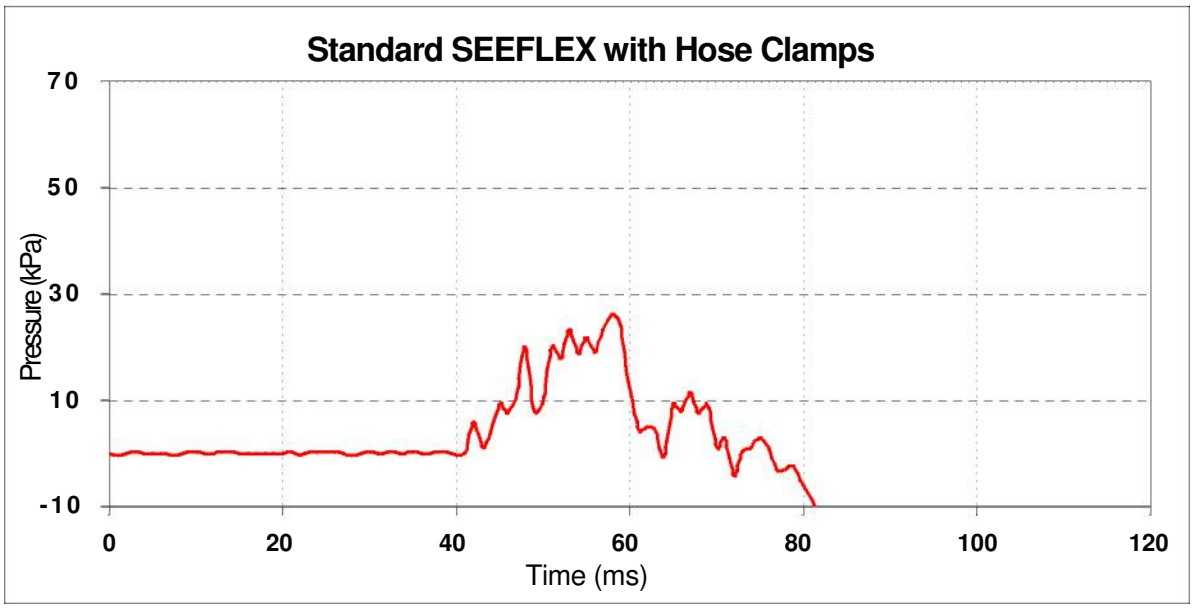

SEEFLEX 040AS with WM12K Cover #2
Pressure (kPa)
130
110
90
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)

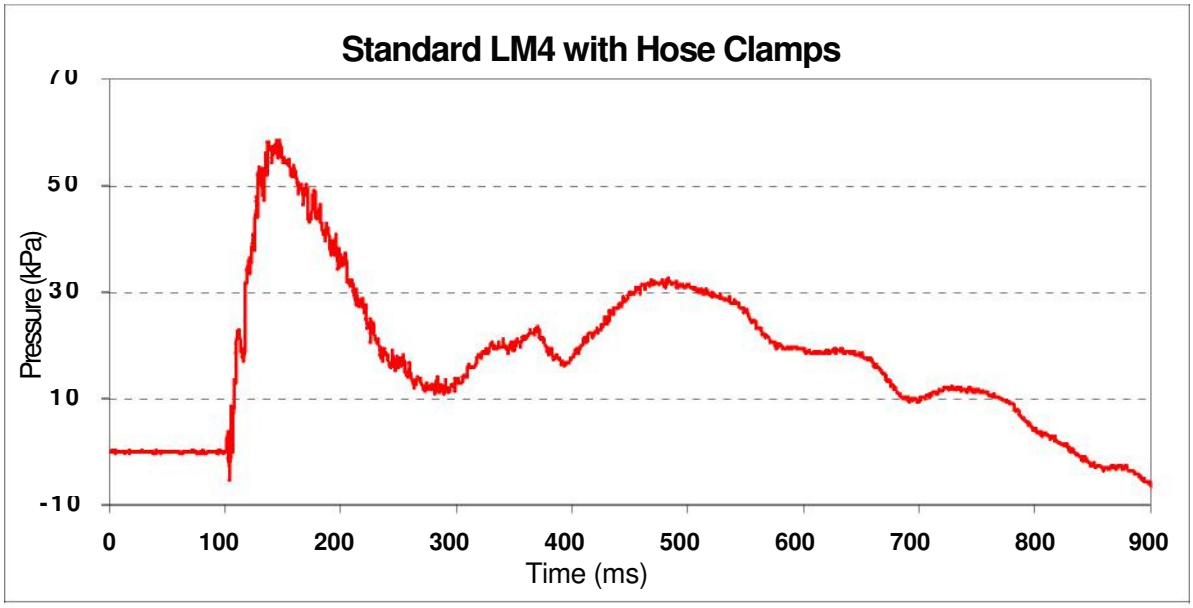

SEEFLEX 040AS with WM12K Cover #3
Pressure (kPa)
130
110
90
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)

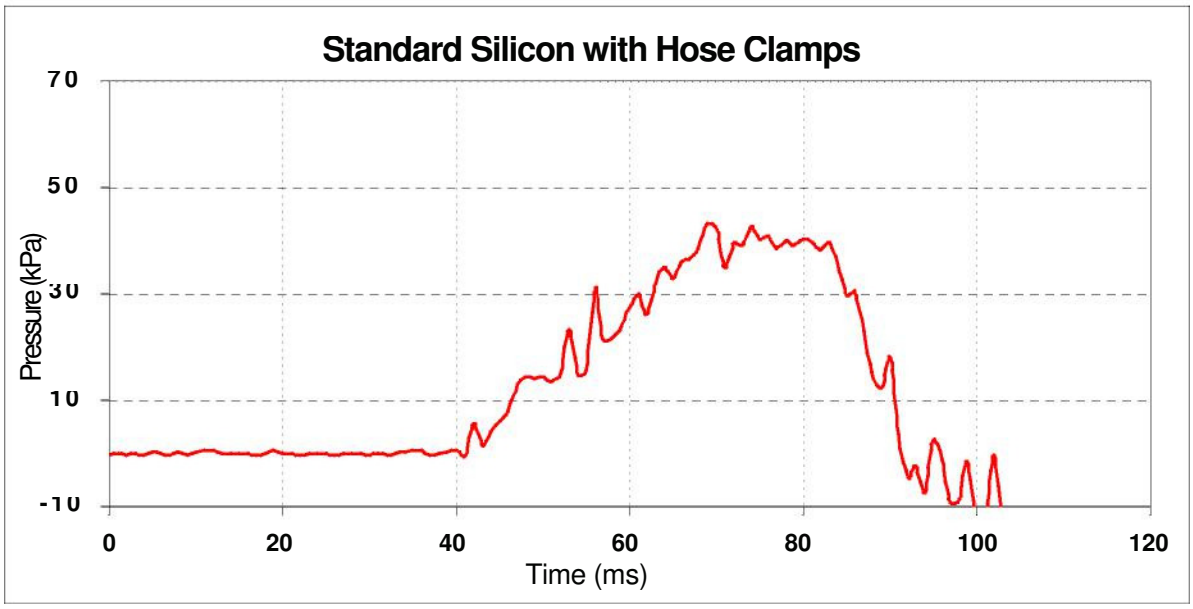

SEEFLEX 040AS with WM12K Cover #4
Pressure (kPa)
130
110
90
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)


SEEFLEX 040AS with WM12K Cover #5
Pressure (kPa)
130
110
90
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)


SEEFLEX 040AS with WM12K Cover #6
Pressure (kPa)
130
110
90
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)


Standard SEEFLEX with Hose Clamps
Pressure (kPa)
70
50
30
10
-10
0
20
40
60
80
100
120
Time (ms)


Standard LM4 with Hose Clamps
Pressure (kPa)
70
50
30
10
-10
0
100
200
300
400
500
600
700
800
900
Time (ms)


Standard Silicon with Hose Clamps
Pressure (kPa)
70
50
30
10
-10
0
20
40
60
80
100
120
Time (ms)