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COMPACT project: Hydro burst testing of impact damaged four-inch pressure vessels

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English summary

Twelve four-inch pressure vessels made of carbon fibre reinforced plastic (CFRP) have been produced at FFI. The applied material system is a carbon fibre reinforced prepreg system, TCR UF3325-95/M30SC. The vessels have been impact damaged, and thereafter inspected by different non-destructive testing methods. This report summarizes the test results from the hydro burst testing of eleven impact damaged pressure vessels. The production and hydro burst testing is performed by FFI on behalf of the COMPACT project.

Two different lay-ups are included in the test set-up: 1) [30/30/90], referred to as XXO, and 2) [90/30/30], referred to as OXX. The hydro burst test results show that the burst pressure for XXO vessels is reduced by approximately 60 % for the low energy impact level and around 66 % for the high energy impact level. For OXX vessels, the burst pressure is reduced by approximately 41 % for the low energy impact level, and around 68% for the high energy impact level.

Sammendrag

Tolv firetommers trykkflasker i karbonfiberkompositt har blitt produsert ved FFI. Materialsystemet som er benyttet er et karbonfiberforsterket prepreg-system, TCR UF3325-95/M30SC. Trykkflaskene har blitt slagskadet, og deretter inspisert ved bruk av ulike metoder for ikke-destruktiv testing. Denne rapporten oppsummerer testresultatene fra trykktesting av elleve slagskadde trykkflasker. Trykktestingen er utført for COMPACT-prosjektet.

To ulike lagoppbygninger er inkludert i testoppsettet: 1) [30/30/90], referert til som XXO, og 2) [90/30/30], referert til som OXX. Testresultatene viser at sprengtrykket for XXO-flaskene reduseres med om lag 60 % for det lave slagenerginivået, og med om lag 66 % for det høye slagenerginivået. For OXX-flaskene er sprengtrykket redusert med rundt 41 % for det lave slagenerginivået, og med rundt 68 % for det høye slagenerginivået.

Contents

1 Introduction

This report summarizes the test results from hydro burst testing (HBT) of eleven impact damaged four inch pressure vessels made of carbon fibre reinforced plastic. The applied material system is TCR UF3325-95/M30SC, and two different lay-ups are included in the test set-up: 1) [30/30/90], in the report referred to as XXO, and 2) [90/30/30], in the report referred to as OXX.

Initially, twelve four inch pressure vessels were produced at FFI. They were then sent to the contractor for impact testing. Thereafter, the vessels were inspected using different non-destructive testing methods, before they were returned to FFI for HBT.

The production and the hydro burst testing is performed by FFI on behalf of the COMPACT project. More details about the COMPACT project and its research activities and goals may be found here: http://www.sintef.no/home/Materials-and-Chemistry/Synthesis-and-Properties/Polymer-and-Composite-Materials/Compact/#.Ui2UiVPFyi4.email .

2 Hydro burst test laboratory at FFI

FFI has test facilities for performing hydro burst testing of pressure vessels and composite rocket motors.

Figure 2.1 Mounting of the pressure vessel in the burst test chamber.

In short, the hydro burst test is carried out by first mounting the vessel into the test rig, as shown in Figure 2.1. The vessel is then filled with water, and a piston pump is used to increase the pressure until the vessel bursts. The pressure value at burst is the reported *burst pressure value*.

Note that prior to HBT, the vessels are sealed using a polymer liner (Rencast 6427A/Rencast 5427B) to make it water proof.

3 Hydro burst test results

Table 3.1 gives the unique ID for each of the twelve produced pressure vessels, the lay-up, the applied impact energy, as well as the burst pressure values. The following sub sections describe the test results from hydro burst testing in more detail.

3.1 Impacted pressure vessels

Figure 3.1 shows the impact location of pressure vessel CP-11, with visible fibre breakage in the outermost layer of the structure. Similar damage at the point of impact is observed for several of the other pressure vessels.

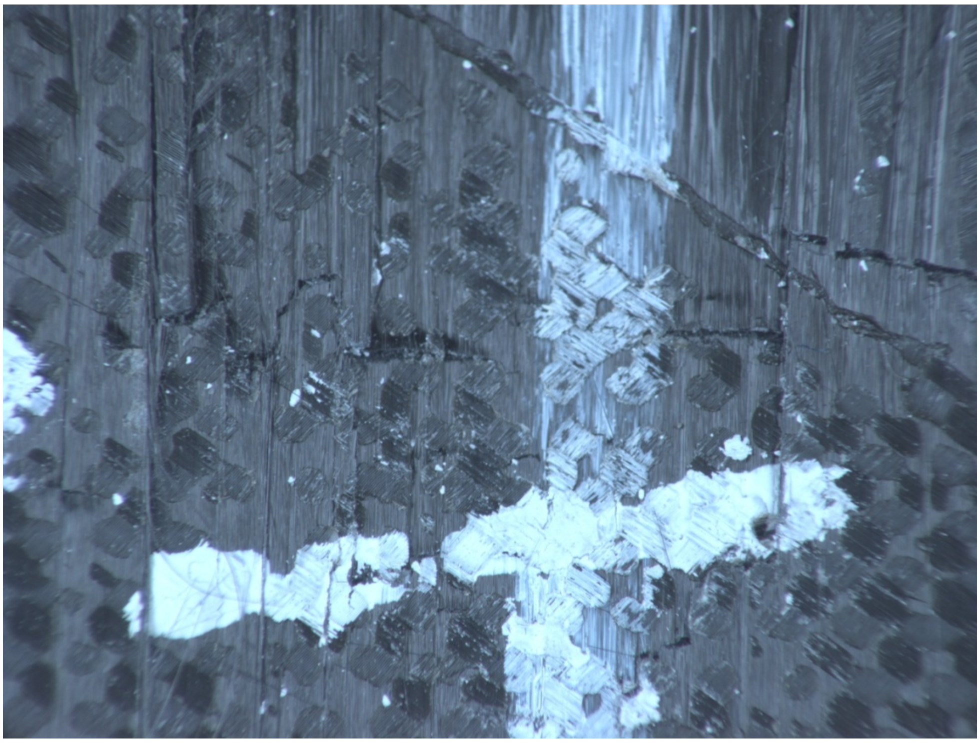

Figure 3.1 CP-11 impact location; before HBT.

3.2 Burst pressure values

As mentioned in the introduction, only eleven of the vessels were burst tested, see Table 3.1. The last vessel (i.e. CP-10) was used for establishing impact levels, and thus no HBT was possible.

As a reference, non-impacted XXO pressure vessels have a burst pressure mean value of around 35 MPa, whereas non-impacted OXX pressure vessels have a burst pressure mean value of around 41 MPa. The higher burst pressure mean value for the OXX vessels is due to the stacking of the layers. For the OXX vessels the innermost load-bearing hoop (i.e. ‘O’) layer is wound on a “perfect” and smooth mandrel surface. For the XXO the load-bearing hoop layer is wound on a more uneven helical (i.e. ‘X’) layer.

Table 3.1 Four inch pressure vessel data and test results.

Vessel ID	Lay-up	Impact energy (J)	Burst pressure (MPa)
CP-1	OXX	10	24.0
CP-2	OXX	10	25.6
CP-3	OXX	10	22.1
CP-4	OXX	25	10.9
CP-5	OXX	25	15.6
CP-6	OXX	25	13.7
CP-7	XXO	10	14.1
CP-8	XXO	10	14.1
CP-9	XXO	25	10.1
CP-10	XXO	-	-
CP-11	XXO	25	9.2
CP-12	XXO	25	14.4

3.3 Pressure curves

Figure 3.2 to Figure 3.12 show the pressure curve for the eleven hydro burst tested pressure vessels. The peak pressure value is the reported burst pressure value, see Table 3.1.

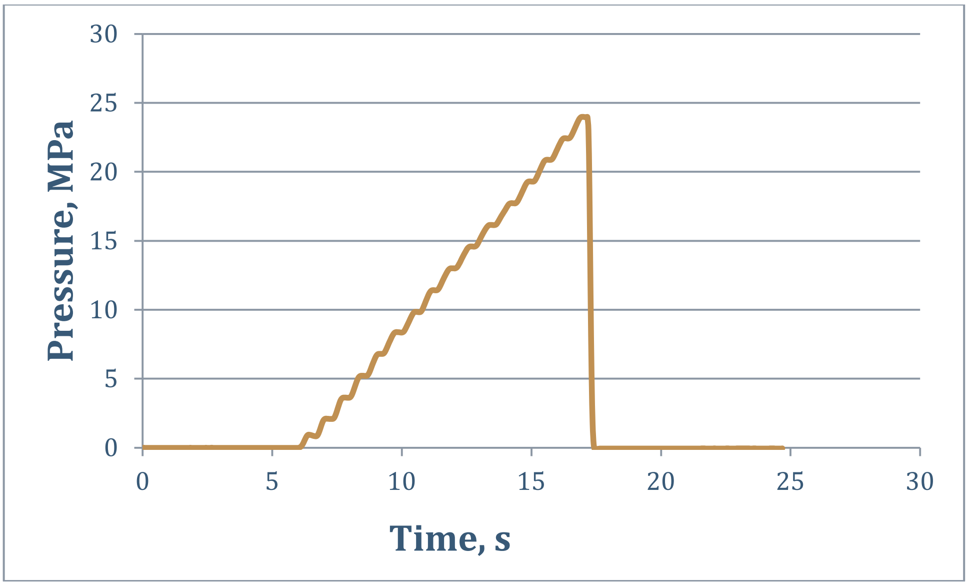

Figure 3.2 Pressure curve for CP-1.

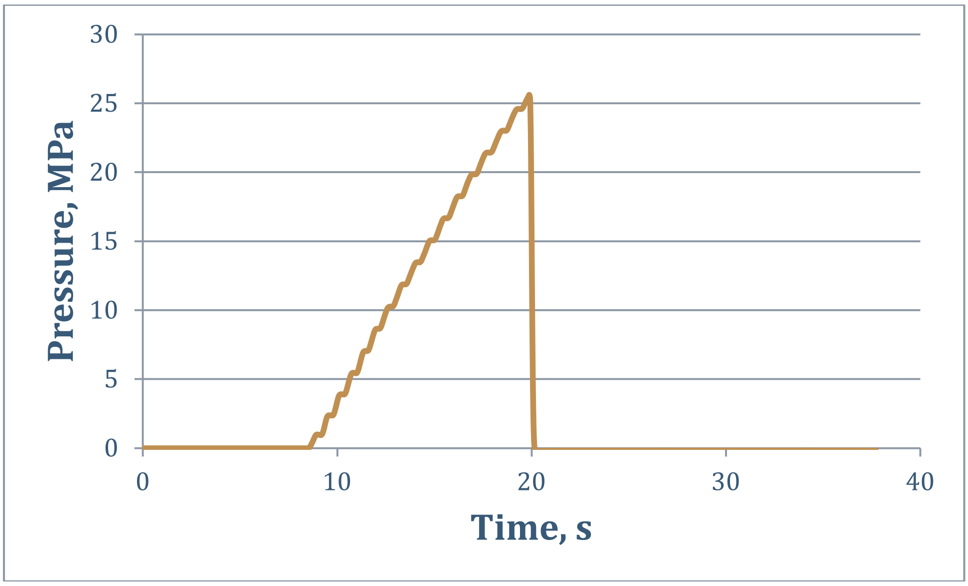

Figure 3.3 Pressure curve for CP-2.

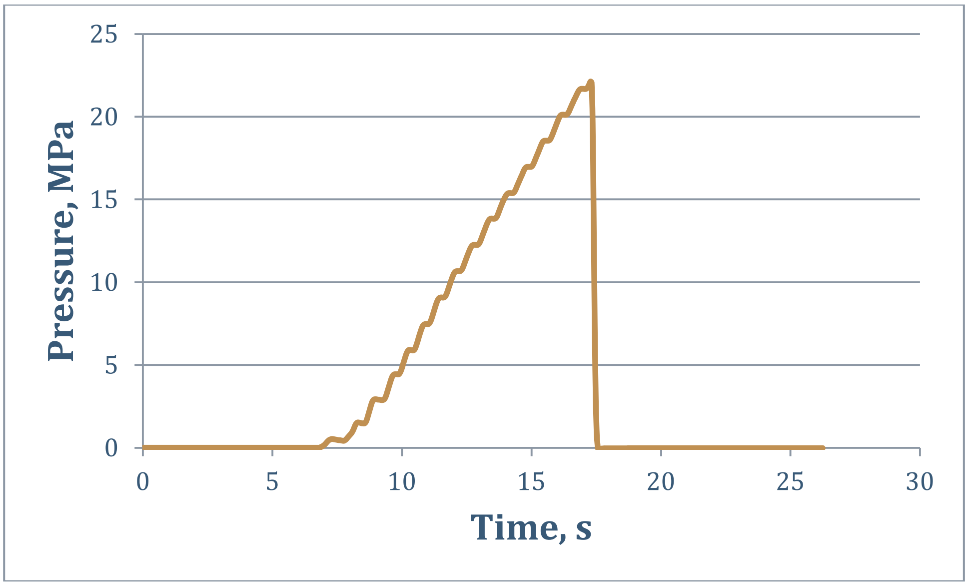

Figure 3.4 Pressure curve for CP-3.

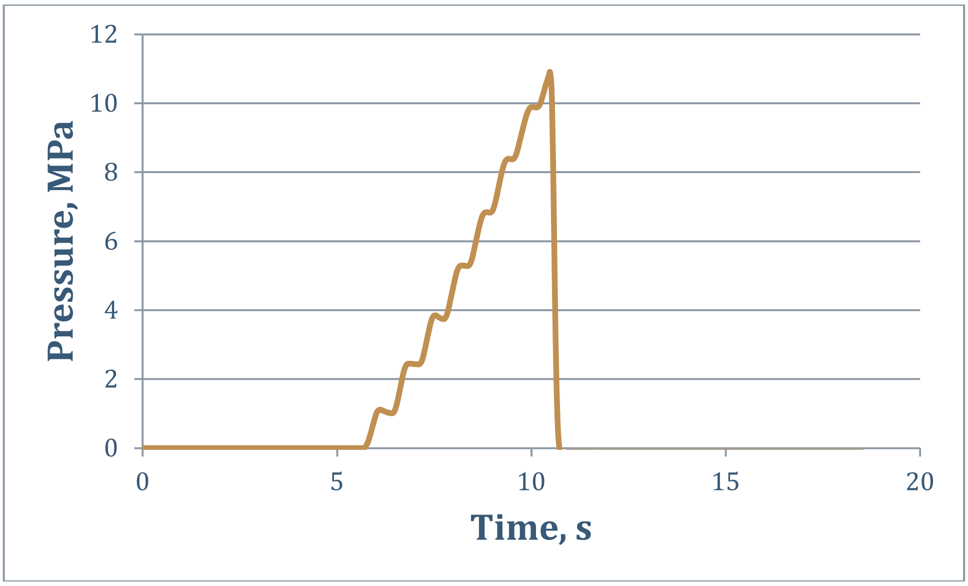

Figure 3.5 Pressure curve for CP-4.

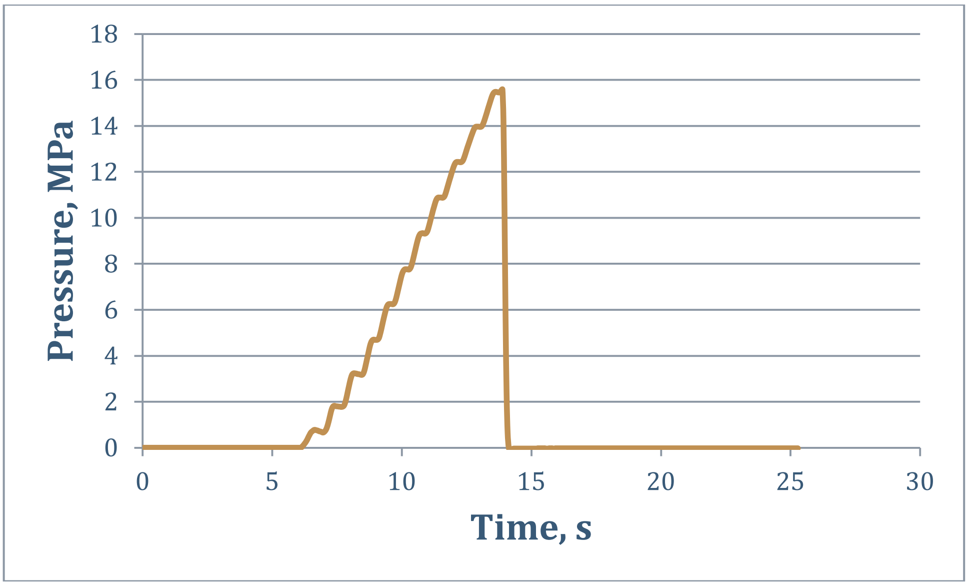

Figure 3.6 Pressure curve for CP-5.

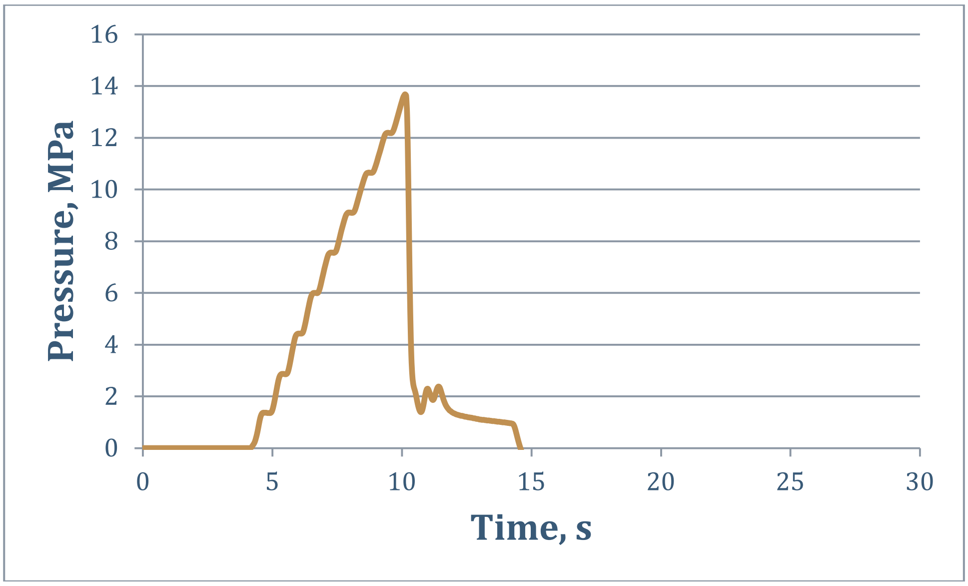

Figure 3.7 Pressure curve for CP-6.

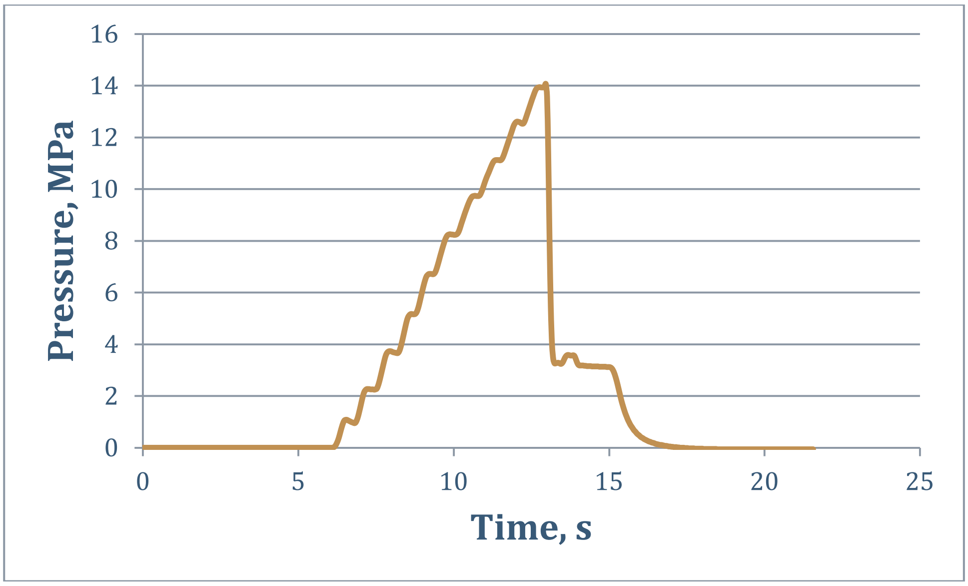

Figure 3.8 Pressure curve for CP-7.

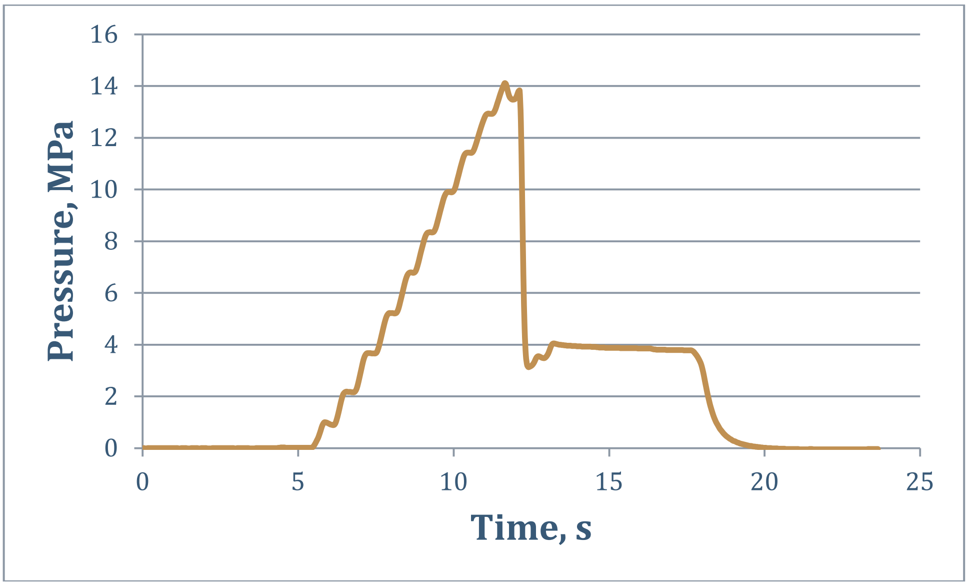

Figure 3.9 Pressure curve for CP-8.

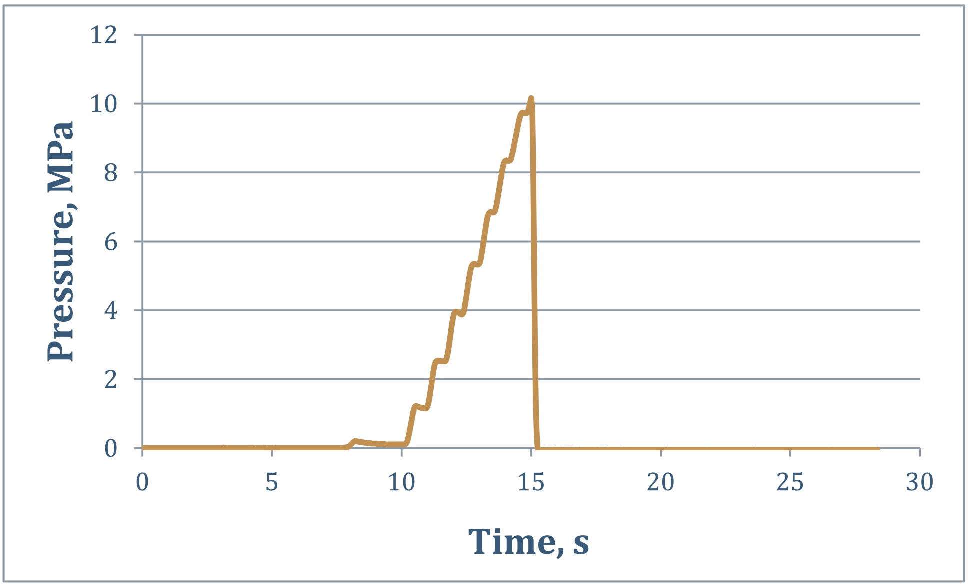

Figure 3.10 Pressure curve for CP-9.

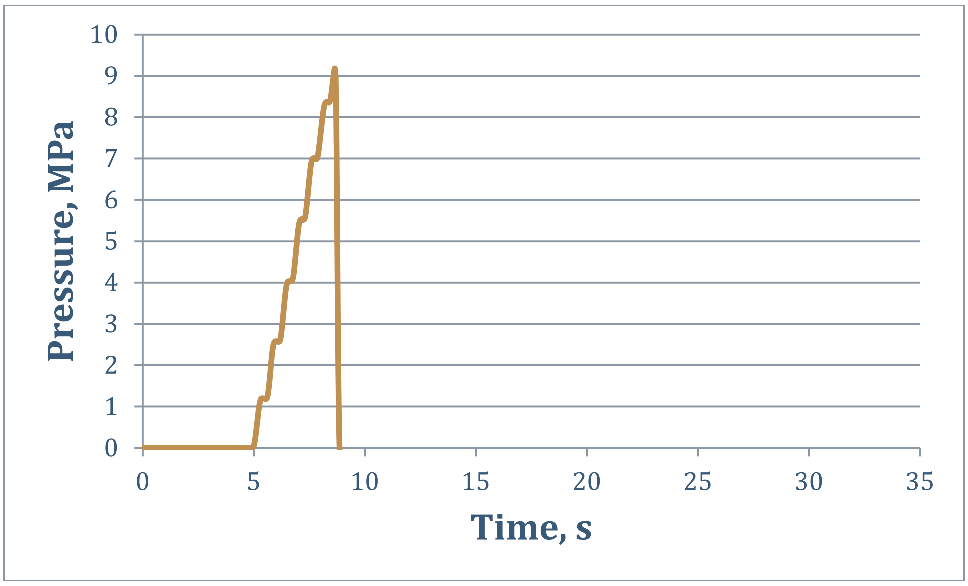

Figure 3.11 Pressure curve for CP-11.

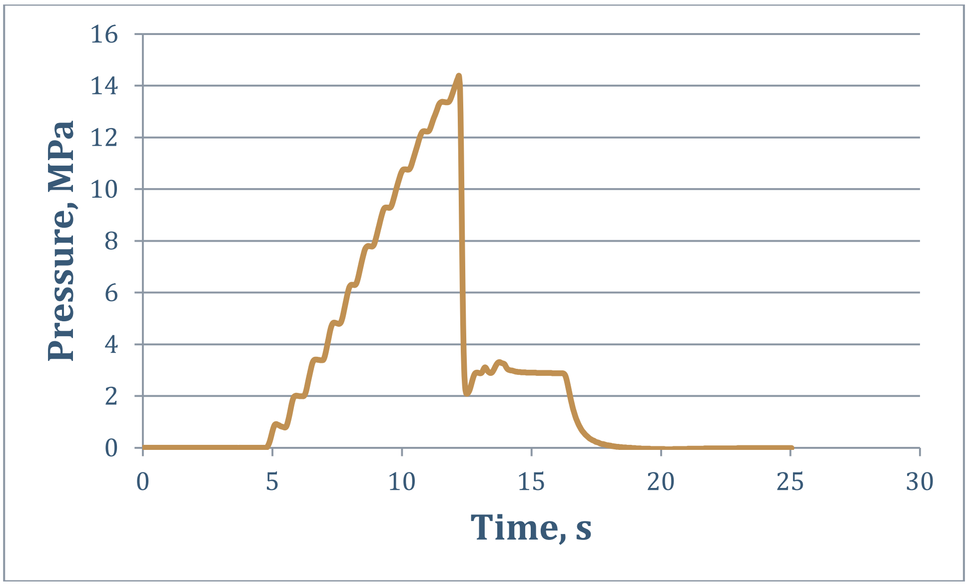

Figure 3.12 Pressure curve for CP-12.

3.4 Pictures of the pressure vessels after burst

Figure 3.13 to Figure 3.23 display the eleven pressure vessels after burst. The destructed area of the vessels after burst is located around the point of impact.

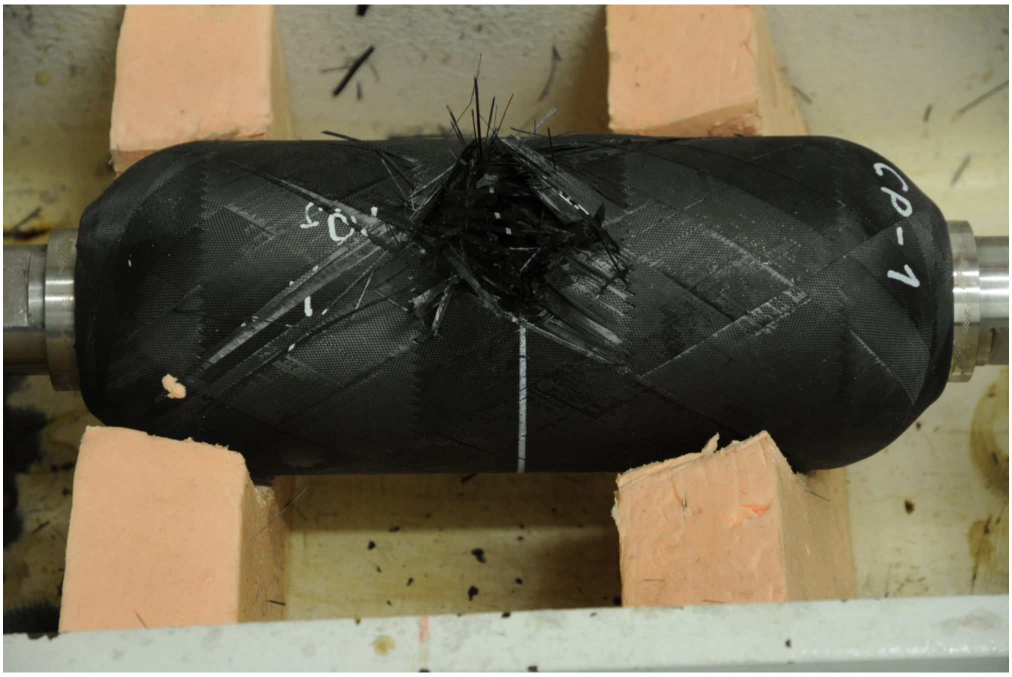

Figure 3.13 CP-1 after burst.

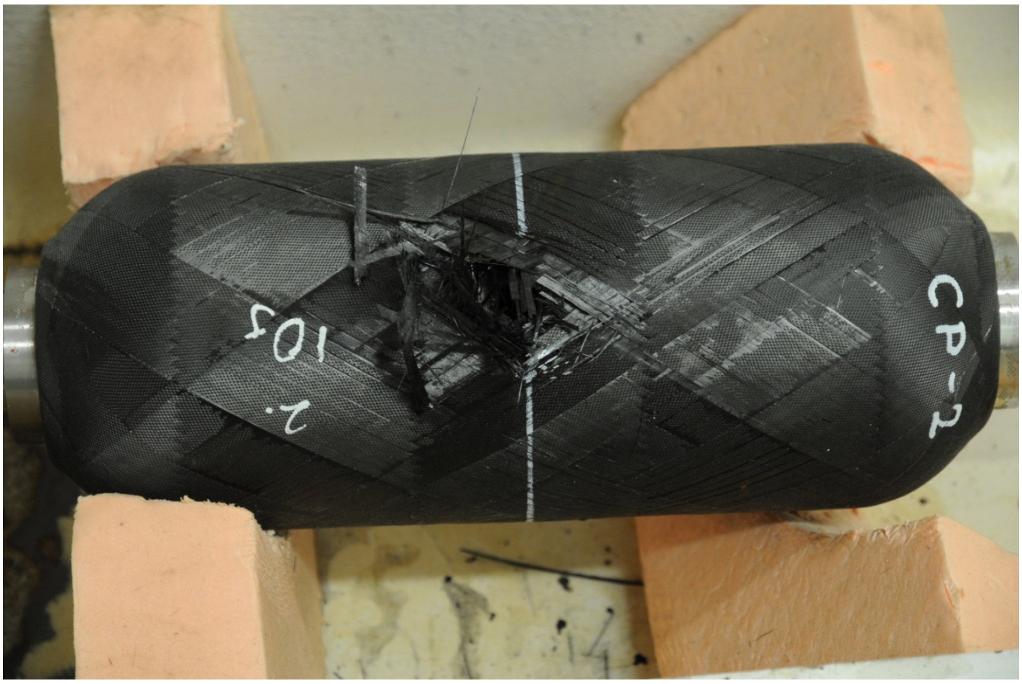

Figure 3.14 CP-2 after burst.

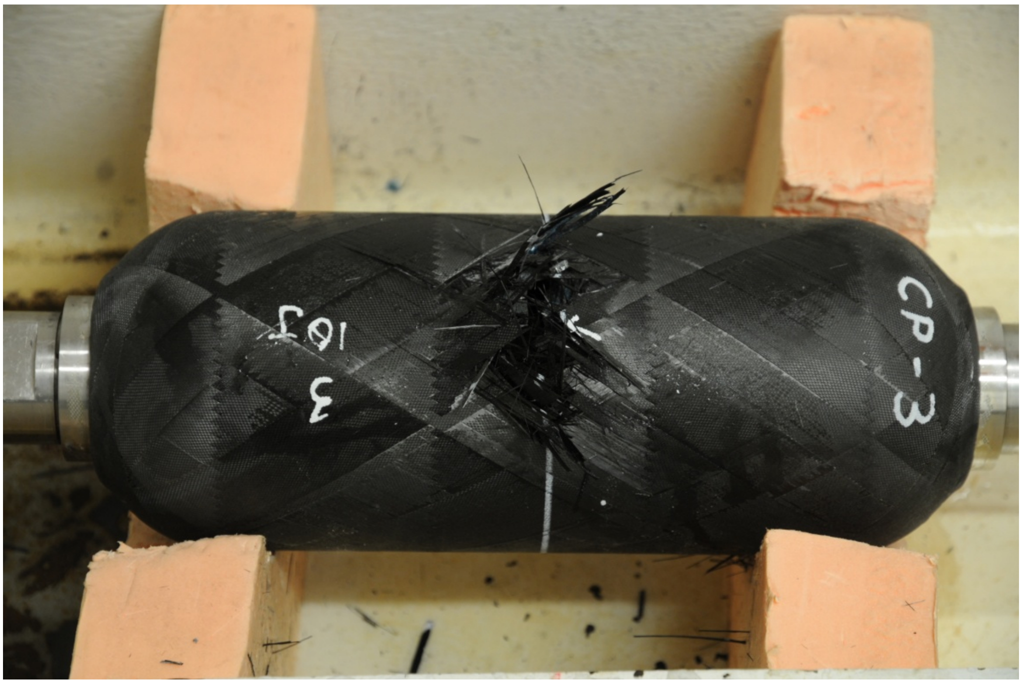

Figure 3.15 CP-3 after burst.

Figure 3.16 CP-4 after burst.

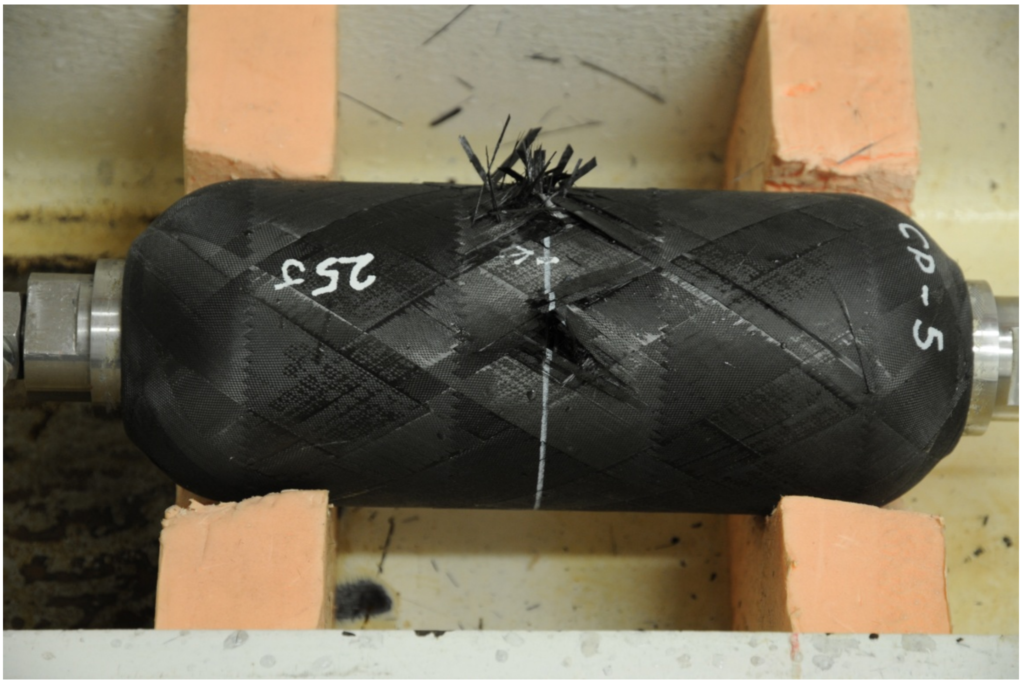

Figure 3.17 CP-5 after burst.

Figure 3.18 CP-6 after burst.

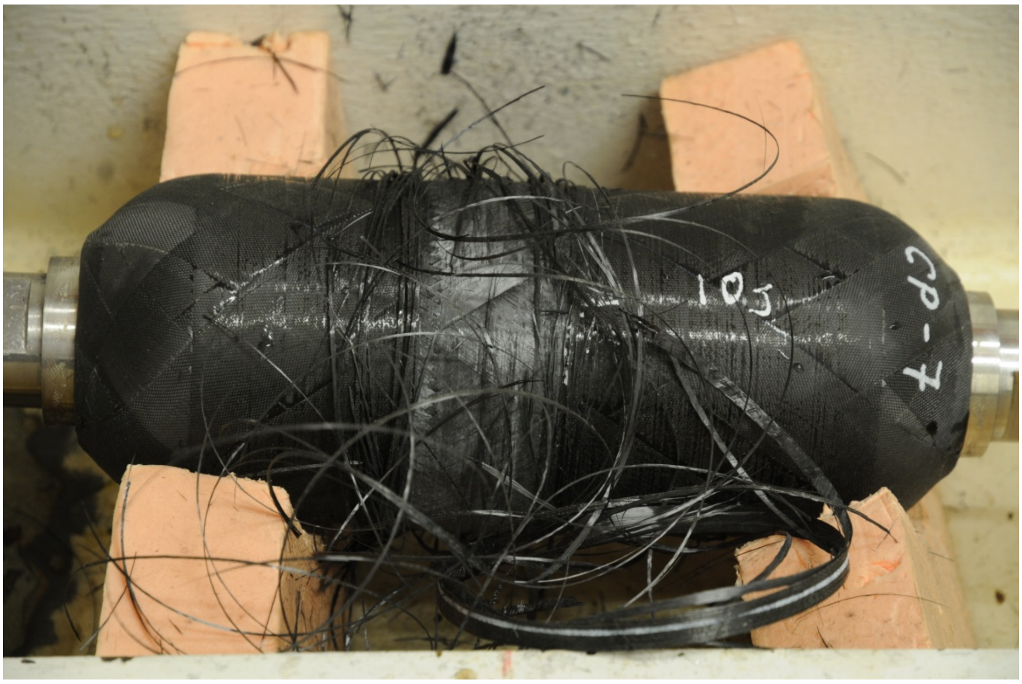

Figure 3.19 CP-7 after burst.

Figure 3.20 CP-8 after burst.

Figure 3.21 CP-9 after burst.

Figure 3.22 CP-11 after burst.

Figure 3.23 CP-12 after burst.

3.5 Observations and discussion

A small set of pressure vessels have been tested in this program after being impact damaged. From this small set, it may be difficult to draw any conclusions. However, from the obtained test results, the following is observed:

- The burst pressure of the impacted vessels is a function of the applied impact energy
- The destructed area of the vessels after burst is located around the point of impact
- Compared to non-impacted vessels with lay-up XXO, which have a typical burst pressure of 35 MPa, the burst pressure is reduced to about 14 MPa (approximately 60 % reduction) for the low impact energy level, and to about 12 MPa (approximately 66% reduction) for the high impact energy level
- Compared to non-impacted vessels with lay-up OXX, which have a typical burst pressure of 41MPa, the burst pressure is reduced to about 24 MPa (approximately 41% reduction) for the low impact energy level, and to about 13 MPa (approximately 68 % reduction) for the high impact energy level

The hydro burst pressure results and observations are as expected. For the XXO vessels the *outermost* layer is the load-bearing hoop layer, whereas for the OXX vessels the load-bearing hoop layer is the *innermost* layer, which thus is protected by the two helical layers. For the low impact energy level the outermost layers are damaged, and the stacking of the layers can hence explain the higher reduction in burst pressure for the XXO vessels, compared to the OXX vessels. For the high impact energy level, there is a more severe damage of the structure, and the stacking sequence is not that decisive for the burst pressure. In addition, the relatively high burst pressure value obtained also for the high impact energy level might be due to the relatively thick liner, which probably serves as a load distributer that engages a larger part of the structure. Pressure vessel CP-10 was not hydro burst tested, but instead cut open, as seen in Figure 3.24. For pressure vessel CP-10 the thickness of the liner is approximately 3 mm.

Figure 3.24 Pressure vessel CP-10, which is cut open. The liner thickness is approximately 3 mm.

4 Summary

In this report, the test results from hydro burst testing of eleven impact damaged four inch pressure vessels are reported. Two different lay-ups are included in the test program: 1) [30/30/90], referred to as XXO, and 2) [90/30/30], referred to as OXX. The same CFRP prepreg material, TCR UF3325-95/M30SC, is applied for all vessels.

The test results show that the burst pressure for the XXO vessels is reduced by approximately 60 % for the low energy impact level and by around 66 % for the high energy impact level. For the OXX vessels the burst is reduced by approximately 41 % for the low energy impact level, and by around 68% for the high energy impact level.