White paper

Fluid tightness characterization I

This document includes the first rounds of results of the tests done to characterize the fluid tightness of MJF printed parts. Additional results will come in the following technical papers published.

Executive summary

MJF printed parts have been proved to be watertight without any additional post-process. Therefore, MJF printed parts could be used as deposits or pipelines that work with water, even under pressure.

These are the main variables of design which define the maximum pressure any given part can withstand:

- Wall thickness
- Shape
- Temperature
- Type of fluid

These are the **recommended values** to have fluid vessels (deposits or pipelines) working with water under pressure at 25°C, over a temporary period of time.

Wall thickness	3 bar	10 bar	20 bar
1.25 mm	Recommended	Not recommended	Not recommended
2.5 mm	Recommended	Recommended	Not recommended
4 mm	Not recommended	Recommended	Recommended

Vessel shape	3 bar	10 bar	20 bar
Spherical	Recommended	Recommended	Recommended
Cylindrical	Recommended	Recommended	Recommended
Cubic	Not recommended	Break	Break

The best shape to work with fluids under pressure is a sphere, because the pressure is better distributed and there are no flat surfaces, which will deform and break easier. Therefore, **it is recommended to design fluid vessels as close to a spherical shape as possible**, because this will help to withstand higher pressures.

PA12 has high chemical resistance to a wide variety of commonly-used fluids in the industry. In the following table, the main groups of fluids that could be used with PA12 fluid vessels are listed.

Fluid	Chemical resistance
Diluted alkalis	Good
Concentrated alkalis	Good
Hot water	Neutral
Chlorine salts	Good
Alcohol	Good
Esters	Good

Ethers	Good
Ketones	Good
Aliphatic hydrocarbons	Good
Motor oil	Good
Aromatic hydrocarbons	Good
Toluene	Good
Unleaded petrol	Good
Dot 3 brake fluid	Good
Chlorinated hydrocarbons	Neutral
Trichloroethylene	Neutral

Next technical papers content about fluid tightness

The following round of results of the fluid tightness characterization will contain the following information:

- Characterization of air vessels with different wall thicknesses and shapes
- Characterization of brake-fluid vessels with different wall thicknesses and shapes
- Characterization of gasoline vessels with different wall thicknesses and shapes
- Additional chemical resistance results

Variables to characterize in the full-fluid tightness characterization:

	Fluid	Shape	Pressure [bar]	Wall thickness [mm]	Temperature [°C]
Values	Air	Sphere	1	0.5	25
	Water	Cylinder	3	1.25	75
	Brake fluid	Cube	5	2.5	-
	Gasoline	-	10	4	-
	-	-	20	-	-

Water tight applications

Thanks to the water tightness of the HP High Reusability PA12, the printer parts have the following advantages when they are used as fluid vessels replacing other traditional technologies:

Ducts

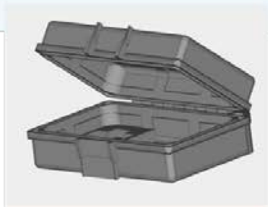
- **Unification** of different ducts together.
- **Efficiency improvement** by designing geometries not possible with other technologies.
- **Fluid tightness** without any post-processing.

Deposits

- **Optimization** of product space by designing geometries not possible with other technologies.
- **Any geometry** can work for fluids at low pressure.
- **Fluid tightness** without any post-processing.

Waterproof covers

- **Customization and personalization** of design.
- **Waterproofness** without any post-processing.



Water tightness test characterization

Leakage test results

The leakage test has been done to determine the possible of leaks and pressure losses of MJF parts working with a fluid under pressure.

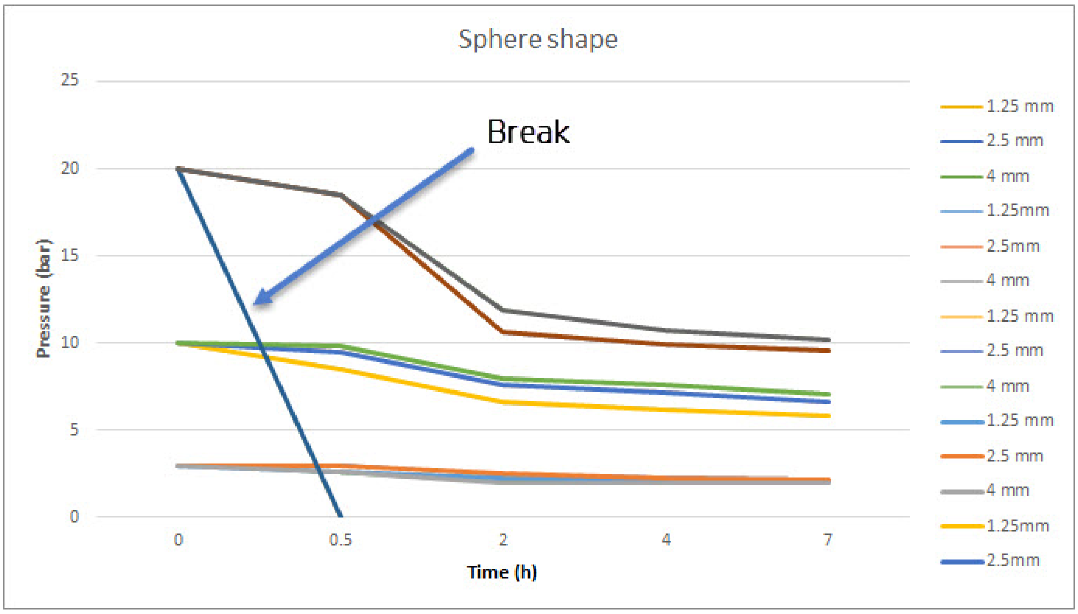
The water is introduced into the different test specimens at a specific pressure and is left for a period of 7 hours. During that time, the specimens are checked to detect any pressure loss that could appear due to material deformation or leakage.

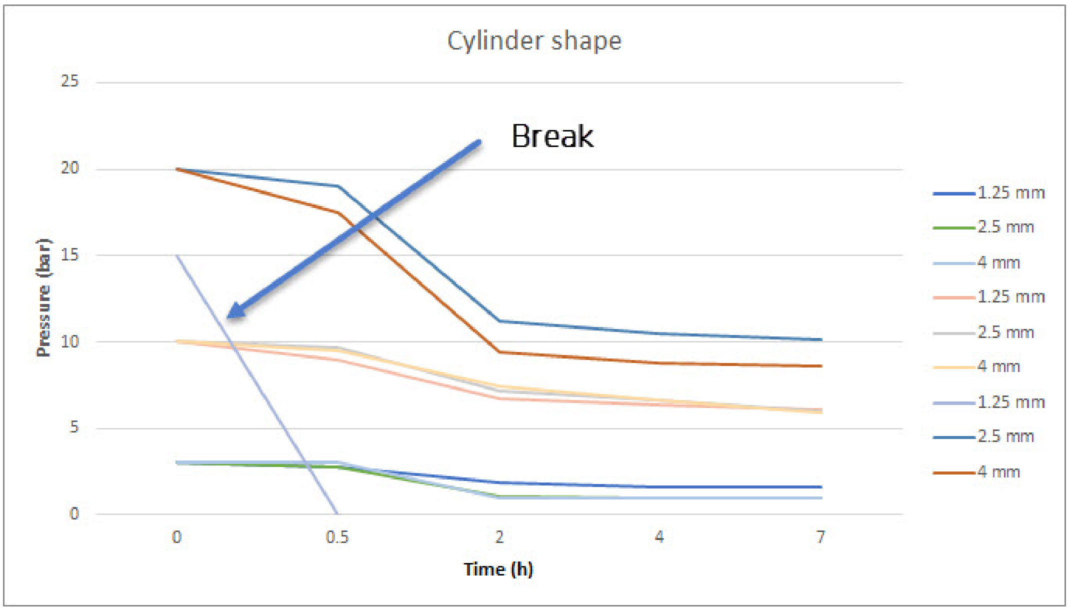
Wall thickness analysis

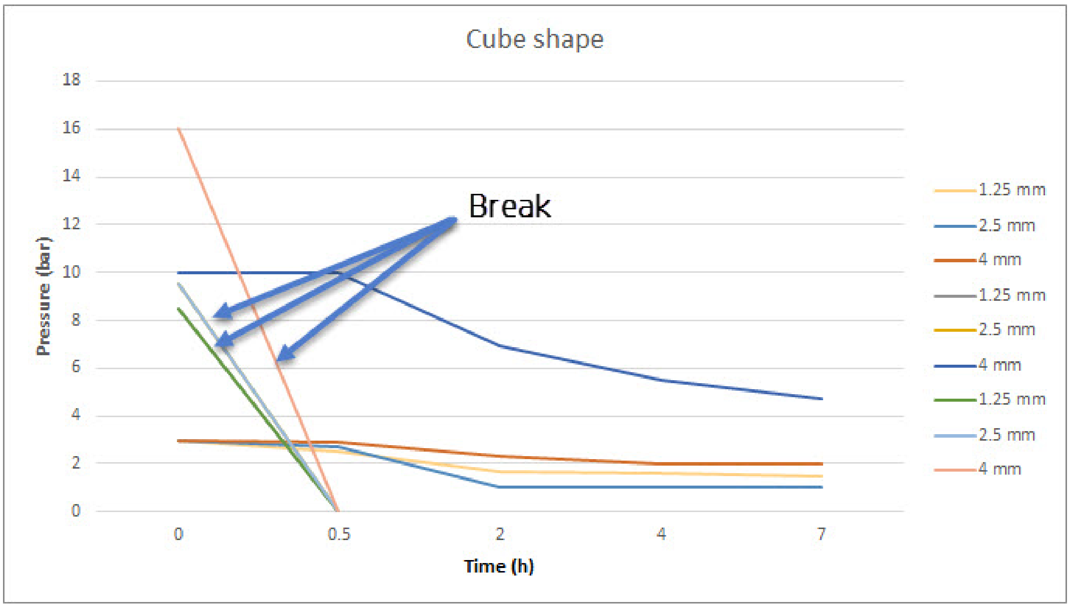
The water tightness characterization test has been done using 3 different wall thicknesses. These have been selected due to their wide use in fluid-vessel components: 1.25 mm, 2.5 mm and 4 mm.

The behavior of the parts with different wall thicknesses under different pressures will identify the best wall thickness depending on the circumstance. From the test results, the recommended values obtained are:

Wall thickness	3 bar	10 bar	20 bar
1.25 mm	Recommended	Not recommended	Not recommended
2.5 mm	Recommended	Recommended	Not recommended
4 mm	Not recommended	Recommended	Recommended







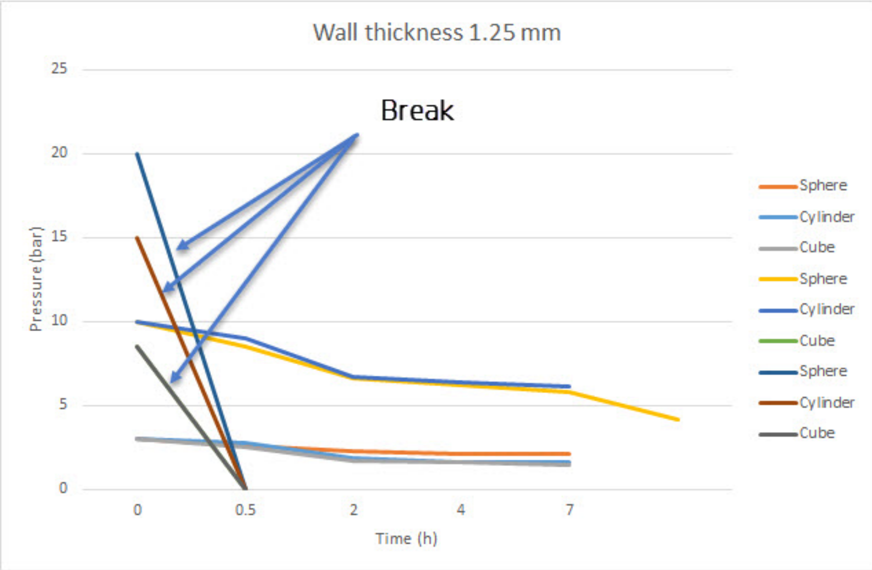
Vessel shape analysis

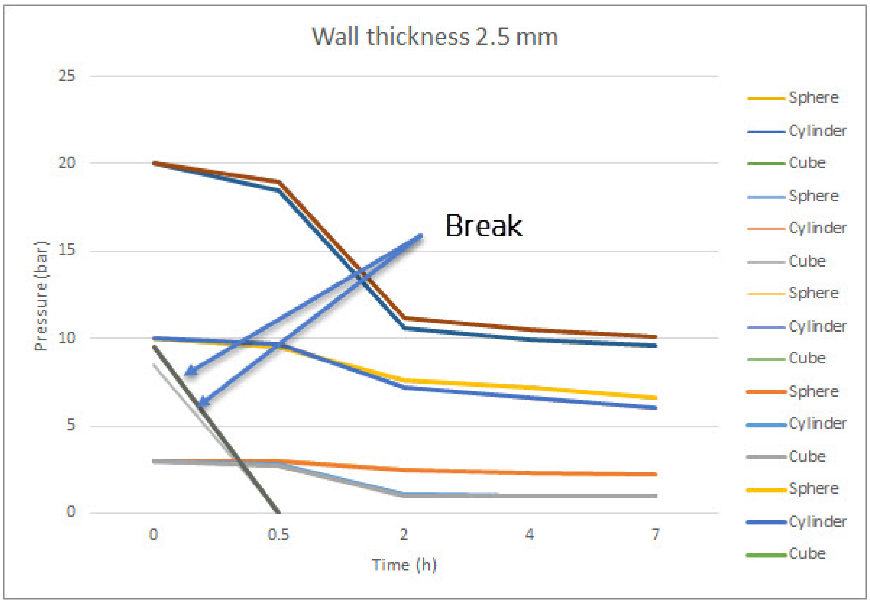
The water tightness characterization test has been done using 3 different shaped vessel that simulate the different geometries used in pipelines or deposits that could contain water.

The best shape to work with fluids under pressure is a sphere, because the pressure is better distributed and there are no flat surfaces, which will deform and break easier. Therefore, **it is recommended to design fluid vessels as close to a spherical shape as possible**, because this will help to withstand higher pressures.

The cubic deposits could work only under low pressure, as its geometry is more prone to adverse effects when under higher pressure.

Vessel shape	3 bar	10 bar	20 bar
Spherical	Recommended	Recommended	Recommended
Cylindrical	Recommended	Recommended	Recommended
Cubic	Not recommended	Break	Break


Wall thickness 1.25 mm
Break
Pressure (bar)
25
20
15
10
5
0
0
0.5
2
4
7
Time (h)
Sphere
Cylinder
Cube
Sphere
Cylinder
Cube
Sphere
Cylinder
Cube


Wall thickness 2.5 mm
Break
Pressure (bar)
25
20
15
10
5
0
0
0.5
2
4
7
Time (h)
Sphere
Cylinder
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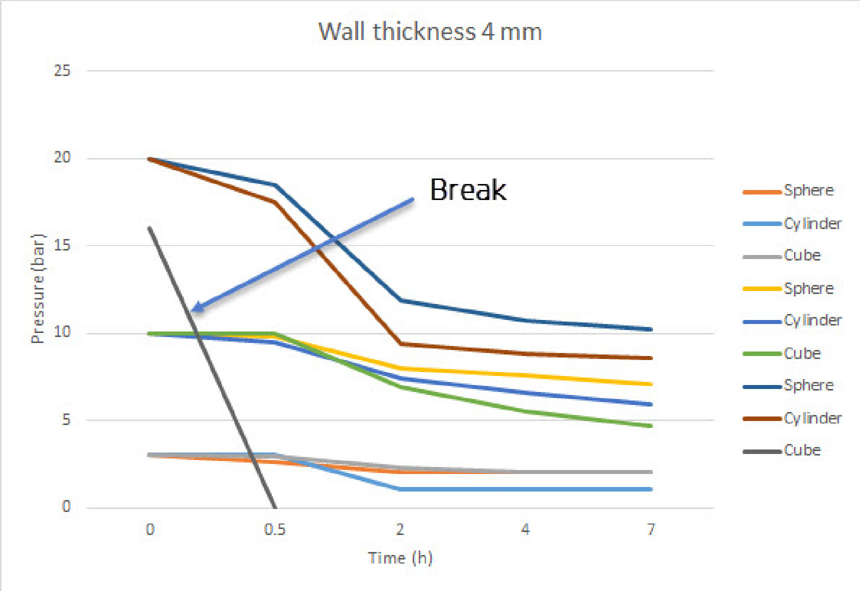


Vessel deformation impact in the pressure

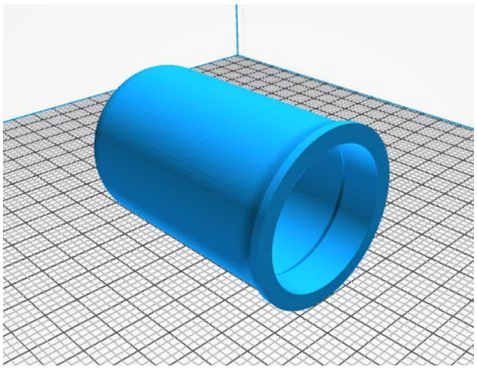
The water is an incompressible fluid. Thus, when it is introduced into a vessel under pressure, small variations in the vessel volume will imply higher variations in water pressure.

PA12, similarly to other plastics, deforms when it is used as a container. If this plastic is used with incompressible fluids such as the water, the initial deformation will imply a variation in the vessel pressure. This effect is commonly compensated through the pump, which can keep the pressure in the system constant, if needed. However, to keep the part working under a constant pressure, that pressure needs to be below its creep limit, to assure the part deforms and keeps stabilized in a certain deformation for a long period of time.

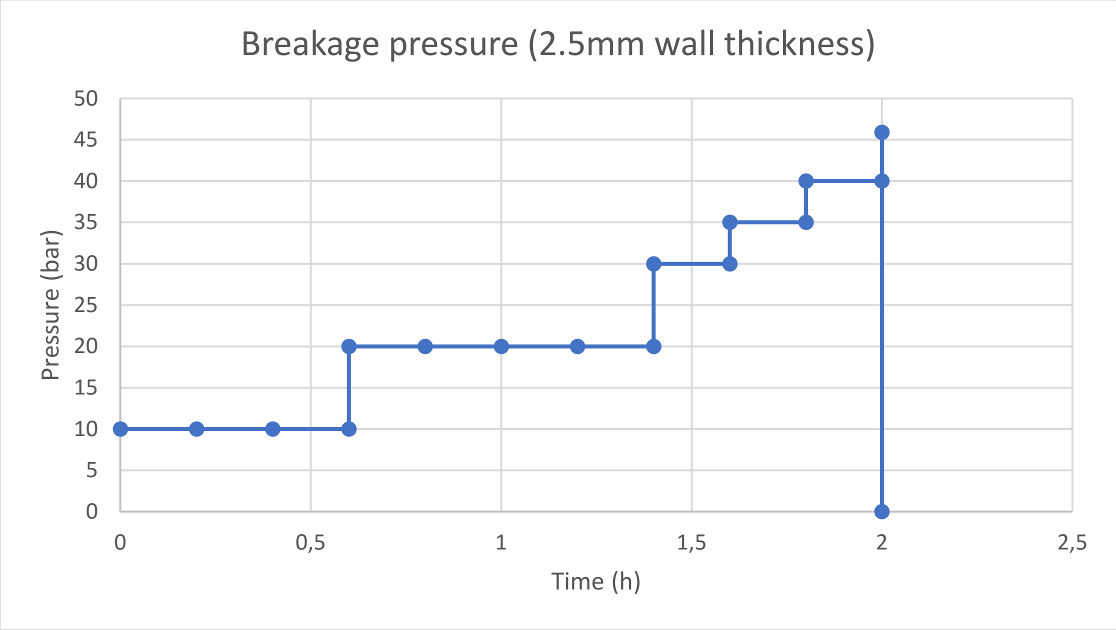
Breakage test results

The breakage test measures what the maximum pressure a sample can withstand before it breaks is.

The preliminary results are done by a customer, which used a test sample of 2.5mm of wall thickness (see picture below):



The sample reached 45.9 bar without breaking, as shown in the following graph:



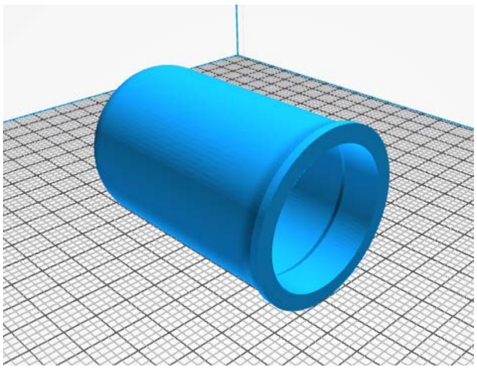
Comparison against other technologies

The breakage test has been also done with other materials in order to benchmark the performance of MJF printed parts compared to competitors.

MJF parts can withstand similar pressures to SLS, and higher than other technologies, such as SLA or Material Jetting.

Machine	Technology	Material	Temperature	Pressure resistance (wall thickness 2.5 mm)			
				10 bar	20 bar	30 bar	Broken at
Objet Connex500	Material Jetting	Photopolymer Vero Clear	30°C	✓	✓	✓	40 bar
Projet 3500 Max	Material Jetting	VisiJet (Crystal) SR200	30°C	✓	✓	✓	30 bar
Projet 6000	SLA	VisiJet Tough	30°C	✓	✓	0	25 bar
Projet 6000	SLA	VisiJet Hi-Temp	60°C	✓	✓	✓	30 bar
EOS Formiga P100	SLS	PA2200	30°C	✓	✓	✓	45 bar
HP Jet Fusion 4200	SLS	PA12	30°C	✓	✓	✓	45 bar

The benchmark test has been done with the same sample of 2.5mm thickness:



The following technical papers will include a breakage test comparing SLS and MJF with different wall thicknesses.

Chemical resistance

PA12 has high chemical resistance to a wide variety of fluids commonly used in the industry. In the table below the main groups of fluids that could be used with PA12 fluid vessels are listed:

Fluid	Chemical resistance
Diluted alkalis	Good
Concentrated alkalis	Good
Hot water	Neutral
Chlorine salts	Good
Alcohol	Good
Esters	Good
Ethers	Good
Ketones	Good
Aliphatic hydrocarbons	Good
Motor oil	Good
Aromatic hydrocarbons	Good
Toluene	Good
Unleaded petrol	Good
Dot 3 brake fluid	Good
Chlorinated hydrocarbons	Neutral
Trichloroethylene	Neutral

This technical paper includes a detailed list of the chemical resistance of PA12 against a list of commonly-used fluids in the industry currently.

A car-wash tunnel manufacturer that is interested in MJF has also tested the chemical resistance of the parts against shampoo (0.1% concentration in water) and bleach (0.05% concentration in water) with positive results. The test was done over a period of 500 hours at 67°C.

Annex 1. Test procedure

This section describes the equipment used for the performance of the tests and the test setup.

Test specimens

The following table shows the types of specimens and the geometries selected for testing in order to simulate fluid ducts and containers under pressure:

	Sphere	Cylinder	Cube
Ø [mm]	Ø98.5	Ø66x100	79.5
R [dm]	0.4925	0.333	0.795
V [L]	0.50	0.50	0.50

Table 1. Geometry of the test specimens (inner dimensions)

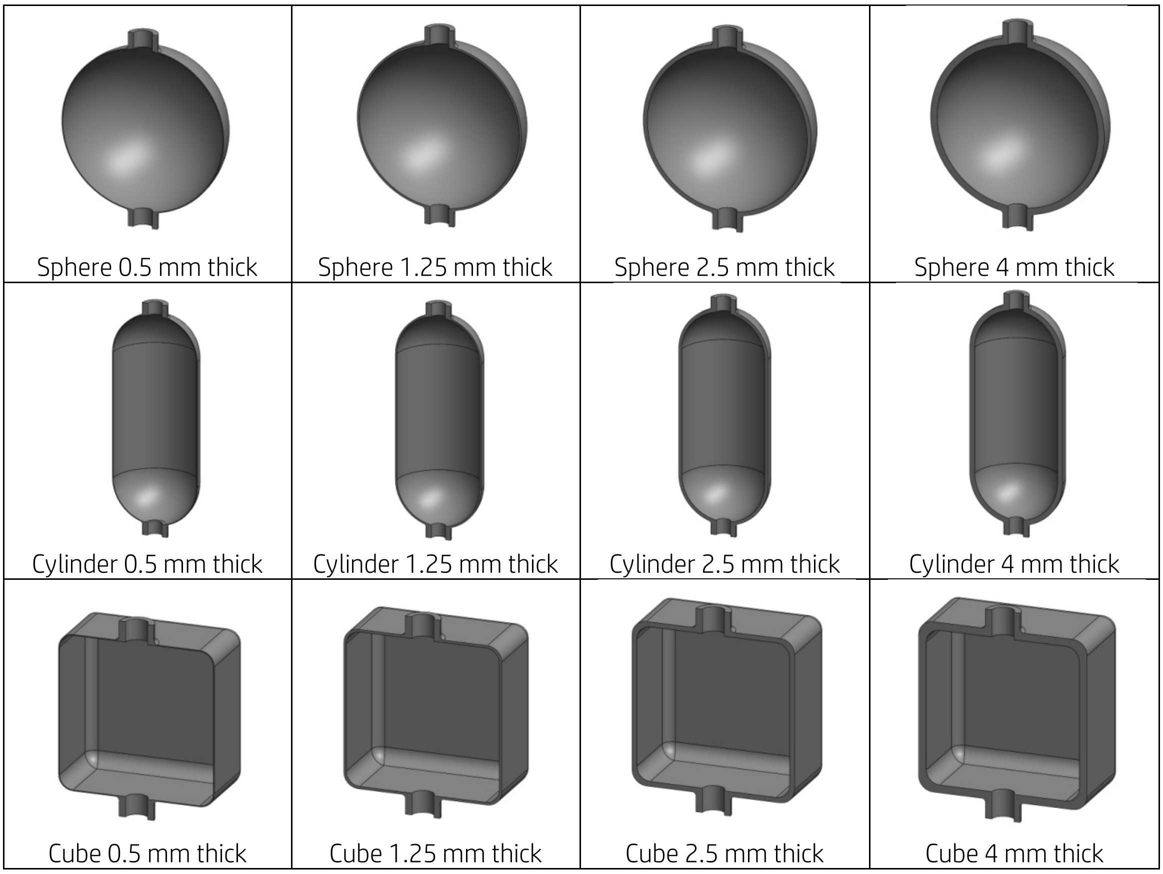


Figure 1. CAD model of the test specimens, with the different wall thicknesses

Equipment

The following images show the components used and their assembly in order to test the specimens under pressure, and avoid leakage of the connectors:

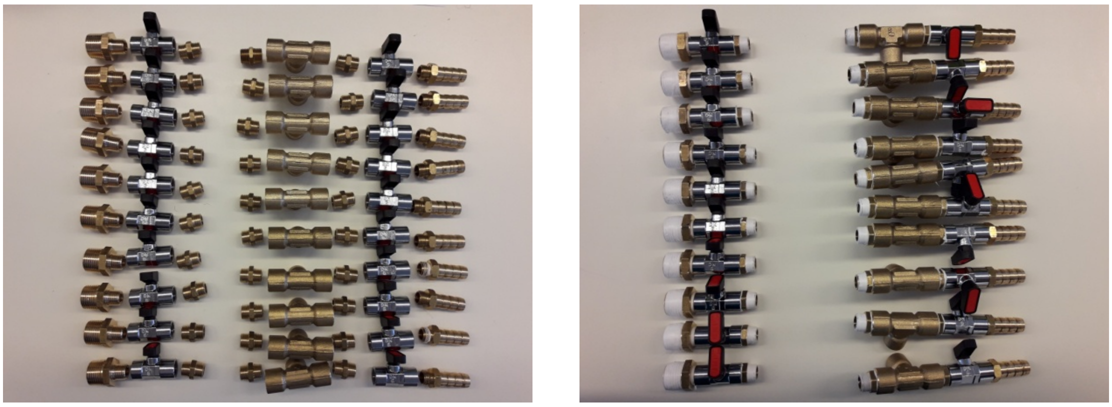


Figure 2. Connectors used for the tightness tests

A mechanical pressure instrument (pressure gauge) is used to measure the pressure on each specimen in line and control the pressure loss on the inside.

A testing pump for the pressure testing of fluid lines and containers is used in order to pump water into the test specimens and reach the desired pressure.

Figure 3. Left: pressure gauge.

Figure 4. Example of an assembled specimen ready to be tested

Test setup

Specimens are initially purged with water in order to extract the air completely from the interior. Then the outlet valve is closed, and pressure is increased with the pump. When the desired pressure is reached, the inlet valve is closed and the specimen is isolated during the duration of the test.

Figure 5. Procedure and setup of the test and the specimens

Tests performed

The first set of experiments executed corresponds to tests of the DoE, showed in the following table:

Test	Fluid	Shape	Pressure [bar]	Wall thickness [mm]	Temperature [°C]	Experiment ID
Leakage	water	1	3	1.25	25	51
Leakage	water	2	3	1.25	25	52
Leakage	water	3	3	1.25	25	53
Leakage	water	1	3	2.5	25	54
Leakage	water	2	3	2.5	25	55
Leakage	water	3	3	2.5	25	56
Leakage	water	1	3	4	25	57
Leakage	water	2	3	4	25	58
Leakage	water	3	3	4	25	59
Leakage	water	1	10	1.25	25	60
Leakage	water	2	10	1.25	25	61
Leakage	water	3	10	1.25	25	62
Leakage	water	1	10	2.5	25	63
Leakage	water	2	10	2.5	25	64
Leakage	water	3	10	2.5	25	65
Leakage	water	1	10	4	25	66
Leakage	water	2	10	4	25	67
Leakage	water	3	10	4	25	68
Leakage	water	1	20	1.25	25	69
Leakage	water	2	20	1.25	25	70
Leakage	water	3	20	1.25	25	71
Leakage	water	1	20	2.5	25	72
Leakage	water	2	20	2.5	25	73
Leakage	water	3	20	2.5	25	74
Leakage	water	1	20	4	25	75
Leakage	water	2	20	4	25	76
Leakage	water	3	20	4	25	77

Table 2. Experiments executed on this first delivery