RTP 103.014/FFI/1.2.2/TR/103/Overview of the Norwegian testing

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8) ABSTRACT

This document is generated in Work Element 1.2.2 and forms a part of the Norwegian contribution to WEAO project Europa 103.014 ”Lightweight low cost carbon fibre composite materials and structures for Armoured Fighting Vehicle Platforms - CAFV”. Material testing will be conducted in WP2 and WP3 in order to select the best materials for use when building and testing the Application Case (AC) in WP6.
For testing at sample/panel level (WP 2 and WP3) this document identifies available test methods and testing facilities within the Norwegian consortium and indicates the associated cost.
The document identifies tests and outlines test procedures for testing of the Norwegian application case (AC) in WP6. It provides an overview of the available testing facilities and estimates of the associated cost for each test.
WP2 will consist of a screening phase followed by testing of material properties, impact testing and test of joining methods. The screening phase is included in order to limit the number of materials in the complete test program.
The material test program should establish properties such as; ultimate in plane strength in tension, compression and shear for the main types of reinforcement and resins. In addition the out of plane strength parameters such as ILSS and tensile strength in flat wise plane should be verified.
WP3 consist of ballistic testing and will be conducted according to Annex C of STANAG 4569.
The testing of the AC within WP6 will be divided into laboratory testing and field testing. In addition to the panels that will be mounted onto the vehicle platform, test panels will be prepared and tested separately.

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1 BACKGROUND

WEAO project Europa 103.014 ”Lightweight low cost carbon fibre composite materials and structures for Armoured Fighting Vehicle Platforms - CAFV” is a Government supported project between industry in United Kingdom, Italy, Denmark, Norway, France and the Netherlands. In order to participate in the project, a Norwegian consortium consisting of Kværner Eureka AS, FIRECO and FFI was formed. Kværner Eureka AS did withdraw from the project in November 2005.

The Norwegian participation in this project is motivated from the desire to develop a competent Norwegian supplier of lightweight armoured military vehicles using state of the art materials technology.

The Norwegian army has well over 1000 Bv206 all terrain vehicles, see Picture 1.1. These have no ballistic protection and cannot be used in situations where an armed assault is probable. With the downsizing of the Norwegian armed forces, a number of these vehicles will be obsolete and are therefore relatively easy to obtain for development purposes.

In agreement with NDLO/Materiel division, it was decided that an armoured version of the Bv206 front vehicle should form the basis of the Norwegian application case. Ballistic protection of the vehicle is to be achieved by replacing the existing glass fibre reinforced plastic (GFRP) hulls of the front and rear car with new carbon fibre reinforced plastic (CFRP) hull that allows for the incorporation of ballistic protection.

The army’s strong interest for a protected version of the Bv206, for use in national and international operations, was the main reason for choosing the Bv206 as the Norwegian application case (NOAC).

Picture 1.1 BV 206 all terrain vehicle

2 SCOPE

This document identifies tests and outlines test procedures for testing of the Norwegian application case (AC) in WP6. It provides an overview of the available testing facilities and estimates of the associated cost for each test.
For testing at sample/panel level (WP 2 and WP3) this document identifies available test methods and testing facilities within the Norwegian consortium and indicates the associated cost.
Detailed determination of the scope of testing at sample/panel level within WP2 and WP3 was depending on the materials selection process, and hence determined at a later stage in the project.
This document has been a living document throughout the project. Therefore it has been updated several times. This final version should describe the basics of the Norwegian testing. For all details it is referred to the individual test reports in the different WP's.

3 MATERIALS TESTING (WP2)

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3.1 Introduction

There is generally a strong need to control the raw materials for FRP products, since the suppliers of e.g. fibre reinforcements are numerous, and the quality of the different products are widespread (size, tex, fibre type, etc.) The same goes for the resins to be used, and the compatibility between the fibres and the resin is of major importance.
Strict control and full traceability on all raw materials to be used is essential for the final material quality. For reinforcement to be qualified and used, the same traceability and conformity of ingoing raw materials must be ensured. All possible changes to reinforcement specification after qualification according to this program, including raw materials like numbers of filament (k)/tex, type and sizing are subject to re-qualification of the material for production. Detailed evaluation of the fabrics, including visual appearance, process specification for the reinforcement and other parameters is subject to qualification, and must be controlled. Data sheets for all raw materials including resins and adhesives shall be delivered with each batch no. and shipment. The purchase orders for any materials used in the qualification test and production has to reflect these requirements.
Equally important is the control of the manufacturer and manufacturing process, since the FRP building material is made in the workshop during construction of the structure. A material qualification program may therefore be divided into two main parts, with a number of interacting relations:

- Qualification of raw materials and material suppliers
- Qualification of process and fabricator

The reason for the interaction between the two parts is that the function of different raw materials in the production process may very well greatly influence the final material parameters. Hence, the qualification of raw materials must be closely related to the chosen manufacturing process and vice versa. Using the qualified raw materials and manufacturing procedures for production, a test program for establishing material properties for design shall be performed.

The purpose of the test program is not to fully test all possible material combinations found in the structure, but rather to determine basic material data (UD ply data) for laminates, and to document the feasibility of this data for characterisation of a range of laminates.

This philosophy will give larger possibility of improvement and optimisation of the different parts and structures in the FRP sandwich structure, based on detailed direct analyses. However, it must be emphasized that the raw materials going into the different reinforcement types must be kept at a consistent quality. It is not necessary to use only one type of fibre in all reinforcements, but the quality and performance of the fibre types to be qualified must be consistent. All fibre types to be used in the range of reinforcements, as well as process data for making the reinforcement must be fixed during the qualification period.

The method to obtain actual UD ply data is to “back calculate” these from testing of various laminates made up of the basic reinforcement types to be used in the actual design. Per definition, the strongest layer in all tested laminates will contribute most to the ultimate measured load capacity for each laminate. This layer will have significantly different stress conditions in each laminate depending on the orientation of surrounding plies. Therefore, the ultimate load carrying capacity of this layer will vary due to various combined stress states for the actual ply.

The Tsai-Wu criterion and the described test methods have been used for qualification of raw materials and to establish material parameters for several projects including both the Oksøy and Skjold marine projects in Norway. The documented experience with this methodology has proven to be very good. Some more details and background information is given in Appendix A.

3.1.1 Failure criteria

The design philosophy incorporates important aspects of a combined stress state failure criterion, and for the Norwegian consortium it is chosen to use the Tsai-Wu failure criterion. A failure criterion proven to give conservative and consistent results for failure prediction must be used for the determination of UD data based on the laminate tests. The Tsai-Wu based stress criterion for Skjold and Oksøy class vessel is verified through the material test program where the laminates are fabricated at the production site. The Tsai-Wu failure criteria is described in Appendix B.

3.2 Mechanical test methods

3.2.1 General

In this document only the test program for the FRP laminates are addressed. The testing of core materials, adhesives and fillers, which are part of the sandwich construction, are not specified here. The reason for this is that the core manufacturer, which has qualified, characterised and tested their products, mainly covers this.

It is essential to establish relevant test data for FRP laminates to be able to use test results in actual design of a large structure. Due to the nature of composite materials, it is always necessary to make qualified evaluation of the test results, bearing in mind the important aspects that will determine the strength of the final design.

A very important aspect when testing composite materials, is to address the possible errors in interpretation of in-plane strength properties obtained from FRP test standards. While the test standards specify how to determine ultimate stress values based on force divided by measured thickness and width of each specimen, the designer should concentrate on finding the correct parameter for strength evaluation of the structure to be produced (ultimate force). The variation in thickness is generally caused by variation in resin content and inaccuracy in measuring techniques, and will have no significant effect on the in-plane strength properties of the laminate when the amount of fibre is constant.

Taking into account that almost all the strength parameters of a laminate are fibre dominated, and the fact that the amount of reinforcement in the specimen is constant, this thickness variation should not be included in the result evaluation. The above is valid for in-plane strength of laminates, hence directly applicable to sandwich constructions. When considering single skin constructions, the thickness of the laminate can of course be an important parameter, defining local buckling strength, bending strength etc.

In the following, a complete test program aiming to establish FRP laminate material parameters is described. The material data and the test program are specifically oriented towards establishing the necessary design data for FRP laminates, and in some cases, accuracy and strictly scientific approach may be replaced by simplifications and a conservative methodology.

The results from material testing shall be used for verification of chosen design criterion, accounting for combined stress effects.

Test methods and standards for laminates and sandwich construction are included.

3.2.2 Standard coupon test methods for laminates and sandwich beams

All the below referenced coupon test standards and test methods are suitable for determining comparative results for preliminary testing and qualification of materials. In addition, any recognised international standard found suitable by the testing institution might be used to present additional or comparable data. In general, all stiffness or Young's modulus data may be derived from coupon testing, as well as the through thickness strength parameters and the matrix dominated laminate properties. For the fibre dominated in-plane strength parameters of laminates, it is somewhat more complicated to obtain correct values using normal coupon

testing. However, the results generated by coupon tensile testing are normally OK, although conservative. For the compression in-plane properties, a specially developed method with 4-point bending of sandwich panel strips is recommended, see section 3.2.3.
The total extent of the test program (number of tests) is a result of the number of resins and reinforcement types to be evaluated. The choice of construction method, single skin or sandwich, will also determine the number of tests needed.
Test standards that are to be used in this project are given in Table 3.1:

Table 3.1 Test standards

ASTM C 297	Tensile strength of flat sandwich constructions in flat wise plane
ASTM C 393	Flexural properties of flat sandwich constructions (beam)
ASTM D 790	Flexural properties of unreinforced and reinforced plastics and electrical insulating materials
ASTM D 2344	Apparent inter laminar Shear strength of reinforced plastics by short beam method
ASTM D 3039	Tensile properties of fibre-resin composites
ASTM D 3410	ITRII compression test, Procedure B
ASTM D 3518	In-plane Shear Stress-Strain response of Unidirectional polymer matrix composites

General report and documentation requirements to in-plane testing of laminate properties
Test reports should always be according to requirements presented in the test standard, but not limited to this. If not covered/specified by the test standard, the following results should always be presented for each tested specimen, traceable to each individual specimen:

- Measured coupon dimensions (width and thickness)
- Fibre content from panel where coupons where taken
- Maximum force
- Maximum force/width
- Stress/strain curves, or load/displacement curves whatever possible/applicable
- Failure mode and evaluation of validity of results

3.2.2.1 Cutting of test specimens/samples

When preparing test specimens/samples, the edges have to be clean cut with no fuss or unevenness. This will help limiting the edge effect. All single skin samples in the test program are cut with a calibrated water jet cutting equipment, and all sandwich panels are cut with circular saw with a diamond coated saw blade.
Sandwich panels are wearing down the saw blades fast, and the quality of cutting must be assessed prior of cutting any test sample series.

3.2.3 In plane strength tests, 4-point bending of sandwich panels

The 4-point bending test performed is based on a modified ASTM C 393 test standard. When not specified in the text below, dimensions and test arrangements may be guided according to the recommendations given in the ASTM C 393. The specification of the test samples is described in Table 3.15. The test setup is shown in Picture 3.1.

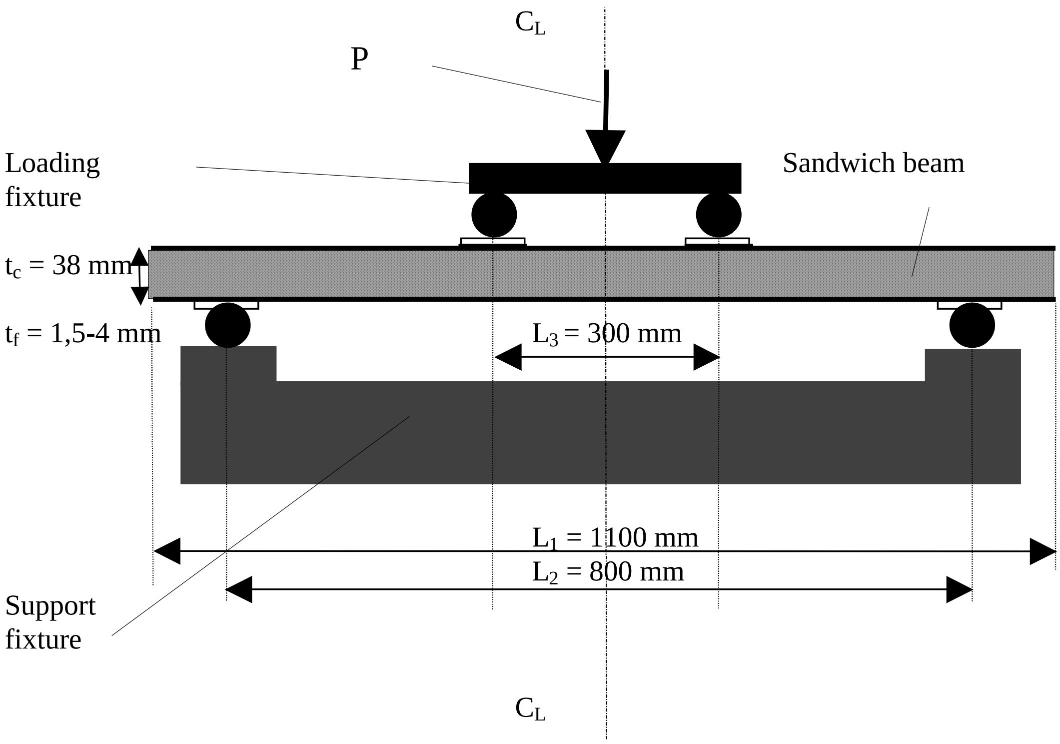


Figure 3.1 Test arrangement, 4 point bending test of sandwich panel stripes

Primer and reinforcement layers above is to be laminated or VARI on both sides of the core according to panel production procedures. Panels to be fabricated, and then specimens of 100 mm width and 1100-1200 mm length are to be cut from these panels for testing.
Be sure to always include a CSM layer towards the core, since this is a very important factor for keeping stable processing quality and mechanical properties on produced laminate to core interface.

Specimen lay–up:

Core material:	tc = 38 mm thick Divinycell HCP 90 core
Core primer:	approx. 200-250 g/m^2 for VE resins: Rubber toughened VE. For epoxy resins, priming is not required
Faces	1 layer of 100 g/m2 CSM mat towards primed surface of core. No. of layers of reinforcement to be tested, e.g. 4 layers [0˚/90˚] with area weight ~ 400-450 g/m2.

Picture 3.1 Test setup for ASTM C-393 4-point bending of sandwich beam

3.2.3.1 Data to be recorded during 4P-bending test of sandwich panel:

Specimen dimensions:

- Width in mm (nominal value 100 mm)
- L2 and L3 according to Figure 3.1 (nominal value 800 and 300 mm, respectively)
- Total sandwich panel thickness in mm
- Core thickness in mm (preferably control measurements prior to panel fabrication)

Results:

- Force and displacement curves, as well as maximum values from test of each specimen
- Failure mode and evaluation of validity of results shall be included in test report.

A test of 100 mm wide specimens of pure core is needed to establish a force displacement curve for the core without any laminate. This force displacement curve is used to subtract the contribution from the core to the measured total force during testing. The total force minus the core contribution is used to calculate the capacity of the laminate based on standard simplified sandwich theory, or the formulas/procedures described in the ASTM C 393. The only difference from the standard is that the load contribution from the core bending is subtracted prior to calculation of the laminate capacity, described in section 3.2.3.2.
The 4-point bending test using sandwich panel strips as specified in section 3.2.3 has shown great stability and low scatter in results. The test method also includes the important cooperation and compatibility between core and laminate in a realistic structure. These extremely important parameters for skin buckling (compression side) and or debonding are important for qualification of materials, as well as procedures and personnel.

This test type is therefore essential to provide information about the core material tested in a realistic manner in the actual environment. Prior to this, the manufacturer should qualify core material suppliers by investigating data sheets and do some sample raw material testing of core in house or require the supplier to deliver data. The real qualification will however always be depending on compatibility with the other constituents of the sandwich.

3.2.3.2 Subtraction of core contribution in 4-point bending test of sandwich:

A test of 100 mm wide specimens of pure core is used to establish a force displacement curve for the core without any laminate. This force displacement curve is used to subtract the contribution from the core to the measured total force during testing. The non-linear response of the core is modelled as a stepwise linear response as shown in Figure 3.2. As can be readily seen from the figure, the accuracy is quite high, even with such a simple definition. In addition, the difference in shear deflection of a sandwich panel strip compared to the pure core specimens will result in a conservative "force contribution" subtracted from the total force measured for calculation of skin laminate strength.

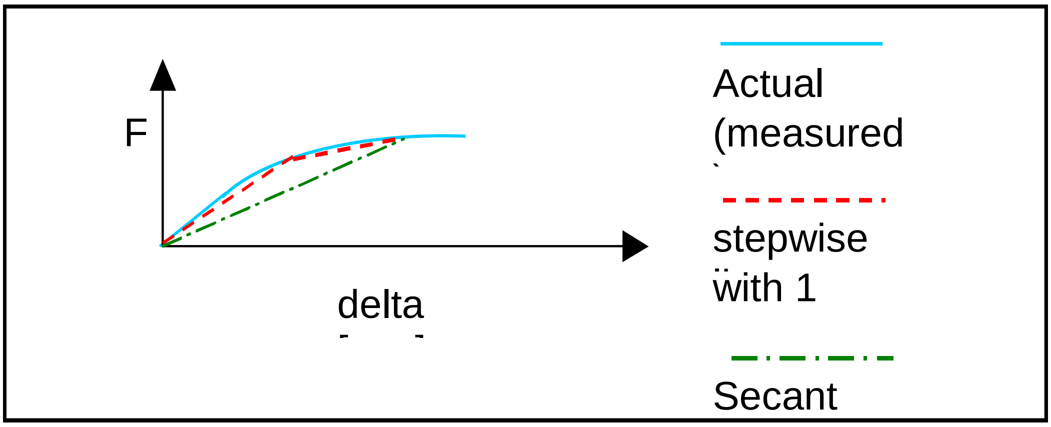


Figure 3.2 Force deflection characteristics used in 4-P bending test.

3.3 Tests for material screening

In the phase of material selection, different material combinations (fibre/resin) and process parameters are going to be assessed to identify their potentials. In order to keep the testing cost at a reasonable level, a few specific test standards are used in order to differentiate the properties of the alternative materials in the down selection phase. Three screening phases are planed in order to evaluate the matrix and fibre combinations:

- Screening phase 1A, described in section 3.3.1
- Screening phase 1B, described in section 3.3.2
- Screening phase 2/Material characterisation, described in section 3.3.3.

The specification of all test laminates is included in the mechanical test report RTP103.014/FFI/2.1.2/TR/1/ -CAFV Results of mechanical testing" (1).

3.3.1 Screening phase 1A (Sp1A)

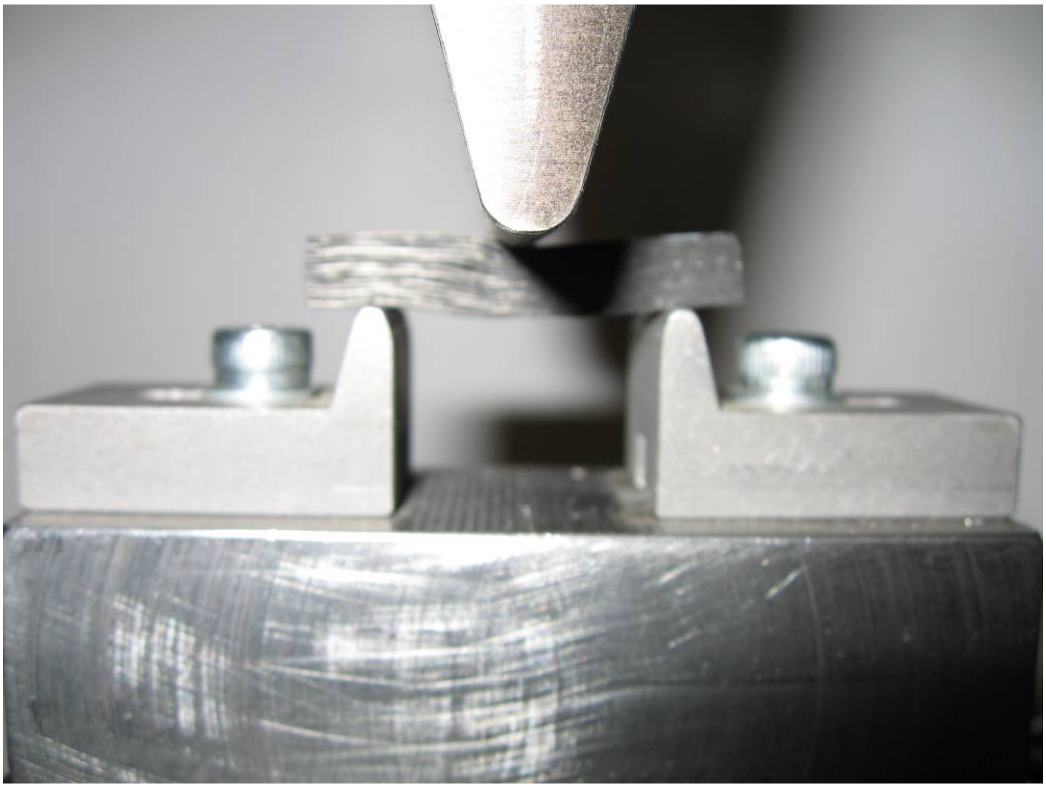
For the assessment of the compatibility of the matrix and the resin, the Inter Laminar Shear Strength (ILSS) based on ASTM D 2344 is used. Good compatibility represented by good values, indicates that the fibre/matrix have some potential with respect to compressive properties. All laminates are to be manufactured, post cured and tested identically. The resin down selection is ending up with 2 epoxy and 1 vinyl ester resin systems. The test program for screening phase 1A is shown in Table 3.2, where to determine matrix dominating properties, see Table 3.3. The single skin flexural test based on ASTM D 790 is used to determine fiber-dominated properties, see Table 3.4. The test setup for ASTM D 2344 is shown in Picture 3.2, and the test setup for ASTM D 790 is shown in Picture 3.3.

Table 3.2 Test program for screening phase 1A

			ILSS			Single skin		
						Flexural		
			ASTM D 2344			ASTM D 790, m.2		
Laminat	Screening Phase		Orientation	Thickness	Parallell	orientation	Thickness	Parallell
ID			+45	(mm)	No.	+45	(mm)	No.
	Screeningphase 1A							
	SP Systems Prime 27 / Prime 20 Slow							
1	Ep1 - Vf1 - 50C - 60 - +45 - D		1	3	6	1	3	5
2	Ep1 - Vf1 - 50C-tmp - 60 - +45 - D		1	3	6	1	3	5
3	Ep1 - Vf1 - 5631 - 60 - +45 - S		1	3	6	1	3	5
	Huntsman LY 3505 / Aradur 3403							
4	Ep2 - Vf1 - 50C - 60 - +45 - D		1	3	6	1	3	5
5	Ep2 - Vf1 - 5631 - 60 - +45 - S		1	3	6	1	3	5
	Huntsman LY 3297 / Aradur 3298							
6	Ep3 - Vf1 - 50C - 60 - +45 - D		1	3	6	1	3	5
7	Ep3 - Vf1 - 50C-tmp - 60 - +45 - D		1	3	6	1	3	5
8	Ep3 - Vf1 - 5631 - 60 - +45 - S		1	3	6	1	3	5
	Huntsman LY 5052 / Aradur 5052							
9	Ep4 - Vf1 - 50C - 60 - +45 - D		1	3	6	1	3	5
10	Ep4 - Vf1 - 5631 - 60 - +45 - S		1	3	6	1	3	5
	Reichhold DION 9500-501							
11	VE1 - Vf1 - FOE - 60 - +45 - D		1	3	6	1	3	5
12	VE1 - Vf1 - FOE - 60 - +45 - S		1	3	6	1	3	5
	Reichhold DION 9102							
13	VE2 - Vf1 - FOE - 60 - +45 - D		1	3	6	1	3	5
14	VE2 - Vf1 - FOE - 60 - +45 - S		1	3	6	1	3	5

Table 3.3 ASTM D 2344 - Interlaminar shear strength (ILSS) (Sp1A)

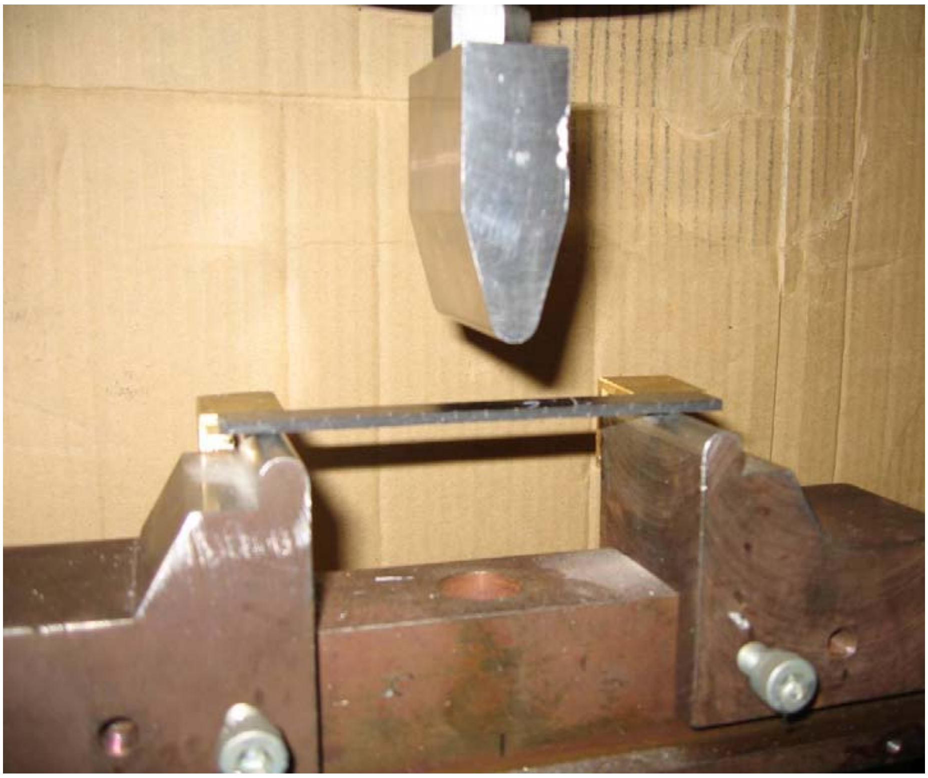
ASTM D 2344 Test specification	ASTM D 2344 Sample specification
Test standard: ASTM D 2344 Test type: Short beam shear test No. of parallels = 6 pcs Test in fiber direction Nose rad. = 3 mm Support rad. = 1.5 mm Support span = 12 mm Testing rate: 1 mm/min.	Panel with 6 layers of ± 45º reinforcement Samples cut in fibre direction Thickness = ~ 3 mm Length = 30 mm Width = 7 mm
ASTM D 2344 Results	ASTM D 2344 Deviation from standard
Force vs. displacement curve and failure mode. Curve is used for calculation of *short beam strength*.	Width is rounded upwards to 7 mm Length is increased to 30 mm, based on trial testing



Picture 3.2 ASTM D 2344 - Test setup.

Table 3.4 ASTM D 790 - Flexural properties (Sp1A)

ASTM D 790 Test specification	ASTM D 790 Sample specification
Test standard: ASTM D 790, procedure B Test type: Single skin flexural No. of parallels = 5 pcs Test in both fiber directions Nose rad. = 5 mm Support rad. = 5 mm Support span = 96 mm Testing rate: 50 mm/min.	Panel with 6 layers of ± 45° reinforcement Samples cut in both fiber directions Thickness = ~ 3 mm Length = 120 mm Width = 12,7 mm
ASTM D 790 Results	**ASTM D 790 Deviation from standard**
Force vs. displacement curve and failure mode. Curve is used for calculation of *maximum stress*, *flexural strain* and *tangent modulus of elasticity*.	



Picture 3.3 ASTM D 790 - Test setup.

3.3.2 Screening phase 1B (Sp1B)

For the assessment of fibre/fabric capabilities in compression, a 4-point bending test based on sandwich construction is used. All laminates are to be manufactured, post cured and tested identically. This screening phase is to result in a fabric/fibre down selection, ending up with 3 different material systems. The test program for screening phase 1B is shown in Table 3.5, but the laminates cannot be defined before the end of Screening Phase 1A. The 4-point bending test of sandwich laminate based on ASTM C 393 is to determine fibre dominated properties with respect to compression properties, see Table 3.6.

Table 3.5 Test program for screening phase 1B

			4-point bending sandwich 4PB Mod. ASTM C 393		
Laminat ID	Screening Phase		Orientation + 45	Thickness (mm)	Parallell No.
	Screeningphase 1B				
	SP Systems Prime 27 / Prime 20 Slow				
15	Ep1 - Vf1 - 50C - 60 - +-45 - D		1	1/38/1	5
16	Ep1 - Vf1 - 5631 - 60 - +-45 - S		1	1/38/1	5
	Huntsman LY 3505/Aradur 3403				
17	Ep2 - Vf1 - 50C - 60 - +-45 - D		1	1/38/1	5
18	Ep2 - Vf1 - 5631 - 60 - +-45 - S		1	1/38/1	5
	Reichhold DION 9500-501				
19	VE1 - Vf1 - FOE - 60 - +-45 - D		1	1/38/1	5
20	VE1 - Vf1 - FOE - 60 - +-45 - S		1	1/38/1	5

Table 3.6 Modified ASTM D 393 – 4-point bending (Sp1B)

ASTM D 393 Test specification	ASTM D 393 Sample specification
Test standard: modified ASTM D 393 Test type: Sandwich flexural No. of parallels = 5 pcs Test in fiber direction Nose rad. = 50 mm* Nose span = 300 mm Support rad. = 50 mm* Support span = 800 mm Testing rate: 100 mm/min. * Padding against nose and support of 2 mm steel and 2mm textile reinforced rubber	Laminates with 2 layers of ± 45° reinforcement. Sample cut in fiber direction Thickness skins = ~ 1 mm Thickness core = 38 mm Length = 1100 mm Width = 100 mm
ASTM D 393 Results	**ASTM D 393 Deviation from standard**
Force vs. displacement curve and failure mode.	

3.3.2.1 Core materials

All core materials to be used with Vinyl ester resins, have to be primed in order to close the surface. This action assures an adequate bond of the laminate to the core surface, as well as reducing the risk for resin absorption from the core during lamination, which will increase the resin consumption. Priming with epoxy resins is not necessary, as there is no styrene in the resin that may deteriorate the core material.

Balsa Core
When Balsa is specified only end grain qualities shall by applied. Further, in order to keep the weight to a minimum, all Balsa qualities shall be pre-treated with a surface sealant by the Balsa-suppliers before shipment. A second pre-treatment shall be performed by the manufacturer prior to use the Balsa in production, reducing the risk of filling the core with resin. This double pre-treatment process will ensure that the transversal channels in the end grain Balsa wood are closed with respect to resin absorption during wet lay-up, and especially for vacuum assisted resin infusion. Without this pre-treatment by closing the balsa cells, the core material will absorb considerable amount of resin, which results in unnecessary heavy sandwich panels.

3.3.3 Screening phase 2 (Sp2)/Material characterization

In order to assess the effect on material properties of varying production parameters such as fibre volume fraction and cure cycle, tests are to be performed based on materials from Sp1B. This screening phase is to result in 2 to 3 resin/fibre systems with defined processing parameters. The test program for screening phase 2 is shown in Table 3.7, Table 3.8 and Table 3.9.

Table 3.7 Test program for screening phase 2/ material characterization, Part 1

			ILSS			Single skin Flexural			Through thickness tensile strength		
			ASTM D 2344			ASTM D 790, m.2			ASTM C 297		
Laminat ID	Screening Phase		Orientation +45	Thickness (mm)	Parallell No.	orientation +45	Thickness (mm)	Parallell No.	No. Of tests	Thickness (mm)	Parallell No.
	Screeningphase 2/Characterization	Comment									
	SP Systems Prime 27 / Prime 20 Slow										
21	Ep1 - Vf1 - 50C - 60 - +-45 - D	60 degree cure	1	6,07	6				1	6,07	5
22	Ep1 - Vf1 - 50C - 60 - +-45 - D	60 degree cure									
23	Ep1 - Vf1 - 50C - 80Ep1 - +-45 - D	80 degree cure				1	3	5			
24	Ep1 - Vf1 - 50C - 80Ep1 - +-45 - D	80 degree cure	1	6,07	6				1	6,07	5
25	Ep1 - Vf1 - 50C - 80Ep1 - +-45 - D	80 degree cure									
	Huntsman LY 3505 / Aradur 3403										
26	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure	1	6,07	6				1	6,07	5
27	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure									
27-2	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure									
27-3	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure									
28	Ep2 - Vf1 - 5631 - 80Ep2 - +-45 - S	80 degree cure				1	3	5			
29	Ep2 - Vf1 - 5631 - 80Ep2 - +-45 - S	80 degree cure	1	6,07	6				1	6,07	5
30	Ep2 - Vf1 - 5631 - 80Ep2 - +-45 - S	80 degree cure									
	Reichhold DION 9500-501										
31	VE1 - Vf1 - FOE - 60 - +-45 - D	60 degree cure	1	6,07	6				1	6,07	5
32	VE1 - Vf1 - FOE - 60 - +-45 - D	60 degree cure									
32-2	VE1 - Vf1 - FOE - 60 - +-45 - S	60 degree cure									
33	VE1 - Vf1 - FOE - 80Vz - +-45 - D	80 degree cure				1	3	5			
34	VE1 - Vf1 - FOE - 80Vz - +-45 - D	80 degree cure	1	6,07	6				1	6,07	5
35	VE1 - Vf1 - FOE - 80Vz - +-45 - D	80 degree cure									
36	VE1 - Vf1 - FOE - RT120 - +-45 - D	Room tmp curing				1	3	5			
37	VE1 - Vf1 - FOE - RT120 - +-45 - D	Room tmp curing	1	6,07	6				1	6,07	5
38	VE1 - Vf1 - FOE - RT60 - +-45 - D	Room tmp curing				1	3	5			
39	VE1 - Vf1 - FOE - RT60 - +-45 - D	Room tmp curing	1	6,07	6				1	6,07	5
	Specialities										
40	Ep84 - Vf84 - TBD - 80Ep84 - 0/90 - SP	Prepreg									
42	Ep2 - Vf3 - 5631 - 60 - +-45 - S	Vacuum 0,1 vs Vf%				1	3	5			

Resin system/cured density

Ep1 = SP Systems Prime 27 / 1139 kg/m3
Ep2 = Huntsman LY 3505/Aradure 3403 = ESR3 / ESH3 / 1116 kg/m3
Ep3 = Huntsman LY 3297/Aradur 3298 / 1020 kg/m3
Ep4 = Huntsman LY 5052/Aradur 5052 / 1096 kg/m3
Ve1 = Reichhold DION 9500 / 1120 kg/m3
Ve2 = Reichhold DION 9102 / 1110 kg/m3

Cure cycles:

60 = Cured at 60 deg for 16 houres
Prior to 80 deg cure, geletion is done at 40 deg C for 16 h
80Ep1 = Cured at 80 deg for 16h
80Ep2 = Cured at 80 deg for 16h
80Vz = Cured at 80 deg for 16h
RT60 = 60 days at ambiant temperature
RT120 = 120 days at ambiant temperature

Fibre volume fraction:

Trial	Vf1 = 50 % (Wt.% = 61) vacuum 0,7
SP2	Vf1 = 50 % (Wt.% = 61) vacuum 0,7 / 0,3
SP2	Vf3 = vacuum level 0,7 / 0,1

Carbon fiber size type:

50C-temp = Tempering of T-700 with 1% sizing for epoxy resin prior to lamination
50C = T-700 with 1% sizing for epoxy resin
FOE = T-700 with 0,5% sizing for Vinyl ester resin
5631 = UTS with 1% sizing for epoxy resin

Table 3.8 Test program for screening phase 2/ material characterization, Part 2

			In plane tensile strength ASTM D 3039			4-point bending sandwich 4PB Mod. ASTM C 393		
Laminat ID	**Screening Phase**		**Orientation** + 45	**Thickness** (mm)	**Parallell** No.	**Orientation** + 45	**Thickness** (mm)	**Parallell** No.
	Screeningphase 2/Characterization	**Comment**						
	SP Systems Prime 27 / Prime 20 Slow							
21	Ep1 - Vf1 - 50C - 60 - +-45 - D	60 degree cure						
22	Ep1 - Vf1 - 50C - 60 - +-45 - D	60 degree cure				1	1.8/38/1.8	5
23	Ep1 - Vf1 - 50C - 80Ep1 - +-45 - D	80 degree cure	1	3	5			
24	Ep1 - Vf1 - 50C - 80Ep1 - +-45 - D	80 degree cure						
25	Ep1 - Vf1 - 50C - 80Ep1 - +-45 - D	80 degree cure				1	1.8/38/1.8	5
	Huntsman LY 3505 / Aradur 3403							
26	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure						
27	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure				1	1.8/38/1.8	5
27-2	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure				1	1.8/38/1.8	5
27-3	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure				1	1.8/38/1.8	5
28	Ep2 - Vf1 - 5631 - 80Ep2 - +-45 - S	80 degree cure	1	3	5			
29	Ep2 - Vf1 - 5631 - 80Ep2 - +-45 - S	80 degree cure						
30	Ep2 - Vf1 - 5631 - 80Ep2 - +-45 - S	80 degree cure				1	1.8/38/1.8	5
	Reichhold DION 9500-501							
31	VE1 - Vf1 - FOE - 60 - +-45 - D	60 degree cure						
32	VE1 - Vf1 - FOE - 60 - +-45 - D	60 degree cure				1	1.8/38/1.8	5
32-2	VE1 - Vf1 - FOE - 60 - +-45 - S	60 degree cure				1	1.8/38/1.8	5
33	VE1 - Vf1 - FOE - 80Vz - +-45 - D	80 degree cure	1	3	5			
34	VE1 - Vf1 - FOE - 80Vz - +-45 - D	80 degree cure						
35	VE1 - Vf1 - FOE - 80Vz - +-45 - D	80 degree cure				1	1.8/38/1.8	5
36	VE1 - Vf1 - FOE - RT120 - +-45 - D	Room tmp curing						
37	VE1 - Vf1 - FOE - RT120 - +-45 - D	Room tmp curing						
38	VE1 - Vf1 - FOE - RT60 - +-45 - D	Room tmp curing						
39	VE1 - Vf1 - FOE - RT60 - +-45 - D	Room tmp curing						
	Specialities							
40	Ep84 - Vf84 - TBD - 80Ep84 - 0/90 - SP	Prepreg				1	1.54/38/1.54	5
42	Ep2 - Vf3 - 5631 - 60 - +-45 - S	Vacuum 0,1 vs Vf%						

Resin system/cured density

Ep1 = SP Systems Prime 27 / 1139 kg/m3
Ep2 = Huntsman LY 3505/Aradure 3403 = ESR3 / ESH3 / 1116 kg/m3
Ep3 = Huntsman LY 3297/Aradur 3298 / 1020 kg/m3
Ep4 = Huntsman LY 5052/Aradur 5052 / 1096 kg/m3
Ve1 = Reichhold DION 9500 / 1120 kg/m3
Ve2 = Reichhold DION 9102 / 1110 kg/m3

Fibre volume fraction:

Trial	Vf1 = 50 % (Wt.% = 61) vacuum 0,7
SP2	Vf1 = 50 % (Wt.% = 61) vacuum 0,7 / 0,3
SP2	Vf3 = vacuum level 0,7 / 0,1

Carbon fiber size type:

50C-temp = Tempering of T-700 with 1% sizing for epoxy resin prior to lamination
50C = T-700 with 1% sizing for epoxy resin
FOE = T-700 with 0,5% sizing for Vinyl ester resin
5631 = UTS with 1% sizing for epoxy resin

Core primer:

Huntsman LY3505 / HY2404 - Potlife of 60 min. at 18 deg. C
Reichhold DION 950-501

Table 3.9 Test program for screening phase 2/ material characterization, Part 3

			ITRI compression test			In-plane shear		
			ASTM D 3410, method A			ASTM D 3518		
Laminat ID	Screening Phase		Orient. +45	Thickness (mm)	Parallell No.	Orientation 0	Thickness (mm)	Parallell No.
	Screeningphase 2/Characterization	Comment						
	SP Systems Prime 27 / Prime 20 Slow							
21	Ep1 - Vf1 - 50C - 60 - +-45 - D	60 degree cure						
22	Ep1 - Vf1 - 50C - 60 - +-45 - D	60 degree cure						
23	Ep1 - Vf1 - 50C - 80Ep1 - +-45 - D	80 degree cure	1	3	5	1	3	5
24	Ep1 - Vf1 - 50C - 80Ep1 - +-45 - D	80 degree cure						
25	Ep1 - Vf1 - 50C - 80Ep1 - +-45 - D	80 degree cure						
	Huntsman LY 3505 / Aradur 3403							
26	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure						
27	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure						
27-2	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure						
27-3	Ep2 - Vf1 - 5631 - 60 - +-45 - S	60 degree cure						
28	Ep2 - Vf1 - 5631 - 80Ep2 - +-45 - S	80 degree cure	1	3	5	1	3	5
29	Ep2 - Vf1 - 5631 - 80Ep2 - +-45 - S	80 degree cure						
30	Ep2 - Vf1 - 5631 - 80Ep2 - +-45 - S	80 degree cure						
	Reichhold DION 9500-501							
31	VE1 - Vf1 - FOE - 60 - +-45 - D	60 degree cure						
32	VE1 - Vf1 - FOE - 60 - +-45 - D	60 degree cure						
32-2	VE1 - Vf1 - FOE - 60 - +-45 - S	60 degree cure						
33	VE1 - Vf1 - FOE - 80Vz - +-45 - D	80 degree cure	1	3	5	1	3	5
34	VE1 - Vf1 - FOE - 80Vz - +-45 - D	80 degree cure						
35	VE1 - Vf1 - FOE - 80Vz - +-45 - D	80 degree cure						
36	VE1 - Vf1 - FOE - RT120 - +-45 - D	Room tmp curing						
37	VE1 - Vf1 - FOE - RT120 - +-45 - D	Room tmp curing						
38	VE1 - Vf1 - FOE - RT60 - +-45 - D	Room tmp curing						
39	VE1 - Vf1 - FOE - RT60 - +-45 - D	Room tmp curing						
	Specialities							
40	Ep84 - Vf84 - TBD - 80Ep84 - 0/90 - SP	Prepreg						
42	Ep2 - Vf3 - 5631 - 60 - +-45 - S	Vacuum 0,1 vs Vf%						

Resin system/cured density
Ep1 = SP Systems Prime 27 / 1139 kg/m3
Ep2 = Huntsman LY 3505/Aradure 3403 = ESR3 / ESH3 / 1116 kg/m3
Ep3 = Huntsman LY 3297/Aradur 3298 / 1020 kg/m3
Ep4 = Huntsman LY 5052/Aradur 5052 / 1096 kg/m3
Ve1 = Reichhold DION 9500 / 1120 kg/m3
Ve2 = Reichhold DION 9102 / 1110 kg/m3

Fibre volume fraction:

Trial	Vf1 = 50 % (Wt.% = 61) vacuum 0,7
SP2	Vf1 = 50 % (Wt.% = 61) vacuum 0,7 / 0,3
SP2	Vf3 = vacuum level 0,7 / 0,1

Carbon fiber size type:
50C-temp = Tempering of T-700 with 1% sizing for epoxy resin prior to lamination
50C = T-700 with 1% sizing for epoxy resin
FOE = T-700 with 0,5% sizing for Vinyl ester resin
5631 = UTS with 1% sizing for epoxy resin

Sp2 is using the same tests as performed in Sp1A for comparison purposes, where the Inter Laminar Shear Strength (ILSS) based on ASTM D 2344 is to indicate the fibre to matrix compatibility, see Table 3.3. The single skin flexural test based on ASTM D 790 gives indication of the total quality of the laminates due to the several failure modes that are addressed in, the test is described in Table 3.4. In addition, the through thickness tensile strength test based on ASTM C 297, is used to get an extra base of comparison in order to evaluate the process parameters and the quality of laminate production. The test is described in Table 3.11.

The screening phases described in section 3.3 including Sp1A, Sp1B and Sp2 results in 2 to 3 materials, with its associated process parameters to be checked for production repeatability and quality. The tests are the same as in the previous Screening Phases, with the addition of an in-plane shear test based on ASTM D 3518, shown in Table 3.12 and ASTM D-3410 ITRII-compression test, shown in see Table 3.13.

The test program shall establish ultimate in plane strength in tension, compression and shear for the reinforcements and resins to be used in the construction. In addition, the out-of-plane strength parameters such as ILSS and tensile strength in flat-wise plane shall be verified.
All bi-directional laminates must be tested in both strongest and weakest direction, e.g. in both 45° and 0° direction on a [±45º] oriented laminate. All different fibre types and resin types to be used will make a new laminate, producing a new test series for establishing design data.
The laminate material specification for the next stages is determined by the previous screening phase. The processing parameters of the selected fiber/resin combination, is determined in the completion of Screening Phase 2. The material selection flow is as follow:
Material SOTA → Screening phase 1A → Screening phase 1B → Screening phase 2/Material characterization
Full test specimen array to establish material data and design parameters for the structure built with carbon fibre reinforcements, are defined in Table 3.12 to Table 3.15.
The specification of all test laminates is included in the mechanical test report RTP103.014/FFI/2.1.2/TR/1/ -CAFV Results of mechanical testing" (1).

3.3.4 Coupon test for production quality assessment of laminates

The two tests presented in Table 3.10 and Table 3.11, are mainly performed for production and material quality assessment purposes. The data obtained are not intended to provide any input values for structural analysis. These data must be established at a stable and predictable level prior to start of manufacturing laminates and sandwich panels for further testing (in plane testing).

Table 3.10 Test for in plane shear, laminate quality assessment for one matrix type and production method (Sp2)

ASTM D 2344 Test specification	ASTM D 2344 Sample specification
Test standard: ASTM D 2344 Test type: Short beam shear test No. of parallels = 6 pcs Test in fiber direction Nose rad. = 1.5 mm Support rad. = 3 mm Support span = 24 mm Test rate = 1mm/min.	Panel with 6 layers of ± 45º reinforcement Samples cut in fibre direction Thickness = ~ 6 mm Length = 36 mm Width = 12 mm
ASTM D 2344 Results	**ASTM D 2344 Deviation from standard**
Force vs. displacement curve and failure mode. Curve is used for calculation of *short beam strength*.	

Table 3.11 Test for through thickness, laminate quality assessment for one matrix type and production method (Sp2)

ASTM C 297 Test specification	ASTM C 297 Sample specification
Test standard: modified ASTM C 297 Test type: Single skin through thickness No. of parallels = 6 pcs Test direction = Out of plane Support: = Glued on steel dollies, Ø 25 mm Test rate = 0.5 mm/min	Panels with 12 layers of ± 45° reinforcement Thickness = ~ 6 mm Diameter = Ø25 mm^2
ASTM C 297 Results	ASTM C 297 Deviation from standard
Force vs. displacement curve and failure mode, and *Ultimate flat wise tensile stress.*	Test samples are bonded to a steel plate of minimum 10 mm, with a dolly on top for load application

Laminates provided by Italy and Denmark, based on the selected materials in each country, are included in the ASTM C297 “Through thickness tensile test”. This was agreed in order to provide the project with a broader base for comparison between the different testing method and materials used by the individual countries. Although the values will not give any relevant design data, they will be used in order to rank the materials based on the test results and the failure area assessment.

3.3.5 Coupon test for the determination of in plane properties, material data and design parameters

Initially, additional tests were planed in order to obtain the poisons ratio value. However, due to economical constraints it is decided to include additional parallel testing to assess laminate quality and repeatability. The poisons ratio value for the carbon fibre laminates is assumed, and taken from experience on testing of similar laminates, and is determined to be: ν_{12} = 0,888.

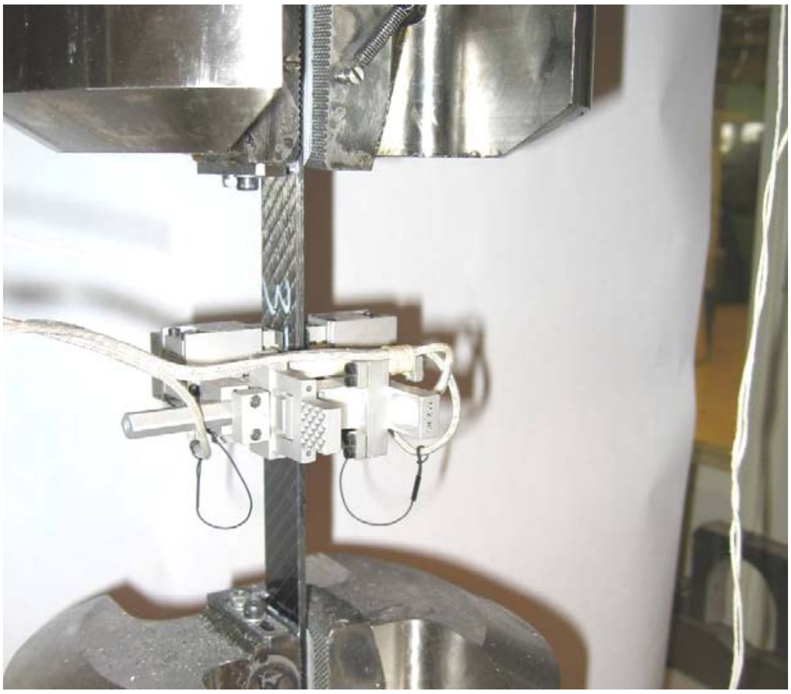
3.3.5.1 ASTM D-3039 for in plane tension

The tensile test and resulting material parameters is presented in Table 3.12 for the ASTM D-3039. The test setup is shown in Picture 3.4.

Table 3.12 Specification of coupon tests for in plane tensile properties, material data and design parameters for one matrix type and production method (Sp2)

ASTM D 3039 Test specification	ASTM D 3039 Sample specification	Input back calculation of UD material parameter (test dir. related to fibre angles/ input)
Test standard: ASTM D 3039 Test type: In-plane tensile test Tabs: To be included No. of parallels = 6 pcs Test in both fiber directions Test rate = 2mm/min	Panel with 6 layers of ± 45º reinforcement Samples cut in fiber direction (ref app C) Thickness = ~ 3 mm Length = 250 mm Width = 25 mm	0º / E1, E2, σ_{tUD90^o}, σ_{tUD0^o} (Poisons ratio of ν12 = 0,888)

ASTM D 3039 Results	ASTM D 3039 Deviation from standard
Stress vs. strain curve and failure mode. Curve is used for calculation of *ultimate tensile stress, ultimate tensile strain* and *E-modulus.*	None



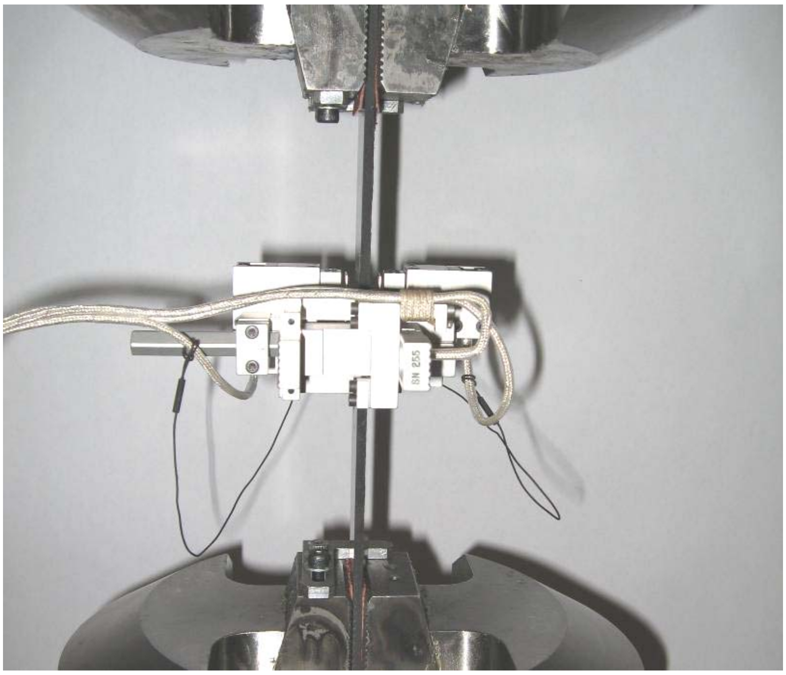
Picture 3.4 ASTM D 3039 - Test setup.

3.3.5.2 ASTM D-3518 for in plane shear

The shear test and resulting material parameters is presented in Table 3.13 for the ASTM D-3518. The test setup is shown in Picture 3.5.

Table 3.13 Specification of coupon tests for in plane shear properties, material data and design parameters for one matrix type and production method (Sp2)

ASTM D 3518 Test specification	ASTM D 3518 Sample specification	Input back calculation of UD material parameter (test dir. related to fibre angles/ input)
Test standard: ASTM D 3518 Test type: In-plane shear test Tabs: No tabs No. of parallels = 5 pcs Test 45º to both fiber directions Test rate = 2mm/min	Panel with 6 layers of ± 45º reinforcement Samples cut 45º to both fiber directions Thickness = ~ 3 mm Length = 250 mm Width = 25 mm	45º / G_{12}, τ_{12} (Poisons ratio of ν12 = 0,888)
ASTM D 3518 Results	ASTM D 3518 Deviation from standard	
Stress vs. strain curve. Curve is used for calculation of *maximum shear stress*, *maximum shear strain* and *shear-modulus.*	Shear strain calculated from longitudinal strain measurement, and an estimated Poisson's number.	



Picture 3.5 ASTM D 3518 - Test setup.

3.3.6 Coupon test for in plane compression strength using ASTM D-3410 (single skin)

The tests and resulting material parameters are presented in Table 3.14.

Table 3.14 Specification of coupon tests for compression properties, material data and design parameters for one matrix type and production method (Sp2)

ASTM D 3410 Test specification	ASTM D 3410 Sample specification	Input back calculation of UD material parameter (test dir. related to fibre angles/ input)
Test standard: ASTM D 3410 – procedure B Test type: In-plane compression test Tabs: Tabs to be used No. of parallels = 5 pcs Test 45º to both fiber directions Test rate = 1,5 mm/min	Panel with 6 layers of ± 45º reinforcement Samples cut in fiber direction Thickness = ~ 3 mm Length = 250 mm Width = 25 mm	0º / σ_{cUD90^o}, σ_{cUD0^o} (Poisons ratio of ν12 = 0,888)
ASTM D 3410 Results	ASTM D 3410 Deviation from standard	
Force vs. displacement curve and failure mode, and *Maximum compression stress.*	None	

3.3.6.1 4-point bending test for in plane compression test using ASTM C-393 (sandwich beam)

The compression test and resulting material parameters is presented in Table 3.15 for ASTM C-393.

Table 3.15 Specification of 4- point bending test on sandwich beam, material data and design parameters for one matrix and production method (Sp2)

ASTM C 393 **Test specification**	**ASTM C 393** **Sample specification**	**Input back calculation of UD material parameter (test dir. related to fibre angles/ input)**
Test standard: mod. ASTM C 393 Test type: Sandwich flexural No. of parallels = 5 pcs Test in both fiber direction Nose rad. = 50 mm* Nose span = 300 mm Support rad. = 50 mm* Support span = 800 mm Test rate = 100 mm/min * Padding against nose and support of 2 mm steel and 2mm textile reinforced rubber	Laminates with 4 layers of ± 45° reinforcement. Samples cut in fiber direction Thickness skins = ~ 2 mm Thickness core = 38 mm Length = 1100 mm Width = 100 mm	0º / σ_{cUD0^o}
ASTM C 393 **Results**	**ASTM C 393** **Deviation from standard**	
Force vs. displacement curve and failure mode, and *Maximum compression stress.*		

All reinforcement types to be used in construction must be tested. Information about core pre-treatment is given in section 3.3.2.1.

3.3.7 Low velocity impact testing

Low velocity impact considers the effect of unidentified objects, considerably smaller than the typical vehicle panel, hitting the vehicles at varying speeds. (Maximum speed of Bv206 fully loaded is 12.5 m/s). Ballistic impact and head-on collisions are thus not considered here. The goal is to assess the damage tolerance of the materials, and to differentiate between different material systems, in order to verify how the final structure, including ballistic add-on panels, will withstand impacts from low velocity or static objects that the vehicle may be exposed to.

Thrown objects:
The threat is supposed to originate at a distance of several meters. Thus thrown objects like stones, metal parts and wood may typically represent the threat.

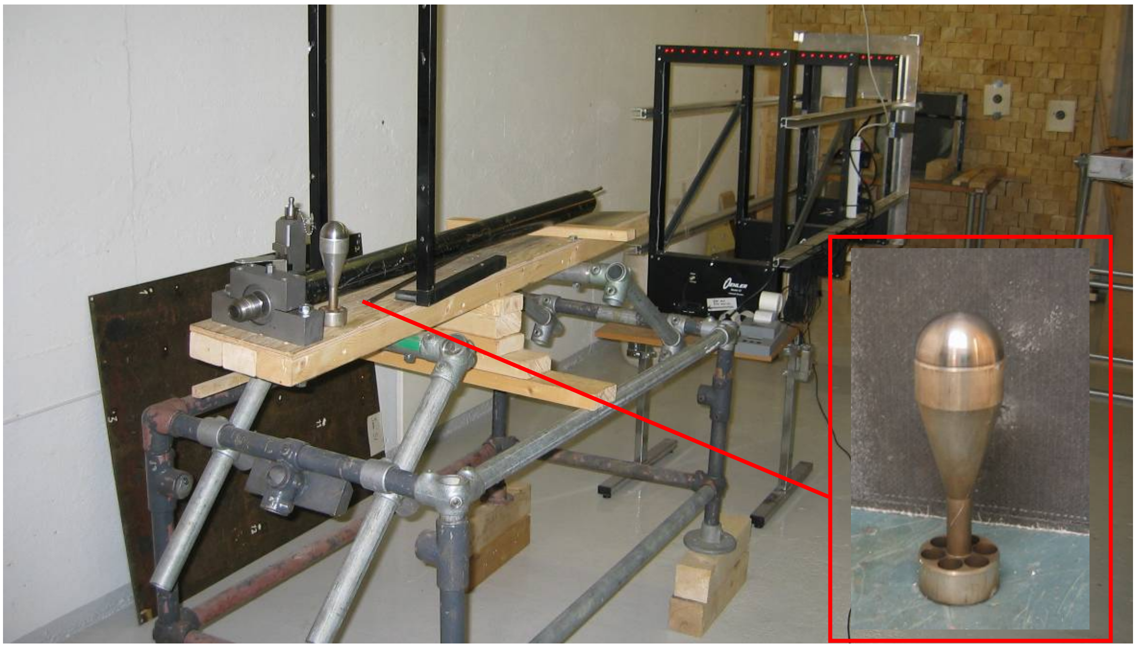
Quasi-static loading:
This test will establish material behaviour in the form of a force vs. displacement relation for different impactor shapes. The result will be used for simulations of dropped equipment.

Dynamic loading:
The main threat is supposed to be impacts from wooden branches when driving through forests.

3.3.7.1 Low velocity impact test methods

Thrown objects:
A typical object could be an object with a mass of around 0.5 kg. This weight is not chosen arbitrarily. It is the approximate weight of a hand grenade, which is made to be thrown as far as possible for an adult male. With full human power it is believed that such an object can be launched at a speed of 30 m/s. A more typical speed would be 20 m/s. In order to make a controlled test of these properties, a special projectile with 50 mm calibre is launched through a short-barrelled gun to get the required velocity. The test setup is shown in Picture 3.6.

For the thrown objects test, the panels will be tested against the described threat both with and without the add-on armour. Sandwich panels with different core types should be tested, as well as selected add-on armour panels. Different impactor shapes should also be used, according to Table 3.16.



Picture 3.6 Test setup for thrown objects.

Quasi-static loading:
Testing will be carried out in a uniaxial testing machine as shown in Picture 3.7. This test set-up was used for characterizing low velocity impact in glass fiber composites in RTP 3.8. An

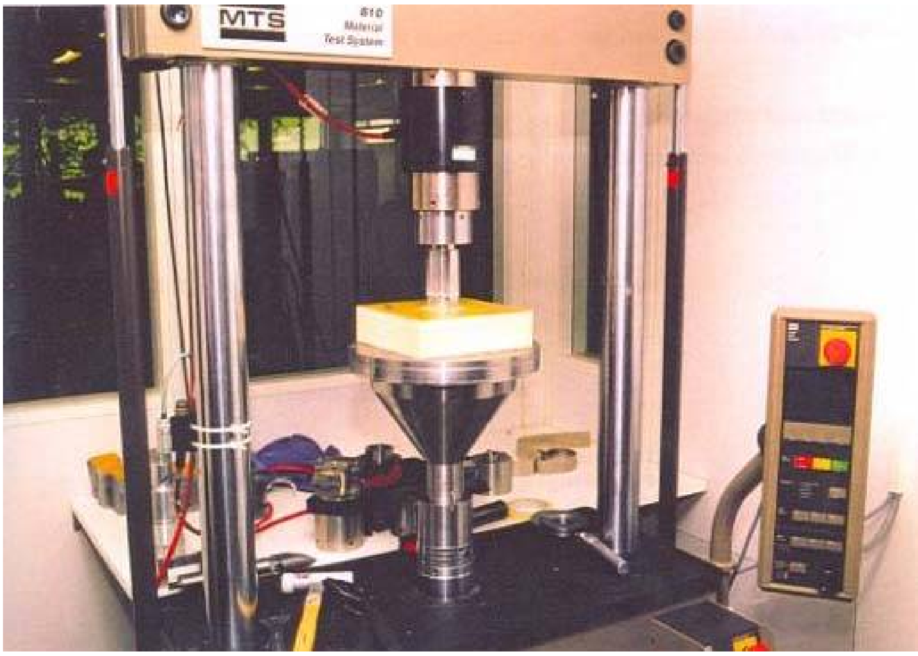
impactor will be driven into the sandwich or single skin material, fixed around its edge to a solid foundation. Different impactor geometries are readily available. The impactors will be a steel hemisphere with 50 mm diameter, and a pyramid. The speed will be 1mm/min. The results should be compared to the results from the dynamic testing to verify the influence of the impact object velocity.

Dynamic loading:
The intention was to use the same device as above, and do tests with impact speeds up to 13 m/s. However, there exists documentation showing that the impact velocity has little effect on the failure force or the fracture characteristics for CFRP sandwich panels (6). The resources intended for the dynamic loading tests will be used on quasistatic loading and on thrown objects.

Dropped equipment:
The results from the quasi-static and dynamic testing could be used as input to a spring-mass model in order to find the duration of the impact pulse. Knowing the mass, acceleration and the duration, a model can be established for calculation of impact damages from various dropped equipment scenarios. There will not be performed any testing on dropped equipment

Table 3.16 Low-velocity test procedure

Test type	**Test equipment**	**Typical velocity**	**Impactor mass**	**Impactor shape and size**	**Panel description**	**Number of panels**
Thrown objects	Short-barrelled gun	20-30 m/s	500g	Hemisphere, D=50mm Pyramid, lxbxh=35x35x31	Carbon fiber laminate sandwich panel. Ceramic/Aramide add-on HDPE add-on	1-2 PVC sandwich 1-2 Balsa sandwich 1 Ceramic/Aramide add-on 1 HDPE add-on
Quasistatic loading	Uniaxial testing machine	1mm/min		Hemisphere, D=50mm Cylinder, D=50mm Pyramid, lxbxh=35x35x31	Carbon fiber laminate sandwich panel	3 PVC sandwich 3 Balsa sandwich



Picture 3.7 Low-velocity impact test setup.

3.3.8 High velocity impact testing

High velocity impact testing under WP 2 is, for Norway, focused toward the ballistic performance and properties of the carbon fibre reinforced plastic materials without the armour protection. The protection level offered by the structural material without armour will be sought as well as the materials behaviour under ballistic impact. Ballistic testing will be carried out according to STANAG 4569. However, some additional measurements not described in the standard may be required. The specimens should be examined before and after testing to observe the failure and energy absorption mechanisms. It may also be necessary to do x-ray examination of the materials to reveal the spread of delamination around the impacted plate.

3.3.9 Testing facility and cost

3.3.9.1 Testing facilities

FiReCo does not have any facilities for material testing within the company. In the project we will use testing facilities at the following places:

FFI (Kjeller)
Most of the material testing to be carried out by the Norwegian consortium will be undertaken by FFI. Standard mechanical and thermal test equipment at FFI include:

- MTS 810.23 Universal Test System
    - Servo hydraulic testing machine with 25 ton load capacity
    - Heating chamber

- Zwick tabletop uniaxial tensile test machine
- MTS 819 High rate test system
    - Capacity of up to 13 m/s
- Light-optical microscope
- Scanning electron microscope (SEM)
- Acoustic emission equipment
- Rheometer
- Thermal analysis equipment (DMA, DSC, TGA)

In case some tools and fixtures are needed there is an on-site engineering workshop with excellent capabilities.

For high velocity and ballistic testing the instruments include:

- Powder gun test facility
    - 13 and 20 mm standard fragment simulation testing
- Various types of standard ammunition (in door facility):
    - 7.62mm (x51, x39, x54R (Dragunov))
    - 12.7mm (x99)
    - (12.7 x 107, 14.5 mm at NDLO/T&D)
    - 5.45 mm, 5.56mm
    - 9 mm
    - 7.62mm fsp
- Methods of observation
    - Velocity measurements using infrared light or other techniques as required
    - Use of witness plates
    - X-ray equipment
    - Access to high speed cameras

For environmental testing FFI have a 1*1 m vibration table, various shakers and climatic control chambers.

Øst-Tech (Fredrikstad)

In cases where FFI does not have the required equipment or personnel it is possible to use the facilities at Øst-Tech, which is a private company with experienced testing personnel and good equipment. The equipment to be used is a hydraulic 70-ton testing machine.

3.3.9.2 Cost of testing

The cost of testing for each standard used for the screening and characterization phases, are shown in Table 3.17

Table 3.17 Cost of testing

Test standard	Test type	Parallels	Test cost (NOK/parallel)	Test cost (NOK/series)
ASTM C 393, modified	4-point bending, sandwich	5	800	4000
ASTM C 297, modified	Through thickness tensile, single skin	5	500	2750
ASTM D 790, method 2	Single skin flexural	5	300	1500
ASTM D 2344	Inter laminar shear	6	183	1100
ASTM D 3039	In-plane tensile strength	6	583	3500
ASTM D 3518	In-plane shear strength	6	500	3000
ASTM D 3410, Proc. B	ITRII-compression test	5	300	1500

3.4 Production Control and procedure development

3.4.1 General

Fabrication procedures are the main element of quality control of FRP structure. All work elements of importance to the product shall be carried out according to detailed and qualified procedures.

Production procedures must always be established and maintained by the producer responsible for manufacturing. A production procedure must be made up, accounting for the skills of the operator, the actual work environment and company experience. Transfer of technology and procedures can only be done after implementation of instructions and knowledge into existing procedure framework of the actual manufacturer, and never directly by adopting a procedure taken from another company with different working environment and training program for their personnel.

3.4.2 Production procedures

Following from the work on qualification of materials and fabrication procedures, detailed production procedures shall be developed for at least the following steps in production as shown below. Again the list may not be complete, and the purpose of this test program is not to fully describe the quality assurance of production. However, this list is included for information.

- Raw material control and logistics
- Workshop conditions, temperature, humidity, environment control
- Panel production, lamination/resin infusion
- Handling, storage and transportation of components
- Adhesive bonding, secondary lamination, panel edge sealing etc
- Assembly and joining of sections

Procedures shall in general be easy assessable, straight forward and short, but still detailed enough to ensure a proper and consistent quality of the work. The requirement of this test program and qualification work is that the context and results from the test program is to form the basis for development of the final manufacturing procedures for the manufacturer.

3.4.3 Production control in test program

When performing the material test program, it is necessary to ensure that the framework for production procedures is established to ensure that the produced test pieces and specimen are of consistent quality and representative for production as discussed above. As an example, the bulleted list below shows the type and amount of information to be referenced or directly defined in a production procedure to ensure traceability and consistent quality.
Important! The vital parameters for production shall be defined by the producer responsible for manufacturing on basis of their skills and manufacturing technology, and is not necessarily limited to this list.

Production procedure content:

- Reinforcement material, standard, type, weight/m2
- Core material, standard, type, thickness
- Resin, standard, type
- Accelerator, standard, type
- Catalyst, standard, type
- Lamination parameters
  - Mixing ratios, resin and curing system for priming of core
  - Priming of core
  - Mixing ratios, resin and curing system for lamination/resin infusion
  - Reinforcement type
  - Lay up details (fibre directions and roll direction of each layer)
  - Impregnation of reinforcement/ resin infusion
  - Number of layers
- Curing cycle
  - Curing temperature
  - Curing time

- Demoulding
- Visual control
- Dimension control
- Direction/orientation control
- Item identification
- Weight control

3.4.4 Test standards for production control

A number of different test standards may be applied in the production control or process qualification stage, according to what is found to be the most important aspects to control from the experience of the manufacturer. In general, for this kind of production there must be strict tolerances and follow up of dimension measurements according to specifications and drawings of structures to be built during fabrication.

Looking at the FRP materials and the quality of production, the workshop environment must be controlled with respect to temperature, humidity, cleaning etc. To audit and control that all requirements are met, a log of the temperature and humidity shall be kept along with the production journals. It is also recommended that sample testing from produced panels is performed. It is possible to take out random specimen from cut-outs etc. to check interlaminar tensile strength and / or interlaminar shear strength by testing. Applicable test standards for the production assessment, are listed in Table 3.18.

Table 3.18 Test standards for production control

ASTM D 2583	Standard test method for indentation hardness of rigid plastics by means of a barcol impressor
ASTM D 648 or ISO-75-2	Standard test method for determination of Heat Distortion Temperature (HDT) or Deflection Temperature under Load (DTL) of plastic materials
ASTM C 297	Tensile strength of flat sandwich constructions in flat wise plane

Mechanical test samples from prototypes or joints should be decided after determination of what structures and joints to be built. Both for laminates, sandwich panels and secondary lamination, a tensile test in flat wise plane (through thickness direction) is an important test method for verification of a sound manufacturing process. The necessary equipment and areas to perform such tests are extremely small, and this should be the preferred mechanical test for random as well as periodic testing of production.

4 TEST OF JOINING METHODS (WP2)

Author chapter 4: Gard Antonsen, FiReCo

4.1 Introduction

The joints for the NOAC are not yet designed, but will be performed in WE 6.3 “Detailed design”. There are several alternative joining methods, and the most typical are adhesive bonding, laminating, bolting, among others.

What ever system is chosen for the assembly of a construction, the method needs to be tested and qualified in order to be able to predict and calculate the required bonding parameters to obtain required strength in the joining area.

4.2 Adhesive system

It is envisaged to use adhesive bonding exclusively for the assembly of the NOAC, and it is also envisaged to select a standard adhesive system with well-known properties. This will allow more extensive testing and understanding of the chosen adhesive system, and the effect of varying different bond parameters such as surface treatment, curing cycle, thickness, etc.

4.3 Test program for adhesive joint

The test program is designed in order to address the bond strength with different bond parameters, such as overlap length and adhesive bond thickness. It is also important to assess the effect of parameter variation out of a design setting, which is often the case for industrial production. By addressing this inevitable variation problematic, the confidence of the structural integrity of the adhesive bond will increase as the actual bond strength will be easier to determine. For this reason, the test program includes three thicknesses, five overlap lengths, as well as comparing single and double lap joint. The test program is divided in to two sections:

1. Single lap joint test program shown in

Table 4.1, and typical geometry is shown in Figure 4.1

2. Double lap joint test program is shown in Table 4.2, and typical geometry is shown Figure 4.2

Table 4.1 Test program for single lap joint

	Test sample ID	Comment	Adhesive film thickness	Overlap	Curing temp.	Reinforcement		Base laminate		
						no. of layer	Fibre orient.	Outer layer	Stacking	Thickness
			(mm)	(mm)	(Deg. C)		(deg.)	(deg.)		(mm)
Single lap	**BD1**		**0.3**	20	60	6	0/90	0	$(0/90)_6$	2.8
	BD2		**0.3**	40	60	6	0/90	0	$(0/90)_6$	2.8
	BD3	Glas Weave	**0.3**	40	60	8	0/90	0	$(0/90)_6$	2.8
	BD4		**0.3**	60	60	6	0/90	0	$(0/90)_6$	2.8
	BD5		**0.3**	90	60	6	0/90	0	$(0/90)_6$	2.8
	BD6		**0.3**	75	60	6	0/90	0	$(0/90)_6$	2.8
	BD7		**1.5**	60	60	6	0/90	0	$(0/90)_6$	2.8
	BD8		**3**	60	60	6	0/90	0	$(0/90)_6$	2.8

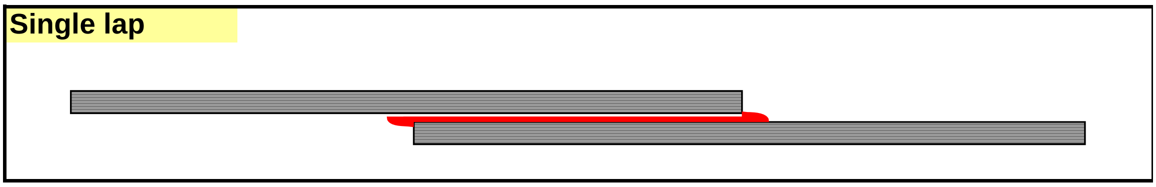


Figure 4.1 Single lap joint geometry

Table 4.2 Test program for double lap joint

	Test sample ID	Comment	Adhesive film thickness	Overlap	Curing temp.	Reinforcement		Base laminate		
						no. of layer	Fibre orient.	Outer layer	Stacking	Thickness
			(mm)	(mm)	(Deg. C)		(deg.)	(deg.)		(mm)
Double lap	**BD9**		**0.3**	10	60	6	0/90	0	$(0/90)_6$	2.8
	BD10		**0.3**	20	60	6	0/90	0	$(0/90)_6$	2.8
	BD11	Glas Weave	**0.3**	20	60	8	0/90	0	$(0/90)_6$	2.8
	BD12		**0.3**	30	60	6	0/90	0	$(0/90)_6$	2.8
	BD13		**1.5**	30	60	6	0/90	0	$(0/90)_6$	2.8
	BD14		**3**	30	60	6	0/90	0	$(0/90)_6$	2.8

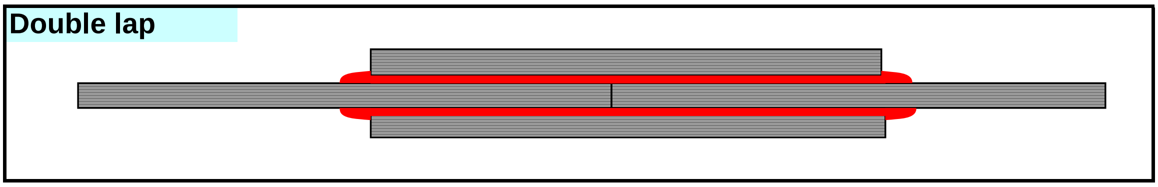


Figure 4.2 Double lap joint geometry

5 BALLISTIC TESTING (WP3)

Author chapter 5: Ove S. Dullum, FFI

Ballistic testing will be made according to Annex C of Stanag 4569, “Procedures for evaluating the protection levels of logistic and light armoured vehicles for KE and artillery threats”. The document describes procedures for performing ballistic test addressing points like

- what ammunition to use
- target setup and instrumentation
- impact point relative to edge of sample
- multiple impact tests
- interpretation of results

The Stanag defines 5 different threat levels of which levels 1 – 3 are of relevance for the application case. Details about the levels are found in RTP103.014 Operational Requirements document.
The Stanag specifies that the minimum shots for verification of a certain material combination, with respect to a given threat level, is 22. However, this number can be reduced to 10 on certain conditions. In the present work, 10 shots would be adequate, except for the final verification, where a full suite of firings should be conducted.
For testing with 20 mm FSP, 3 – 5 shots at each sample would be sufficient
For details on the points above, the reader should consult the Stanag.
The material for the Norwegian application tests will be subject to testing at FFI indoor test facility at Kjeller, Norway. The equipment available for these tests include:

- infra-red velocity measurement device
- 4 heads 150 kV flash x-ray facility
- bullet catching device
- equipment for ammunition laboration, if needed
- rifles for firing 7.62 x 51 mm, 7.62 x 39 mm and 5.56 x 45 mm ammunition
- 30 mm smoothbore gun for firing 20 mm FSP.

6 TESTING OF THE NORWEGIAN APPLICATION CASE (WP6)

6.1 General

The testing of the AC within WP6 will be divided into laboratory testing and field testing. In addition to the panels that will be mounted onto the vehicle platform, test panels will be prepared and tested separately. The goal is to gain confidence in the solutions without performing destructive test on the vehicle itself.

In view of the high cost of the advanced armour materials, dummy armour (steel) will be used wherever possible. Test cases involving ballistic impact will be carried out with the advanced armour in the places of impact. Elsewhere, the goal is to verify the integration of the armour to the carbon fiber structure and to simulate the added weight of the armour. This can be done without using the high cost armour.

Due to budget constraints it might not be possible to carry out all the tests described in this chapter.

6.2 Shock and vibration test

One panel will be used for a shock and vibration test. A side wall, or part of a side wall, will be mounted onto a vibration table and exposed to shock and vibration loads corresponding to the toughest requirements for the vehicle. Vibration test spectrum from 6.5 will be used if available. The goal is to verify that the panel behaviour corresponds to the panel used in the design calculations, the integrity of the armour mounting and possibly effects of damage after ballistic loading.

- Estimated cost of test (incl. VAT): 150 kNOK (Assuming testing at FFI)
- Available test facilities: FFI test laboratory. (Facilities at other industry: e.g. Det Norske Veritas (DNV), Kongsberg Defence & Aerospace, Nammo Raufoss.)

6.3 Repair test

If time allows, a repair test will be performed on a panel that has been locally damaged to evaluate the strength after the repair. A strength critical area, e.g. a fixing for an armour panel will be damaged and then repaired. The panel will be exposed to shock and vibration on a shaker table both before damage and after the repair to assess the effect of the repair. The repair test will be of particular interest if the matrix is TP.

The test should be combined with 6.2.

- Estimated cost of test (incl. VAT): 20 kNOK (Assuming test is done as an continuation of 6.2)
- Available test facilities: FFI test laboratory

6.4 Testing of joints for assembly

The joining methods chosen in 4.3 must be tested on actual AC joints, and must be performed by the company performing the assembly of the NOAC. This will ensure that the selected methods and parameters are applicable for the NOAC. Corner sections similar to the actual

AC joints will be tested in a uni-axial testing machine, in both the opening and closing mode. The test sections will be assembled using the same procedure as for the adhesive bonding of the AC.

6.5 Road and terrain driving

The vehicle will be loaded both to maximum weight, using dummy panels to simulate add-on armour, and a lower (minimum) operation weight. A drive test of the AC will be performed both on roads and in one of the Army's test tracks.
The goal is to evaluate (qualitatively) factors such as structural integrity, noise, vibration, geometrical modification, functionality of add-on armour system, stability and any change in the handling characteristics of the vehicle.
Vibration data should also be recorded and processed, to be used as a basis for the vibration test spectrum in 6.2. (Note! Due to time schedule it might be required to record vibrations on a standard BV 206 DN6 at an earlier stage in the program)

- Estimated cost of test (incl. VAT): 50 kNOK (Assuming support from the Norwegian Army & logging equipment from FFI for recording vibration data.)
- Available test facilities: Norwegian firing/test ranges at: e.g. Trandum/Sessvollmoen or Rena.

6.6 Weapons firing

This section is only going to be performed if the economical situation allows for it.
To evaluate the integration of the on-board weapon a live firing test will be done at one of the Army's firing ranges.
The goal is to investigate how recoil forces from the weapon mounted at the ring mount influences the structure. The structure will be instrumented as required with accelerometers and strain gauges at selected locations. The ring mount may also be instrumented with a load-cell to record recoil forces.
The results will be compared with results from the simulations during the design phase.
The test should be combined with 6.5.

- This test will only be performed if the budget allows it. No costs estimated.
- Available test facilities: Norwegian firing/test ranges at: e.g. Trandum/Sessvollmoen or Rena.

APPENDIX

A CHARACTERISATION OF MATERIAL PROPERTIES

To characterise the in plane properties of a laminate with only one fibre direction, totally 9 different material parameters is needed:
1) Tensile strength ($\sigma_{T0°}$), 2) Compression strength ($\sigma_{C0°}$) and 3) Young's-modulus ($E_{0°}$) in the fibre direction
4) Tensile strength ($\sigma_{T90°}$), 5) Compression strength ($\sigma_{C90°}$) and 6) Young's-modulus ($E_{90°}$) transverse to the fibre direction (90°)
in addition to 7) Poisson ratio ($\nu_{90°/0°}$), transverse strain divided by longitudinal strain,
8) in plane shear strength ($\tau_{0°/90}$) and 9) in plane shear modulus ($G_{0°/90°}$).

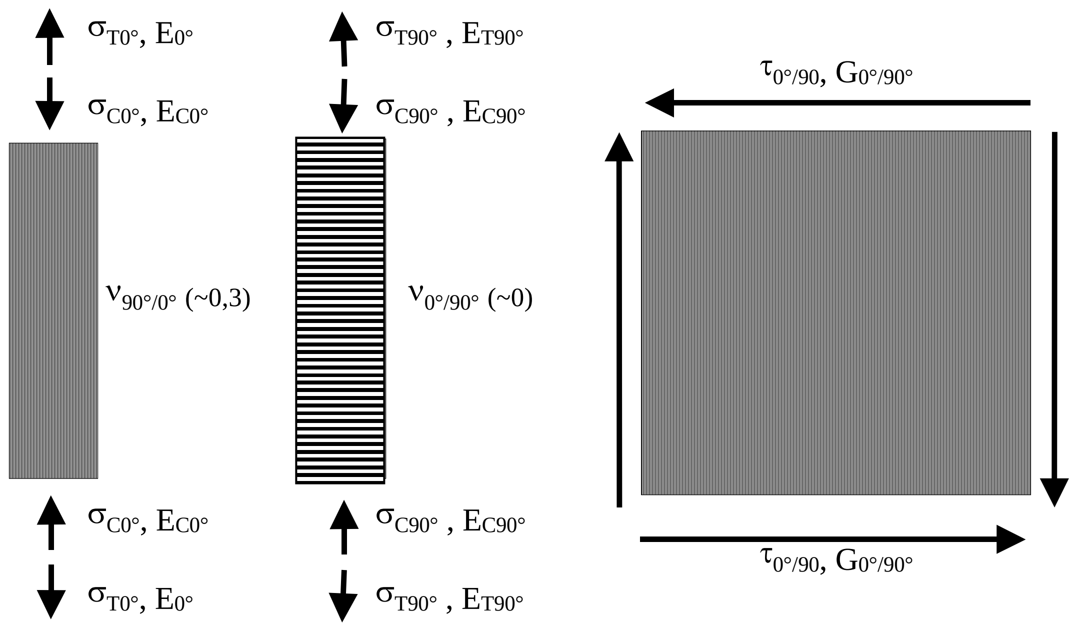
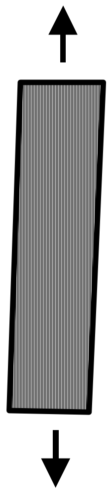


Figure 6.1 Material parameters for a laminate (in-plane properties)

Tensile and compression data for unidirectional laminate, as well as shear data must be established to be able to predict theoretical values for strength and stiffness for several multi axial laminates built with the same ply data using laminated plate theory.
Experience from testing of a variety of laminates shows that reliable strength data for UD laminates is extremely difficult to obtain directly (by testing of UD laminates). The data back calculated from testing of biaxial laminates, shows much less scatter and is therefore more reliable for documentation of strength data.
It is therefore chosen to use only laminates with two or more fibre directions for determination of UD strength data. It is OK to use UD laminates for determination of stiffness data as

modulus and Poisson's ratio only. The different material parameters are characterized in the following way:

1)
Tensile- and compression test of unidirectional [0º] (ASTM D 3039 and ASTM D 695) alternatively (4-point bending test of sandwich panels as described in section 3.2.3) to get optimum values for σ_{T1}, σ_{C1}, E_1
From test of UD laminate one get the following material properties: E_1, ν_{21},
where 1 is in the fibre direction and 2 is transverse to the fibre direction.



Misaligned fibres during production of specimens or cutting of specimens for testing of UD properties are generally visualised. The effect of strength loss from the fibres not being continuous from one end to the other (fixtures) is far more important than the effect of the fibre angle itself.

Experience shows that the results from testing of UD laminates produces at least ~ 20% lower values than compared to data from other tests.

Figure 6.2 Effect of misaligned fibres from cutting or production of specimen

2)
Tensile- and compression tests of [0º/90º] (ASTM D 3039 and ASTM D 695) or (ASTM D 3410) to give the optimum properties for $\sigma_{0°/90°}$, $E_{0°/90.}$
UD strength in the fibre direction for UD plies can be back-calculated from the modulus in the fibre direction from 1), and strain to failure from 2): σ_1 , E_2.
Young's modulus transverse to the fibre direction (E_2) is based on comparison of results from tests 1) and 2) above.
First ply failure (FPF) strength can be determined based on the saturation of micro cracks form acoustic emission measurements, knee point of stress/strain test data, whichever found to be most convenient.

3)
Tensile test of [±45º] (ASTM D 3518)
This test is used to determine shear modulus and shear strength for UD and [0º/90º] laminates, as well as the Poisson's ratio.

$G_{LT} = E_{\pm 45} / [2 (1 + \nu_{\pm 45})]$
$\tau_{LT} = \sigma_{\pm 45} / 2$
$\nu_{\pm 45} = \varepsilon_x / \varepsilon_y$
$\gamma_{\pm 45} = \varepsilon_x - \varepsilon_y$

Tensile test of [±45º] provides a possibility for back calculating the Poisson's ratio for a UD ply (increased accuracy since [±45º] laminates produce a high Poisson's ratio and hence the effect of measuring accuracy is reduced). The data is also verified by testing [±45°] laminates with the 4-point bending test of panel stripes.

A.1 UD ply data

The transverse UD strength value to be used for linear LPF prediction using a modified Tsai-Wu approach can be back calculated from simple tests of a balanced 0º/90º laminate. The actual input value for different laminate qualities can be calibrated quickly. A back calculated transverse upper strength limit is only valid for analysis of laminates with two or more fibre directions. This design approach is accurate and conservative for a given range of laminates as tested and qualified for a certain project.
The longitudinal strength value of UD layers can be calculated from simple tests of tri-axial laminates ($0º_2$/+45º/-45º), which supports the UD fibres in an optimised manner.
The shear capacity of UD fibres is easily calculated with a tensile test of a balanced ±45˚ laminate tested in 0˚ direction, or with a standard shear test specimen. The same property will be obtained with testing of balanced 0˚/90˚ or WR laminates in 45˚ direction, provided that the reinforcements are based on consistent fibre quality. It is important to focus on a tight range of reinforcements with consistent quality, containing only qualified raw materials (fibre and sizing). Variations in fibres, sizing or reinforcement manufacturer will call for additional testing for qualification.
All stiffness properties can be obtained by most standard test methods, as long as the stiffness or modulus is not obtained directly (One should always use nominal thickness values based on nominal fibre content, and never direct thickness measurement for determination of in plane properties).
From the proposed strength tests, most mechanical data can be back calculated or derived. As earlier pointed out, the strength values for UD plies cannot be obtained directly, but the longitudinal stiffness can be obtained directly.

A.2 Design and correlation to test data

To provide background information on the laminate data, we have worked out some tables showing the test results versus predictions of ultimate strength using the Tsai Wu criterion on different laminates and lay-ups.
The chosen design method with Tsai Wu approach to failure prediction is a conservative approach, based on the UD data presented in Appendix A. The failure criterion accounts for the combined stress state of each individual layer in a laminate, and this method provides a quick verification of the highest loaded layers in the FRP construction.
It is essential that the test program must be carried out according to relevant procedures to provide the necessary and relevant input for this criterion.
The basic material parameters have been documented through testing of sandwich panels subjected to 4-point bending. The response of the symmetric sandwich panels in 4-point bending is compressive stress at the top face laminate, and tensile stress at the bottom face.

The core is carrying the shear (for further details on the test, reference is given to ASTM D 393).
A key parameter to interpretation of the results presented in the following tables, is that the laminate in the 4 point bending test may fail in either compression (top face), tension (bottom face), shear (core), or a combination of two or three of the above damage mechanisms.
However, it is evident that none of the ultimate stress levels are lower than the maximum recorded in the test, and for the laminate capacity it can be concluded that the lowest limiting stress level for both compression and tension is clearly identified.
It must be emphasised that the establishment of key laminate data from and transfer of these data into basic parameters for design must be done according to the procedures and test methods described earlier.
The philosophy must be consistent, and the basic principles are to prove the validity and the conservatism in any simplifications introduced to make the design philosophy and testing activity an affordable and yet accurate procedure.

B DESCRIPTION OF TSAI-WU STRENGTH CRITERION

The design of the laminates to be performed in the project is going to be done using an accurate and detailed analysis of laminate strength based on laminated plate theory as described in Composites Design, 4th edition by Stephen Tsai (4). Further details on the Tsai-Wu criterion may be found in this source or other composite theory literature. It is also described in the DNV High Speed Light Craft code.

When a composite laminate is uniaxially loaded, the first damage occurs in the weakest parts of the laminate (fibre layers with orientation 90° to the direction of the load). This damage has little effect on the ultimate strength and stiffness of the laminate, while the fibres orientated in the same direction as the load give strength and stiffness. However, as the damage propagates in the laminate, more and more of the loading is distributed to the non damaged layers. Rupture occurs as the last ply failure occurs, that is when the load reaches the load bearing capacity of the fibres oriented in the load direction.

B.1 Explanation of LPF and Tsai-Wu factor

Last Ply Failure, LPF, is the combined stress in the laminate, which fully utilises the strongest layers of the composite material. The composite material has several layers with different properties (depending on type of fibres, fibre orientation and fibre content), and depending on the direction of the load, the different layers will contribute to strength and stiffness according to composition.

The stresses in the laminate plane are combined to an utilisation factor according to the Tsai-Wu criterion. The Tsai-Wu criterion is a theoretical failure criterion for anisotropic materials corresponding to the Von-Mises criterion for isotropic materials. Since the composite materials are anisotropic, one cannot present the utilisation as a stress level (the material stress capacity is depending on stress direction), and an utilisation factor is introduced. When the Tsai-Wu factor = 1, the load is at the level where failure occurs. If the Tsai-Wu factor is higher than 1, the material is overloaded, while Tsai-Wu lower than 1 is OK. The Tsai-Wu factor is a quadratic equation, and thus the resulting factor from a FEM analysis cannot be linearly scaled to define the rupture load.

For short term loads and dynamic loads
$SF = R_{LPF} = 3,3$ against laminate rupture, (LPF according to the Tsai/Wu criterion)

Applied safety factor against long term static loads on the Tsai-Wu stress criterion is:
$SF = R_{LPF} = 4,5$ against laminate rupture, (LPF according to the Tsai/Wu criterion)

To obtain the specified safety factors on calculation of Tsai-Wu for the construction, the material capacity is reduced to 30% for the required safety of 3,3, and 22% of ultimate when required safety is 4,5 according to above. The Tsai-Wu factor = 1 would then be at the limit allowable load, e.g. 30% of ultimate for a required safety factor of 3,3.

B.2 Definition of the Tsai-Wu failure criterion

The criterion includes the in-plane stress components σ_X, σ_Y and τ_{XY}, and is given by:

$$F_{XX} \cdot (\sigma_X)^2 + 2 \cdot F_{XY} \cdot (\sigma_X \cdot \sigma_Y) + F_{YY} \cdot (\sigma_Y)^2 + F_{SS} \cdot (\tau_{XY})^2 + F_X \cdot \sigma_X + F_Y \cdot \sigma_Y \leq 1 \qquad (6.1)$$

Where:
$F_{XX} = 1/ X \cdot X'$,
$F_X = 1/ X - 1/X'$,
$F_{YY} = 1/ Y \cdot Y'$,
$F_Y = 1/Y - 1/Y'$,
$F_{SS} = 1/S^2$
$F_{XY} = F^*_{XY} \cdot (F_{XX} \cdot F_{YY})^{0.5}$
$F^*_{XY} = -0{,}5$ (ref. Introduction to Composite Materials, Tsai/Hahn)

X = Laminate tensile strength in the fibre direction (0°)
X' = Laminate compressive strength in the fibre direction (0°)
Y = Laminate tensile strength transverse to the fibre direction (90°)
Y' = Laminate compressive strength transverse to the fibre direction (90°)
S = Laminate in-plane shear strength in the fibre direction (0°)

The Tsai-Wu factor shall be lower than 1.
Further explanation of the Tsai-Wu criterion is given in composite literature.

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(2) ANTONSEN Gard Alexander, FJELDLY Tor Alexander, DULLUM Ove, ELVEBAKKEN Dag (2005): RTP103.014/Fireco/1.3.1/WP/1/01, Structural and Ballistic Studies and Concept.

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(4) TSAI, Stephen W. (1988): Composites Design, 4th edition, Think Composites, Daytona, Ohio 45419, USA

(5) Tsai / Hahn: Introduction to Composite.

(6) HUSEBY Geir (1997): EUCLID - CEPA3 - RTP3.8, TD-12312-9701, Normal Impact - experimental studies

Other reference documents

Specifications, standards, and handbooks

STANAG 4569	Protection levels for occupants of logistic and light armoured vehicles (Including new - to be implemented - annex C related to testing)
ASTM C 297	Tensile strength of flat sandwich constructions in flat wise plane
ASTM D393	Flexural properties of flat sandwich constructions
ASTM D648	Standard test method for determination of Heat Distortion Temperature (HDT)
ASTM D 695	Standard test method for compressive properties of rigid plastics
ASTM D 2344	Apparent inter laminar Shear strength of reinforced plastics by short beam method
ASTM D 3039	Tensile properties of fibre-resin composites
ASTM D 3410	Compressive properties of Unidirectional or Cross ply Fiber-Resin Composites
ASTM D 3518	In-plane Shear Stress-Strain response of Unidirectional polymer matrix composites
ASTM D 4255	In plane shear testing of laminates using rail shear test
ASTM D 5467	Compressive Properties of Unidirectional Polymer Matrix Composite Materials Using a Sandwich Beam
ASTM D 2583	Standard test method for indentation hardness of rigid plastics by means of a barcol impressor
ISO 4901	Reinforced plastics based on unsaturated polyester resins - Determination of residual styrene monomer content
ISO-R75	Deflection Temperature under Load (DTL) of plastic materials

List of acronyms

Acronym	Full name/text	Comment
AC	Application case	
AFV	Armoured Fighting Vehicle	
ASTM	American Society for Testing and Materials	
BV	Bandvagn (Tracked-vehicle)	
CFRP	Carbon Fibre Reinforced Plastic	
CSM	Chopped Strand Mat	
DEF STAN	Defence Standard	
DTL	Deflection Temperature under Load	
EMC	Electromagnetic compatibility	
EUROPA	European Understanding for Research Organisation, Programmes and Activities	
FFI	Norwegian defence research organisation (NDRO)	
FRP	Fibre reinforced plastic	
FSP	Fragment simulating projectile	
GFRP	Glass Fibre Reinforced Plastic	
HDT	Heat Distortion Temperature	
ILSS	Interlaminar shear strength	
ISO	International Organization for Standardization	
KE	Kinetic energy	
KEU	Kværner Eureka a.s	
LPF	Last Ply Failure	
LRU	Line replaceable unit	
NDLO	Norwegian Defence Logistics Organisation	National authority w.r.t Stanag 4569
STANAG	Standardisation Agreement	
TBD	To be decided	
VARI	Vacuum Assisted Resin Infusion	
VE	Vinyl ester	
WE	Work Element	
WEAO	Western European Armaments Organisation	
WP	Work package	