METHODS FOR QUALIFICATION OF THE MECHANICAL PROPERTIES OF SANDWICH CORE MATERIALS FOR WIND TURBINE BLADES

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SUMMARY

Methods are suggested for measuring the properties of sandwich core materials for wind turbine blades. The basic properties of the core material in shear, tension and compression are measured under quasi static loading as well as in shear fatigue. The methods proposed are demonstrated on a reference PVC core material.

Keywords: Sandwich core material, qualification testing, static properties, fatigue, wind turbine blades

INTRODUCTION

Larger wind turbine blades are typically made from fibre reinforced polymer based composites. The basic construction concept of a blade is that it consists of two faces, the suction side and the pressure side, which together form an optimized aerodynamic shape. These two faces or shells are bonded around a girder box, or they are integrated with a longitudinal upper and lower beam taking up the longitudinal stresses in tension and compression, supported by longitudinal webs taking up shear forces and supporting the shells against buckling. A typical blade cross section is shown in Figure 1. Reviews on materials and design of wind turbine blades can be found in references [1], [2], and [3].

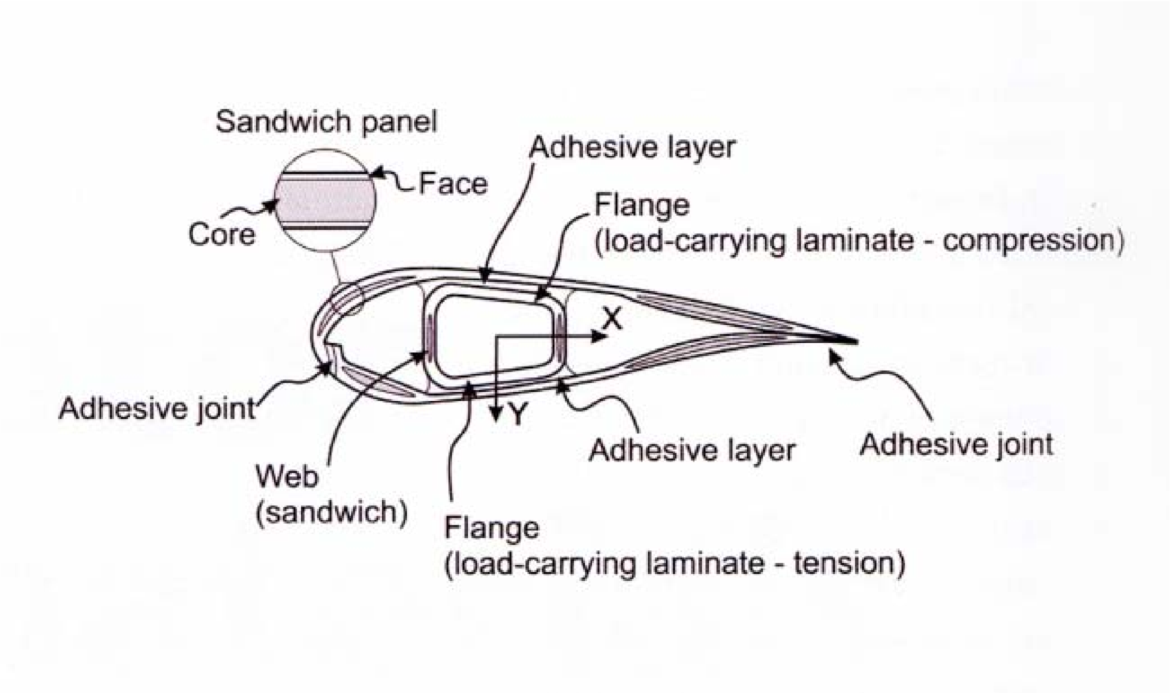

Figure 1. Typical cross sections of wind turbine blade with girder box showing laminate, sandwich and adhesive bonds. Refeference [4].

Sandwich materials are extensively used in wind turbine blades. The sandwich panels in the webs or girder box sides are mainly materials with a biax (±45°) skin layer with a PVC foam or balsa core to take up shear load. The sandwich panes in the shells are mainly triax (±45°/0°) skin layers with similar foam or balsa core. The density and quality of the core materials can be varied with position on the blade.

Classification of materials for use in wind turbine blades are essential for the production quality, the performance and life time of the blades.The materials, fibers, resins, and core materials are required to be qualified before used in the manufacturing. Whereas the methods for qualifying the laminates, both the beam, web, and shell laminates, are well established (references [5] and [6]), the qualification procedures for the core material and the sandwich panels are dubious, even though the mechanical properties of sandwich materials are important design parameters. The properties of the core material influences the deflections of the shell and the tension, the compression, and the shear strength of the core are essential for the bending strength of the sandwich and the buckling load of the blade. The present paper describes the methods used for selecting and qualifying the core material for this application and improvements on the methods are suggested. The improved methods are demonstrated by tests on a core material which can be used as benchmark tests and results for future qualification and specification.

LOADS ON ROTOR BLADES

For loadings on blades described as edgewise, the loading and bending deformation are in the direction of the chord line (the stiff direction). For the loads in the direction normal to this (the more flexible direction) they are called flapwise. The main loads on the blades are the wind loads, which are coupled both flapwise and edgewise bending. Also the gravity for the very large and heavy blades induces edgewise bending when the blade is horizontal and some axial tension or compression when the blade is vertical. Torsional deformations due to the asymmetry of the blade section also need to be taken into account, as do loadings associated with accelerations. The loads change with time because of rotation and because of the disturbance of the air flow by the tower. The materials properties measured on the beam laminates, on the sandwich skin layers, on the core materials and cohesive laws for the adhesive bonds are used in the design of the blades. In the following the methodology for measuring the sandwich core properties are discussed.

MEASUREMENT OF MECHANICAL PROPERTIES OF CORE MATERIALS.

In the sandwich parts of the blades either PVC foam or balsa wood are the dominant core materials used, but because of the strong cost driven competition many new alternative core materials have been developed. In order to get acceptance for using alternative materials a qualification of the mechanical properties must be conducted.

The qualification tests are normally carried out with reference to technical standards primarily from ASTM and ISO. The standards describe methodology for the testing and how to determine the mechanical properties of the test material. Tension, compression and shear tests must be conducted on the core materials or on the actual sandwich panel. For the wind turbine blade design and approvement the following properties are of interest.

Out-of-Plane Static Tensile Properties.

Out-of-plane tension stiffness and strength are design parameters for web strength and buckling, for joints and for dimensioning against shear loads og twisting. The stiffness is a design parameter for the flexibility of the sandwich panels. The properties can be measured according to ASTM C297 – “Flatwise tensile strength of sandwich constructions”. The method determines the flatwise tensile strength of the core, the out-of-plane tensile stiffness of the core, and the core to face bonding when performed on the sandwich.

Out-of-Plane Static Compression Properties.

The properties are design parameters for webs joints, for panel buckling, and further for impact damage. The properties are normally measured according to ASTM C365 – “Flatwise Compressive Properties of Sandwich Cores”. The test method covers the determination of the compressive strength and modulus of sandwich cores.

In-Plane Static Shear Properties.

The in-plane shear properties shear stiffness and shear modulus of the core are the most important properties for the sandwich. These properties are design parameters in the basic design against shear loads and the in-plane compression and tensile loads. The properties are also design parameters for all panels against buckling and twisting. The properties can be measured according to ASTM C273 – “Shear Properties of Sandwich Core Materials”. This test method covers the determination of shear properties of sandwich construction core materials associated with shear distortion of planes parallel to the facings (in-plane rail shear). The properties measured are the shear strength parallel to the plane of the sandwich, and the shear modulus associated with strains in a plane normal to the facings. An alternative to the ASTM standard, the standard ISO 1922 – “Rigid cellular plastics — Determination of shear strength” can be used. These standards are quite similar.

In-Plane Static Shear Properties.

A very common methods used to determining the core properties are the 3 pinnt bending or 4 point bending method according to ASTM C393 – “Core Shear Properties of Sandwich Constructions by Beam Flexure”. This test method covers determination of the core shear properties of flat sandwich constructions subjected to flexure. Although this method is widely used both for static and fatigue qualification because it is an easy and cheap method, it can definitely not be recommended to use it in the qualification. The values measured by this method do not only reflect the quality of the core material, both the shear values measured strongly depends on the skin layer thickness and layup. Hence the method can only be use in comparison of core material when the skin layers are the same. The values measured cannot be used for dimensioning.

In-Plane Fatigue Shear Properties.

The rotor blades are subjected to both static and fatigue loadings. The major concern are the fatigue loads, however standards and recommendations for measuring the fatigue properties of the sandwich materials are few. For core materials only one standards is available, namely ASTM C 394 - Shear Fatigue of Sandwich Core Materials. This test method covers testing of shear properties in a set-up similar to the static in-plane shear test method and is determining the effect of repeated shear loads on sandwich core materials.

IMPROVEMENT OF MECHANICAL TESTING PROCEDURES

The above mentioned test methods have been thoroughly analyzed and tested. In the project KOMPOSAND [7] test methods for core materials were investigated, and this led to suggestions for qualification procedures for these materials.

Improvements have been suggested to the existing standards and benchmark and reference data are now available in the open literature, reference [8]. In the following our suggestions for improved test methodology are presented.

Materials

Test specimens were cut from a 30 mm thick core plate made from Divinycell H130 PVC foam from DIAB. The actual densities were measure on all test samples.

Specimens

Static tensile test were carried out using test coupons 30 mm thick and 80 mm x 80 mm in-plane. Test specimens were glued to 50 mm thick steel plates that are pulled in tension. Figure 2.

Static compression testing were carries out using similar test coupons 30 mm thick and 80 mm x 80 mm in-plane. Test specimens are compressed in a special build compression fixture between parallel planes. Figure 3.

Shear testing on test coupons max 30 mm thick, 80 mm x 360 mm in-plane. Test procedure is a modification of the recommendations given in ASTM C 273. The shear testing is performed both as static tests as well as fatigue tests. See set-up in Figure 4.

One of the fatigue test specimens, HCC1D-06, was bonded to 2 mm thick glass/epoxy cross-ply laminate face sheets which were in turn bonded to 17 mm thick steel plates.

Bonding

Before bonding the steel parts were ground by hand with grit 60 paper and wiped with acetone. The epoxy adhesive 3M ™ 2216 B/A Grey Scotch-Weld™ was used for bonding of the steel adherents to the foam and cured at 40° C for 16 hours.

The face sheets of the (single) shear fatigue sandwich specimen were bonded to the core with 3M ™ 2216 B/A Grey Scotch-Weld™ epoxy adhesive, and the 17 mm steel plates were bonded to the face sheets with 3M™ DP-460 Off-White Scotch-Weld™ epoxy adhesive.

Testing

The tensile tests were performed on a servo-hydraulic testing machine (Instron 88R 1342) with a ±100 kN load cell. The strain was recorded by two extensometers placed on two opposite sides of the specimens. The testing machine was operated in displacement control at 0.5 mm/min with a data acquisition rate of 10 Hz. Results are shown in Table 1.

The compression tests were performed on a servo-hydraulic testing machine (Instron 88R 1342) with a ±100 kN load cell. The strain was recorded by two extensometers placed on two opposite sides of the specimens. Test specimens were compressed in a special build compression fixture between parallel planes. The testing machine was operated in displacement control at 0.5 mm/min with a data acquisition rate of 10 Hz. Results are shown in Table 1.

The shear tests were performed on a servo-hydraulic testing machine (Instron 88R 1342) with a ±100 kN load cell. The shear strain was recorded with an LVDT. The core test specimens were glued to two 17 mm steel plates. These plates were mounted in a fixture consisting of two square profiled tubes. For the static tests the testing machine was operated in displacement control at 2 mm/min with a data acquisition rate of 10 Hz. Results are shown in Table 1.

For the shear fatigue tests the testing machine was operated in load control with an R ratio of 0.1 at a frequency of 5 Hz. The specimen temperature was monitored with an infrared temperature sensor (Raytek Thermalert GP). Load, displacement, LVDT and temperature were stored every 10 cycles. Results from fatigue tests are shown in Table 1 and in Figure 5.

CONCLUSION.

It has been shown that with some improvements selected international standard are useful for qualifying sandwich and core materials. For out-of-plane tension and compression it is demonstrated that at more rigid setup and an improved strain measurement can give modulii and strengths higher and probably more accurate than measured in previous tests. It was demonstrated that the in-plane shear properties measured by using additional reinforcements to avoid large edge effects also improves the reproducibility of the results. It has also been discussed that the used 3 or 4 point bend test according to ASTM E393 gives misleading results and cannot be recommended. Documentation confirming this statement are not completed but will be presented later. Static tests (tension, compression and shear) can be performed with either the core material bonded directly to steel plates or they can be carried out on the sandwich with skin layer. However, when it comes to fatigue, the preliminary results indicates that in this set-up it seems that the test should be performed on the complete sandwich, see Figure 5. This is due to that the interfaces between skin and core appears to be the weakest interface where crack will grow under fatigue loadings. However, this might depend on the density and the quality of the core material. Special care must be taken when preparing the test specimens and the failure modes must be thoroughly analyzed when validating the test and the results.

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Table 1. Test results.

Static TT tension

Results 5 **tests**	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	E 0.05-0.25% (MPa)	Peak load (kN)	Stress at peak load (MPa)	Strain at peak load (%)
Average	**79.0**	**79.2**	**30.26**	**120**	**261**	**32.34**	**5.16**	**2.65**
Standard dev.	0.1	0.3	0.04	1	5	0.46	0.07	0.14
Rel. std. (%)	0.1	0.4	0.14	0.7	2.1	1.4	1.4	5.1

DIAB data sheet values for H130 (nominal density 130 kg/m^3): E = 175 MPa and tensile strength = 4.8 MPa.

Static TT compression

Results 5 **tests**	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	E 0.05-0.25% (MPa)	Peak load (kN)	Stress at peak load (MPa)	Strain at peak load (%)
Average	**79.0**	**79.2**	**30.26**	**120**	**255**	**-18.06**	**-2.88**	**-1.81**
Standard dev.	0.1	0.3	0.04	1	17	0.28	0.04	0.08
Rel. std. (%)	0.1	0.4	0.14	0.7	6.9	-1.6	-1.5	-4.5

DIAB data sheet values for H130: E = 170 MPa and compression strength = 3.0 MPa.

Static TT shear

Results 5 **tests**	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	G 0.1-0.5% (MPa)	Peak load (kN)	Stress at peak load (MPa)	Strain at peak load (%)
Average	**359.7**	**79.6**	**30.22**	**122**	**46**	**61.27**	**2.14**	**35.95**
Standard dev.	0.3	0.2	0.10	3	3	1.67	0.05	3.19
Rel. std. (%)	0.1	0.2	0.34	2.4	6.7	2.7	2.5	8.9

DIAB data sheet values for H130: G = 50 MPa, shear strength = 2.2 MPa and shear strain to failure = 40 %.

Fatigue TT shear (R = 0.1)

Specimen no	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	Peak load (kN)	Peak shear stress (MPa)	Initial stiffness (kN/mm)	Cycles to 10% stiffness degradation	Cycles to failure	Remarks
HCC1D-01	359.8	79.4	30.32	120	30	1.05	19.9	38830	40800	1
HCC1D-02	359.5	79.6	30.15	128	25	0.87	15.8	152700	155430	2
HCC1D-03	359.9	79.5	30.32	124	20	0.70	17.3	174120	183230	1
HCC1D-04	359.8	79.6	30.20	123	45	1.57	17.4	1160	1710	1
HCC1D-05	359.9	79.8	30.28	130	15	0.52	20.5	1273823	1273823	Run-out
HCC1D-06	359.9	79.6	30.23	123	30	1.05	19.5	380820	455370	3

1) Steel / adhesive interface failure & core failure
2) Steel /adhesive interface failure
3) Adhesive / face sheet interface failure & core failure

The stiffness used in the table is defined as the difference in load divided by the difference in cross-head position $(load_{\max} - load_{\min})/(pos_{\max} - pos_{\min})$.

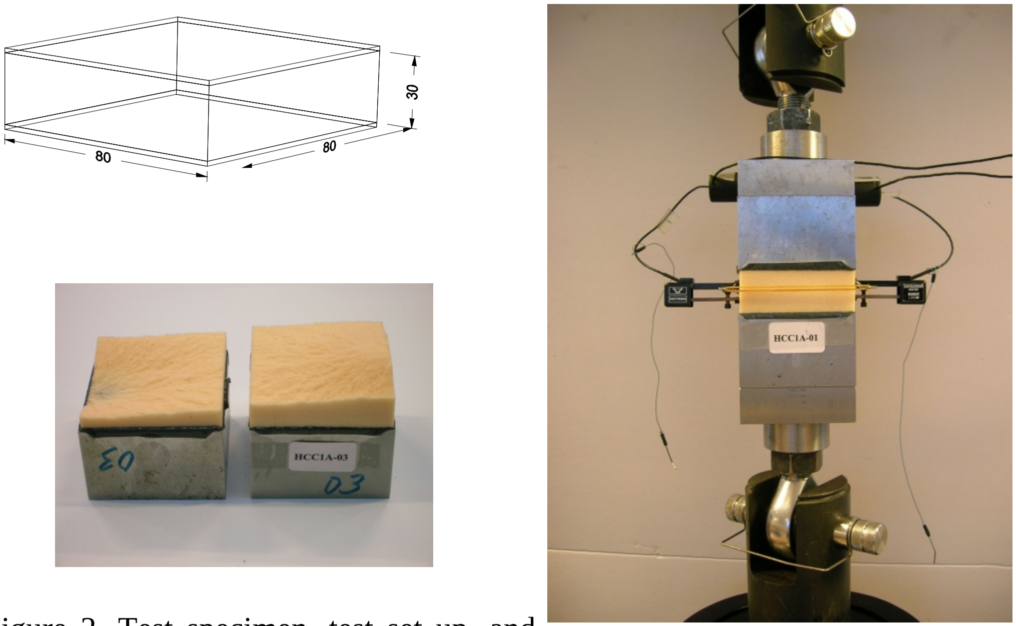

Figure 2. Test specimen, test set up, and failed test specimen for out-of-plane tensile testing. Extensometers are mounted to measure strain for calculation the E-modulus.

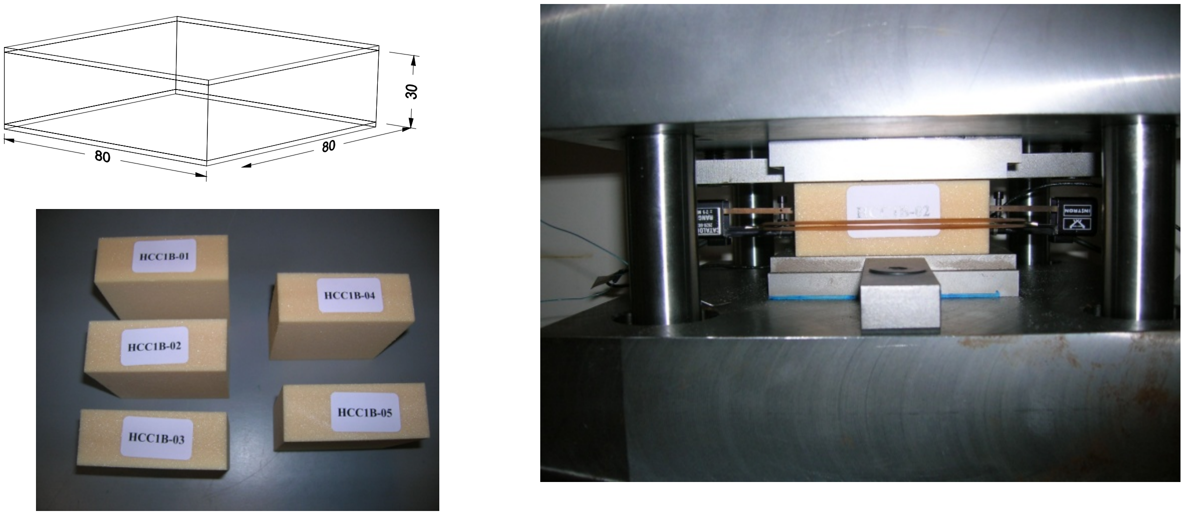

Figure 3. Test specimens and test set up for out-of-plane compression testing. The specimens is loaded in a 4 column guided pressure tool. Extensometers are mounted to measure strain for calculation the E-modulus.

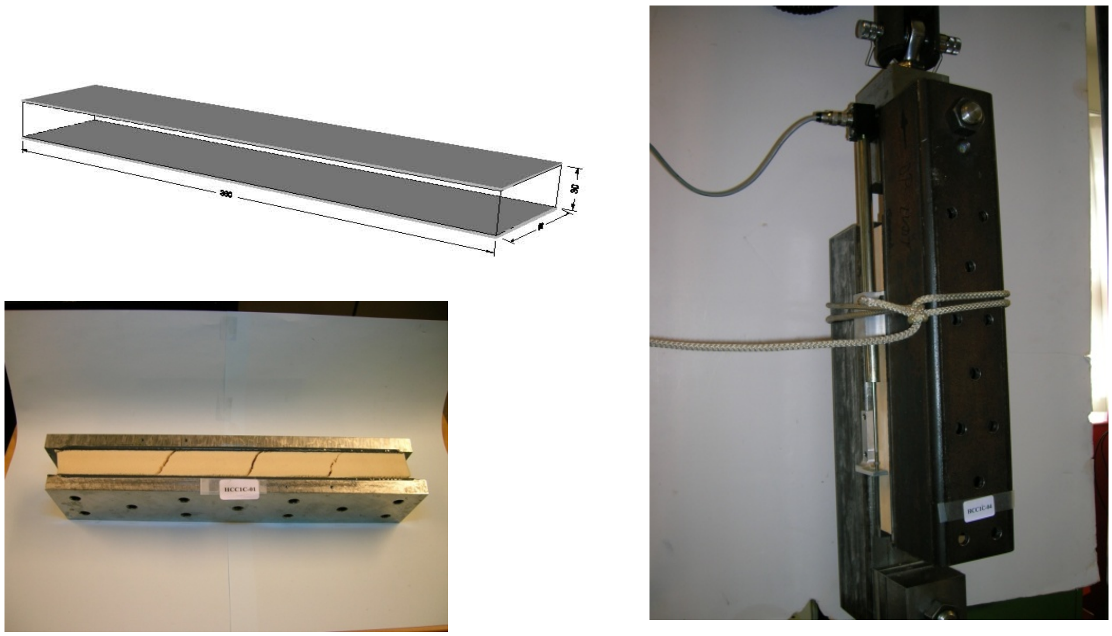

Figure 4. Test specimen, test set up, and failed test specimen for in-plane shear testing. The specimens are bonded to 10 mm thick plates which again are bolted on two square profiled tubes in order to avoid larger edge effects. An LVDT gauge is mounted to measure shear strain for calculation the G-modulus.

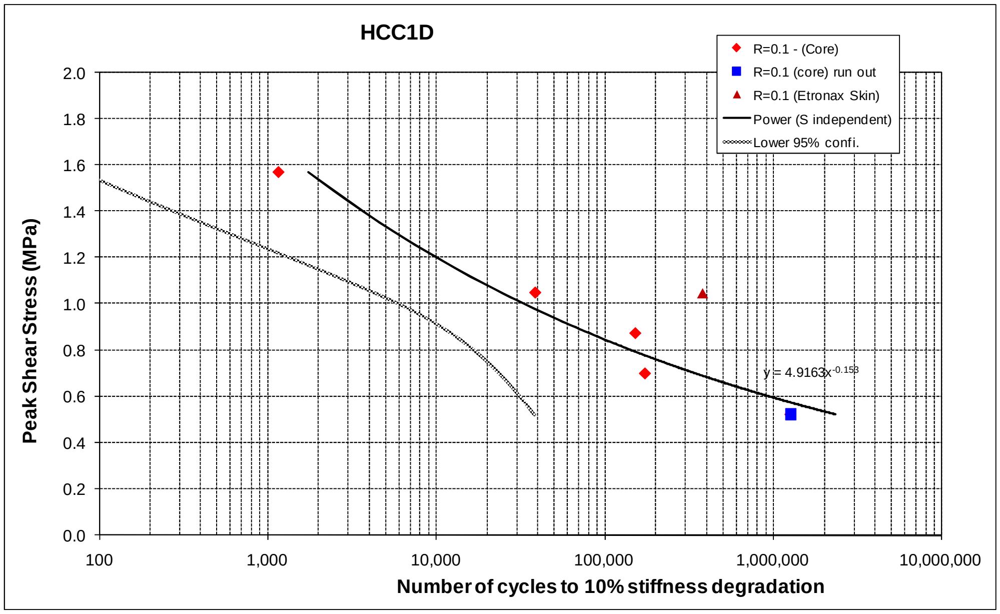

Figure 5. S_N curve with results for tests with core directly glued on the steel support and with the first result from test with same core glued to a standard glass-epoxy skin layer (more results will be available after paper deadline).

REFERENCES

1. P. Brøndsted, H. Lilholt, A.A. Lystrup, *Ann. Rev. Mater. Res.* **35**, 505 (2005).
2. Brøndsted, P., Holmes, J.W., Sørensen, B.F. Wind Rotor Blade Materials Technology. European Sustainable Energy Review (2008) (no.2) , 36-41.
3. Hayman, B.; Wedel-Heinen, J.; Brøndsted, P., Materials challenges in present and future wind energy. MRS Bulletin (2008) 33 , 343-353
4. B.F. Sørensen, E. Jørgensen, C.P. Debel, F.M. Jensen, H.M. Jensen, T.K. Jacobsen, K. Halling, "Improved Design of Large Wind Turbine Blade of Fiber Composites Based on Studies of Scale Effects (Phase 1)—Summary Report," (Report Risø-R-1390(EN), Risø National Laboratory, Roskilde, Denmark, 2004).
5. J. Wedel-Heinen, J.K. Tadich, C. Brokopf, L.G.J. Janssen, A.M. van Wingerde, D.R.V. van Delft, C.W. Kensche, T.P. Philippidis, P. Brøndsted, A.G.Dutton, R.P.L. Nijssen, *Implementation of OPTIMAT in Technical Standards, OB_TG6_R002 rev. 8, ENK6-CT-2001-00552 PROJECT N°: NNE5-2001-00174, OPTIMAT BLADES* (2006).
6. J. Wedel-Heinen, J.K. Tadich, *Proc. 27th Risø Conference on Materials Science, Polymer Composite Materials for Wind Power Turbines*, 115 (Risø National Laboratory, Roskilde, Denmark, 2006).
7. The Innovation Consortium: "Integrated Design and Processing of Lightweight Composite and Sandwich Structures - KOMPOSAND", The Danish Ministry of Research, 2003-2007.
8. H. Toftegaard, Initial Fixture Design for Direct Shear Testing of Sandwich Core Materials. Proceedings of the 27th Risø International Symposium on Materials Science: Polymer Composite Materials for Wind Power Turbines Editors: H. Lilholt et al. Risø National Laboratory, Roskilde, Denmark, 2006.

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