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Special Box Beam Sandwich for the weight optimised, innovative stiffening of large wind turbine rotor blades

Summary
At given tip speeds higher performance wind turbines require larger, longer rotor blades. Lengthening of rotor blades will increase their volume content more than their shell surface area. In spite of higher blade loads the potential from the greater volume should provide for specific weight reductions. Practically, however, larger wind turbines are known to be associated rather with specific overweights which in turn could be the cause of operative and life problems. Uncertainties in the kind of present rotor blade stiffening may also be responsible for such overweights.

Trade marked **PEKATEX**® a unique, prefabricated and very light box beam sandwich made from high value E-Glass and a controlled content of unsaturated polyester resin is being offered. The gridlike structure of the said box beam sandwich, the possibility of angled multilayer build, its energy absorbent damping characteristics will stiffen blade shells by sandwich or stringer lining as well as by struts supporting the blade main beams rationally, durably, innovatively, friendly to the enviroment and always taking weight optimization into account.

Some 10 percent of all wind turbine plants in operation in Germany are recorded and evaluated in a specific programme reported upon in the Windenergie-Report 2002*). The around 1500 wind turbines so listed average eight years in life and are equipped mostly with rotor blades up to just over 20 meters in length. The rotor blades of nearly 20 percent of these wind turbines needed a complete exchange, in particular in initial years of operation. For the few plants evaluated in the programme that are equipped with blades longer than 30 meters no details have been reported upon yet; they are in operation since four years only.

Many problems might have been overcome by now but in 2001 more than 200 rotor blade repairs were registered, reportedly the bulk of them provided by the larger plants. Perhaps this situation does not read across to all wind turbine plants in Germany, but apparently the insuring companies experience similar repair frequencies in all: lately, they ask for comprehensive periodic plant check-ups and they double their premium claims. Acknowledged industrial experts said during DEWEK 2002 also that the wind turbine industry is being urged to develop more powerful wind turbine plants ever although problems with existing (smaller) plants cannot be claimed to be resolved. The development of rotor blades in the 40 and 50 meter length range is in progress at several places. And in so developing the industry has to take recourse to the risk laden smaller blades by escalating and extrapolating from the experience gained with them.

Analogically, at the DEWEK 2002 responsible experts said in this context that weight assumptions made for the development of larger wind turbine plants in practice could not always be met.

Development of longer rotor blades

Presently, several companies are known to be engaged in the development of wind turbines with a nominal performance of four Megawatts and over. Blade tip speed given higher nominal performances require larger blade swept areas which mean longer rotor blades. When a rotor blade 20 meters long will be enlarged to 30, 40 or 50 meters in length the shell surface of the lengthened blade will increase but relatively not as much as its volume content will increase. Although with increasing blade size the blade surface area loads will increase and higher moments have to be absorbed, one would expect that the larger cross sections connected with the volume increase together with its associated potential for more stiffness that the specific weight growth as related to a given blade length increase will be rasther less than the specific shell surface area increase.

So far in practice this goal has not been achieved it seems. Perhaps, known insecurities are met by extra safety charges. Maybe, there are also special weight increasing design features such as for example in the flange area, where half the fibre strands embedded there are being „drilled out“, and need appropriate compensation. Equally, difficult quality assurance measures such as connected with the „hidden“ bondage of sandwich skin laminates may need special safety precaution. Where thinking in glass is en vogue proportional resin shares must not be overlooked. In manufacturing dominated by hand lay-up procedures resin shares could amount to more than 50 percent of weight.

High blade weights affect, of course, in a secondary way the blade flange as already shown, the hub, the main drive, the nacelle weight and more than all that. In any case overweight hardly produces more plant reliability or a longer plant life. The moral: Too much weight costs too much money.

*) Windenergie Report Deutschland 2002, Institut für Solare Energieversorgungstechnik, Kassel, 2002

A special box beam sandwich for blade stiffening

The characteristics, investigations and thoughts following relate to a unique, prefabricated, integral box beam sandwich trade named **PEKATEX**®. The very box beam sandwich incorporates the distance giving structure as well as the skins either side. The box beam sandwich referred to is a homogeneous RFP sandwich for the weight saving direct stiffening of the rotor blade shell against buckling and as a strut structure for limiting buckling areas (by ribs) and further for stiffening of the space between the main beams. The said special box beam sandwich weighs 40 kg/m³ by volume and the maximum resin content will not exceed 40 percent of weight. Performance data for a selected type of the special box beam sandwich are given in table 1–3. The special box beam sandwich mentioned qualifies for the weight optimizing stiffening of rotor blades by a number of unique features:

- The secial box beam sandwich is made from UP-resin and high quality E-glass fibres. Laminates of epoxy resin onto unsaturated polyester will produce a reactive close bondage.

- The special box beam sandwhich will make the flow of manufacture overseeable. Laminating resins can penetrate the gridlike open structure for a reactive and also for a mechanical hooking bondage. By embedding epoxy-foams for example both the blade shell can be stiffened against buckling and also the struts can be joined with the main beams giving low weight and good mechanical properties (see fig. 1). The described box beam sandwich will withstand temperatures up to and over 140°C.

- Towards frame work type of stiffening: The structure, build and the geometry of the special box beam sandwich as referred to will widen the designer's possibilities. The special box beam sandwich can accept additional skins, be it by lamination or by bonding on. However, with the benefit of its low volume weight and its low resin content one should analyse beforehand always to see if it will not be better economically as well as technically to use two ore more layers of the basic configuration of the special box beam sandwich. Thus it can be angle and frame work like arranged as required so that its given 0°/90° fibre orientation can be positioned and combined best according to the flow of forces. The described box beam sandwich can be adapted to the shell curvature and to the loads by chess-board type of lay-up of one or more layers, or alternatively to this sandwich by ribbed stiffening using skeleton profiles consisting of materials and retaining a structure similar to the said box beam sandwich (see fig. 2–4).

- The special box beam sandwich builds upon transparent configuration ever. Its bonds and joints can be looked at and viewed always, to allow quality assurance both in stiffening the shell as well in manufacturing the struts and ribs and their joints. And the described box beam sandwich by its „vented“ structure will hinder any settling of condensation in the blade.

- Excellent damping characteristics: By way of its gridlike structure the said box beam sandwich features a large energy absorbent capacity and will thereby dampen critical vibrations efficiently.

- Outstanding fatigue resistance: Dynamic tests with single layer highly loaded special box sandwich struts two meters high have demonstrated impressively outstanding fatigue resistance. These tests simulate the shear deformation magnitude of so-called century wind gusts' and known to be underlying certification proceedings. So far the struts made of the special box beam sandwich in this test survived five million load intervals without harm.

For the rapid development of larger rotor blades ever, the said box beam sandwich will offer the solution for the manufacture of light, rationally made and durable rotor blades, friendly to the environment. Given the aerodynamic shell geometry and the main beam design much will depend upon the necessary design and manufacturing know-how being conveyed and adapted to certification requirements so that the developing company as well as its customers will draw lasting benefit from the advantages of the special box beam sandwich technology.

PEKATEX® Type RE/RO 30
Structural characteristics

fig. 1

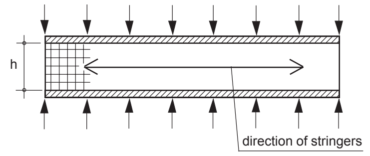
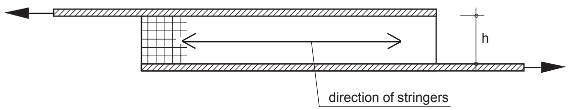
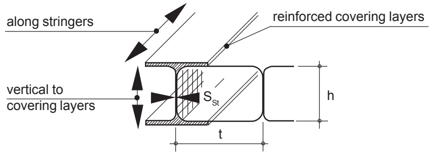


fig. 2



to fig. 1 and 2



Weight ± 10%	G	kg/m²	1.2
Height of stringers	h	mm	30
Space between stringers	t	mm	64
Thickness of stringers	S_{St}	mm	1.63
Length of stringers per m²		m	16
Stringers			
vertical to covering layers according fig. 1			
Compression - Stress to failure		N/mm²	7.5
- Strain at failure load		% of stringer height	2.0
- Modulus		N/mm²	376
- Load to failure		N per mm stringer length	12.2
		N per 16 m stringer length	195,200
Stringers			
over covering layers along stringers according fig. 2			
Shear - Stress to failure		N/mm²	4.4
- Strain at failure load		% of stringer height	4.1
- Modulus		N/mm²	106
- Load to failure		N per mm stringer length	7.1
		N per 16 m stringer length	113,600

Table 1

PEKATEX® Type RE/RO 30
Product characteristics

fig. 1

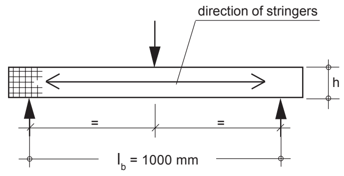
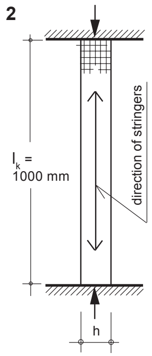
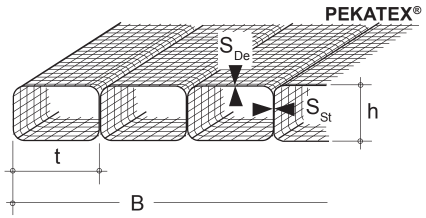


fig. 2



to fig. 1 and 2



Weight ± 10%	G	kg/m²	1.2
Height of stringers	h	mm	30
Space between stringers	t	mm	64
Thickness of stringers	S_{St}	mm	1.63
Thickness of covering layers	S_{De}	mm	0.66
Stringers per m width	B	number	16
PEKATEX®			
Tests according fig. 1			
Flexure - Stress to failure		N/mm²	5.03
- Flexure at failure load		mm	1.5
- Modulus		N/mm²	2,431
- Load to failure		N per 2 stringers (one box)	45.5
		N per 16 stringers	364
PEKATEX®			
Tests according fig. 2			
Buckling, creasing			
- Stress to failure		N/mm²	3.99
- Compression at failure load		mm	2.3
- Modulus		N/mm²	1,735
- Load to failure		N per 2 stringers (one box)	896
		N per 16 stringers	7,168

Table 2

PEKATEX® Type RE/RO 30
Product characteristics

PEKATEX® Structural section at 90° angle to direction of stringers and boxes

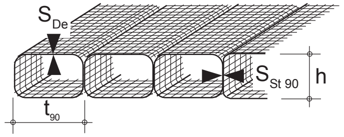


fig. 1

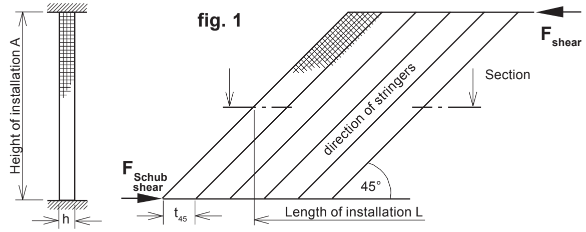
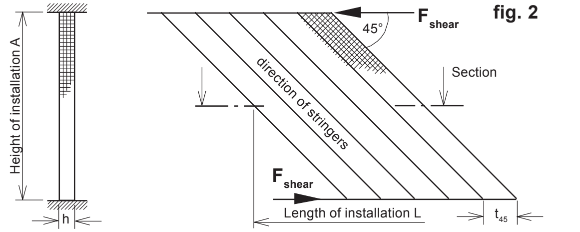
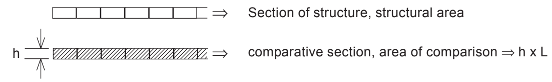


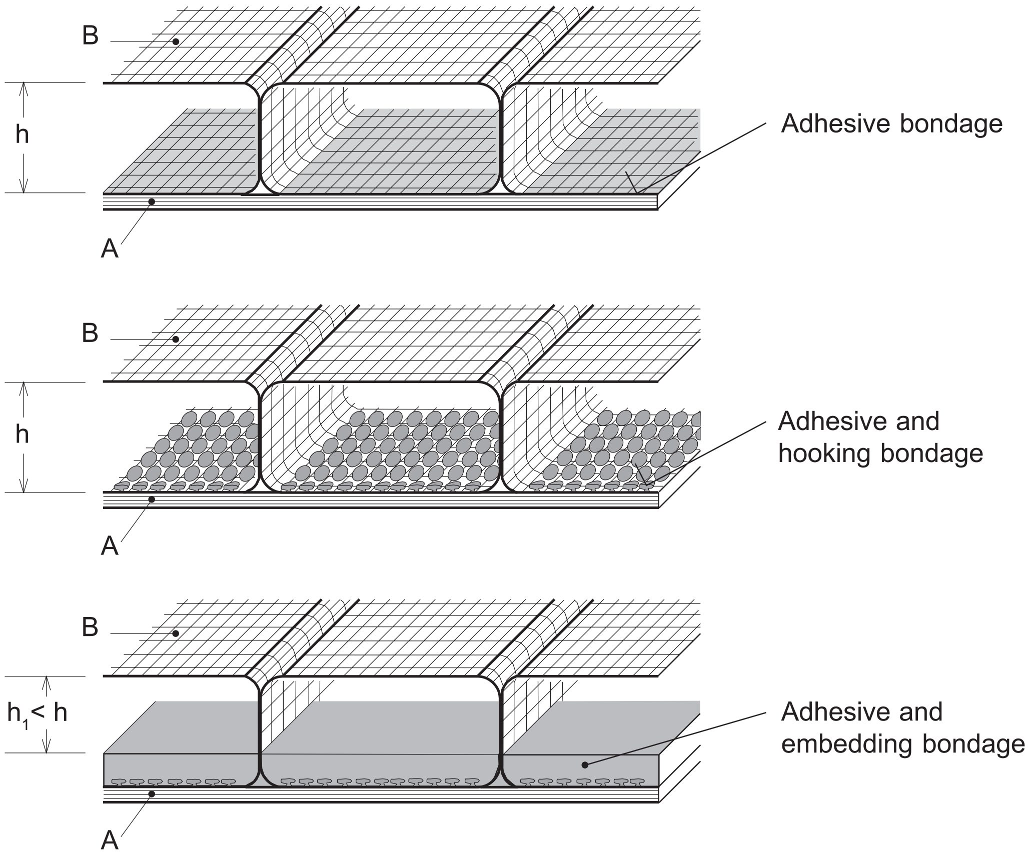
fig. 2





Weight ± 10%	G	kg/m²	1.2
Thickness of sheets/Heigth of stringers	h	mm	30
Thickness of covering layer	S_{De}	mm	0.66
Space between stringers	t_{90}	mm	64
Thickness of stringers	S_{St90}	mm	1.63
Space between stringers	t_{45}	mm	90.5
Thickness of stringers	S_{St45}	mm	2.31
Tests according fig. 1			
(Compressive loads dominant)			
Shear - Stress to failure		N/mm² structural area	1.54
		N/mm² comparative area	(0.11)
- Strain at failure load		% of installation height A	0.73
- Modulus		N/mm² structural area	211
		N/mm² comparative area	(15)
- Load to failure		N per PEKATEX®-box	304
		N per 1 m installational lenght L	3,359
Tests according fig. 2			
(Tensile loads dominant)			
Shear - Stress to failure		N/mm² structural area	33.65
		N/mm² comparative area	(2.43)
- Strain at failure load		% of installation height A	10.7
- Modulus		N/mm² structural area	315
		N/mm² comparative area	(23)
- Load to failure		N per PEKATEX®-box	6,632
		N per 1 m installational lenght L	73,282

Table 3



A ⇒ Shell laminate
B ⇒ PEKATEX®-Box beam sandwich

h or h_1 ⇒ effective height of Sandwich-shear strut

Fig. 1: Stiffening of rotor blade shell against buckling by PEKATEX®-Box beam sandwich
here: Compounding variants

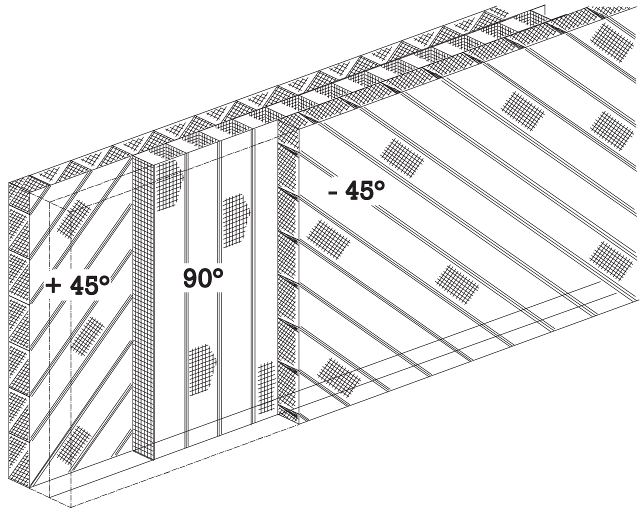


Fig. 2: PEKATEX®-Shear strut for stiffening of space between rotor blade main beams
here: 3-layer configuration

Fig. 3: Shear load test with a two layer ± 45° PEKATEX®-Strut configuration

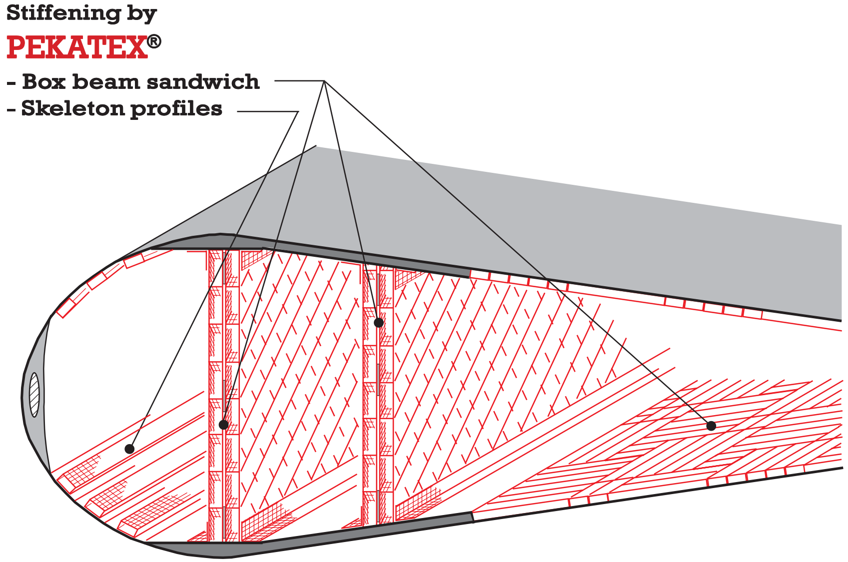


Fig. 4: Rotor blade strut stiffening between main beams and stiffening of the shell against buckling by PEKATEX®-Box beam sandwich or skeleton profiles

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