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Optimized fibre placement for composites

The builders of cathedrals probably didn't even know that the stones and mortar they were using were composite materials: two materials with different properties, stone being the basic element and the mortar, the binder. During the Roman period, and even into the Gothic, they did without rebar, concrete, screws, or metal fittings. And yet the buildings are still standing after many centuries, magnificent and complex engineering works created using intricate workmanship, knowledge and know-how – and all without computer-aided design or finite element analysis.

By

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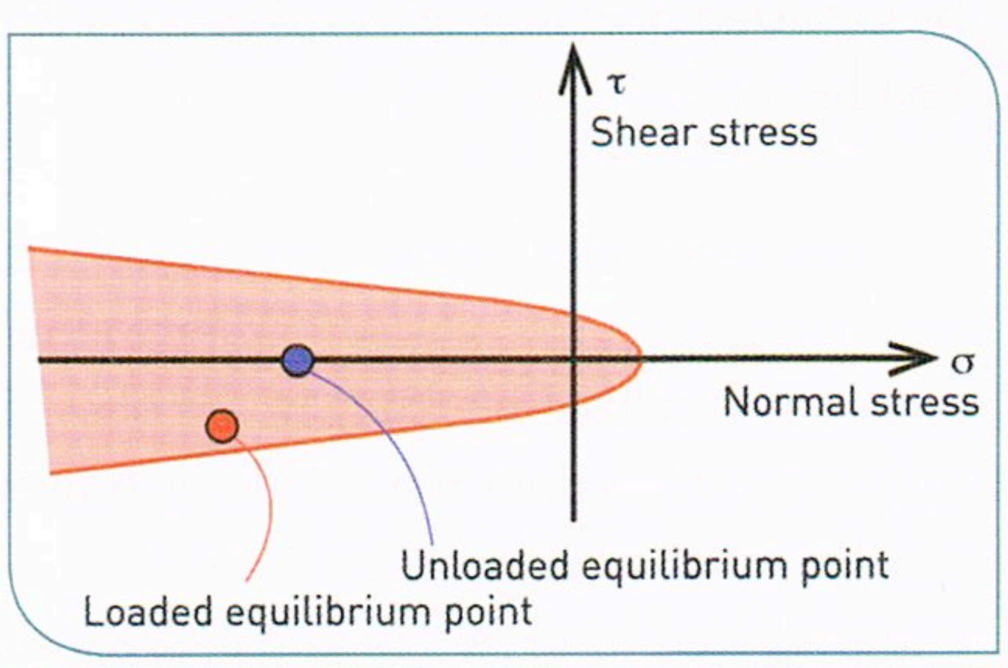
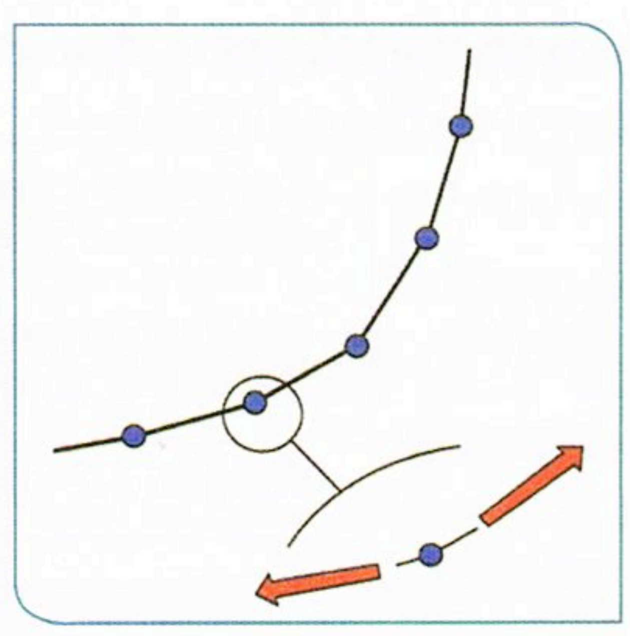
The arches of old bridges are capable of absorbing stress through compression between the stones. Correct bridge design places the stones under compression by the bridge's own weight. The mortar and/or the adhesion between stones allows a slight transverse load (shear), making the engineering structure stable under exterior loads.



Resin area of use

French trade guild's design method

The medieval equivalent of a funi-cular diagram used a cord and weights to determine loads down to the ground and reach an equilibrium. In the arch design, each weight along the cord represented a stone in the future edifice, but in mirror image with respect to the horizontal plane. The result is a simple and efficient compression arch.



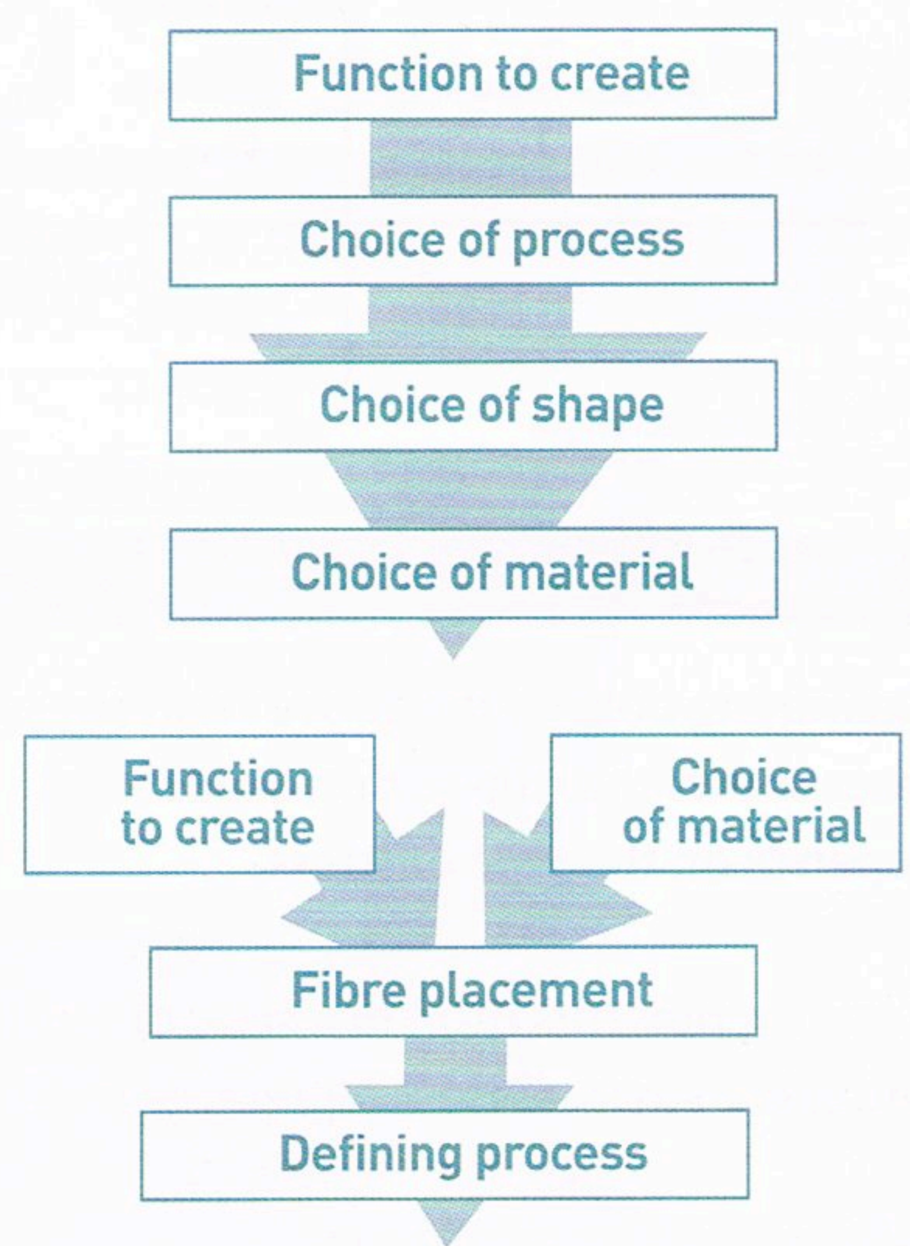
Tension along the cord

Design: looking to the future with a glance in the rear-view mirror

Composite manufacturers complain about poorly designed parts, often with reference to the "black metal" concept, i.e. the idea that the design of these parts tends to be based on methodologies from expertise in metal design that are not directly applicable to composites.

The composite part cannot be defined as a function of:

- design tools,
- modelling tools, or
- production facilities.

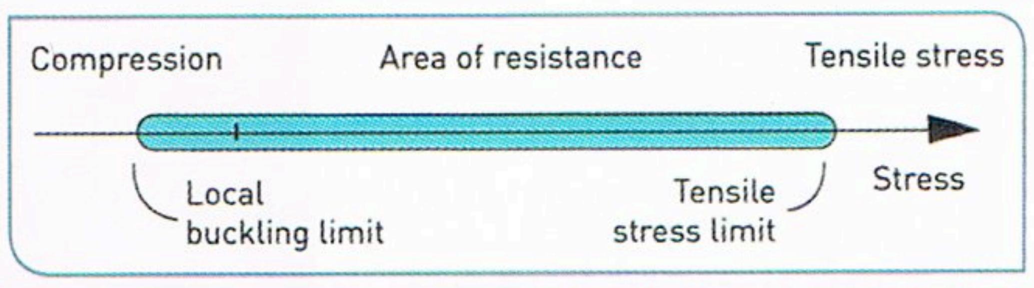


The computer tools must serve the designer by correctly defining the intrinsic performance of the chosen materials, and this means defining the physical phenomena that are capable of destroying the materials. Correct fibre placement is crucial for the mechanical strength performance.
A few simple rules to guarantee correct part

performance are to prioritize fibre tensile and compression strength and to avoid subjecting the resin to stress, particularly to tensile stress.

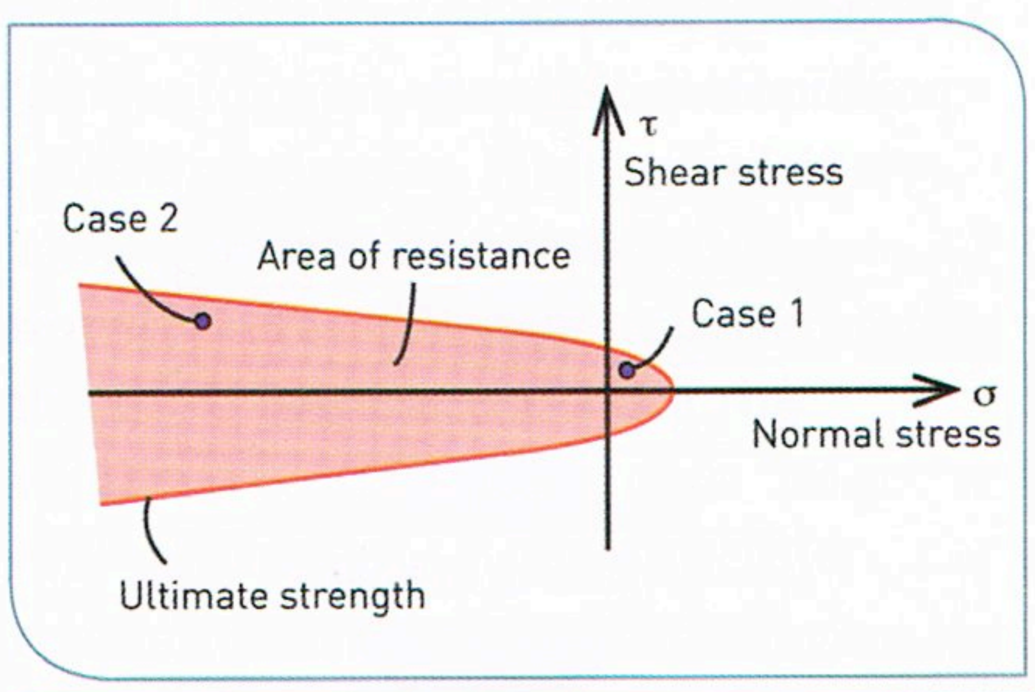
Fibres and resin: like chalk and cheese

By their very nature, fibres and resin are strikingly different materials, for both isotropy and performance level.
Whatever the type, fibres are basically long and thin. They resist local tensile stress and compression (which is limited by local buckling), but not bending or twisting.



Fiber area of use

By nature, resin is a homogeneous and isotropic material, i.e. there is no preferential strength direction. The damage mode is more complicated for this type of material, as illustrated by Mohr's circle.



Resin area of use

Examining both of the above resin stress cases shows that the performance level depends on the type of stress.

Case 1 represents resin in a state of tensile and shear stress. Case 2 represents resin in a state of compression and shear stress.
The shear tolerated in Case 2 is much higher than the shear tolerated in Case 1.

More information

The preliminary design analysis is based on the materials. The fibre placement (location and orientation) must be optimized to enable:
-limited tension and compression on the fibres
-compression and shear on the resin.

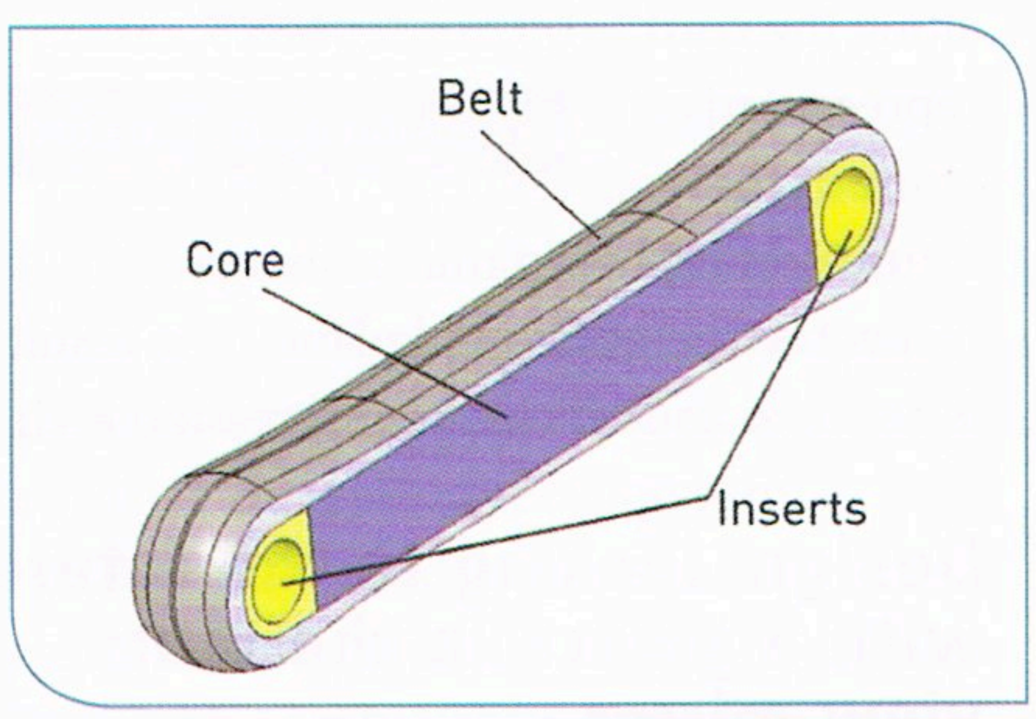
Application to connecting rods

The connecting rod shown is of the heavily loaded type used in aircraft landing gear and in the railway industry. When compression or tensile stress occurs between the eyelets, the areas around the eyelets are subject to heavy shear stress.
The design for the new composite connecting rod is based on the rules mentioned earlier, i.e. relying on the carbon fibre's tensile and compression strength, as the resin is not subjected to stress at all in this application. The TA6V inserts are held in place in a prestressed assembly, sandwiched between a compression core and a tension belt. This concept has been applied to a connecting rod for landing gear with the following characteristics:

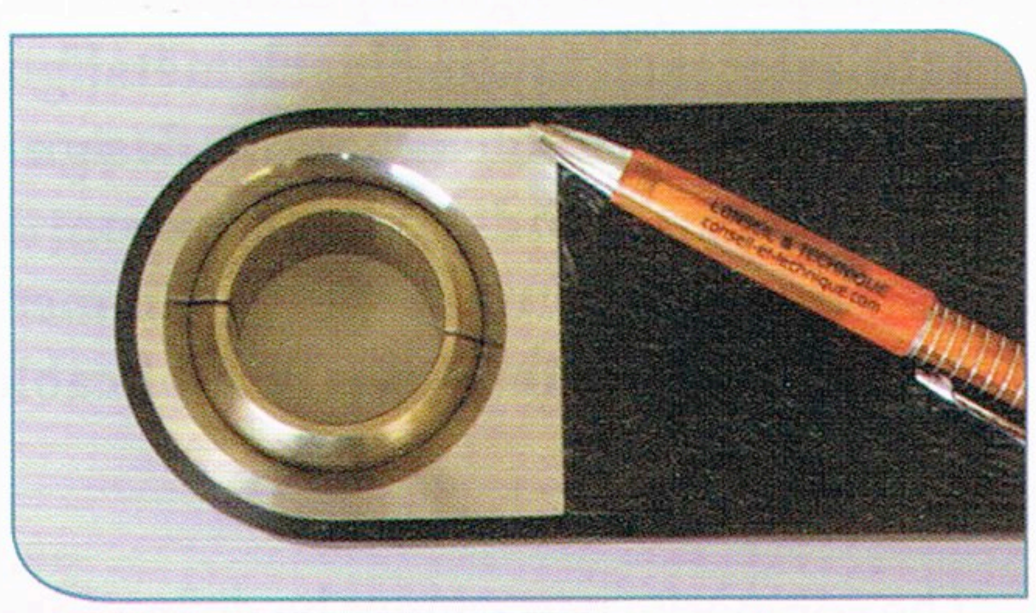
Centre-to-centre distance: 850 mm

Loads: 50 metric tons (tensile & compression)

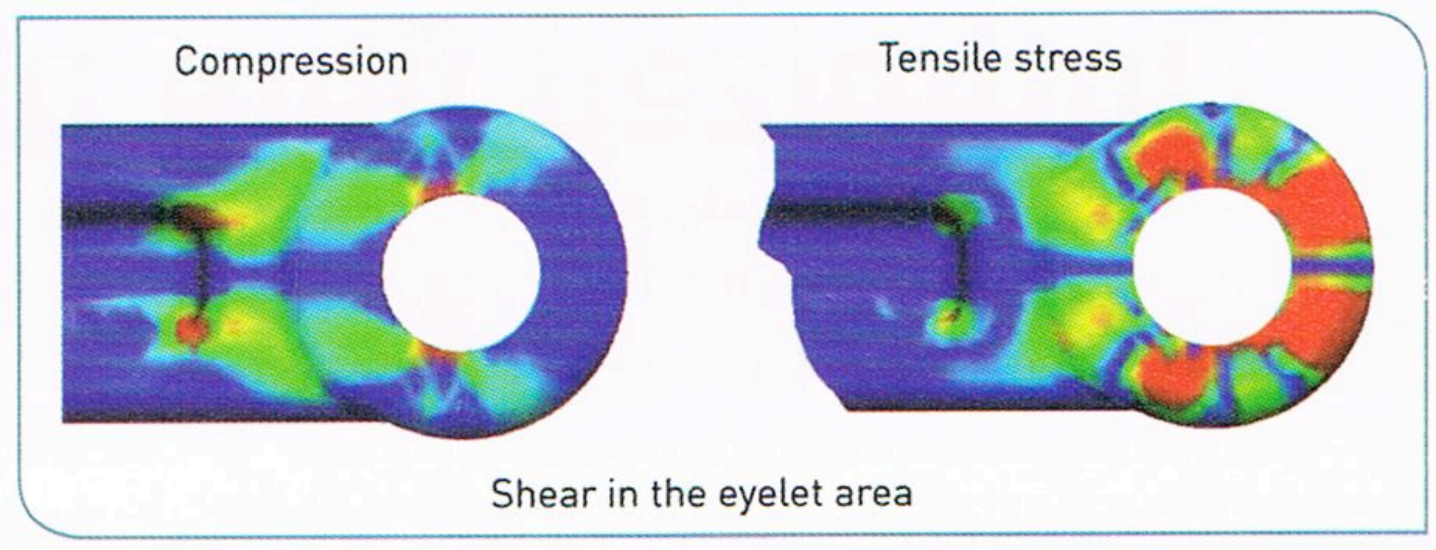
Weight: 4.2 kg



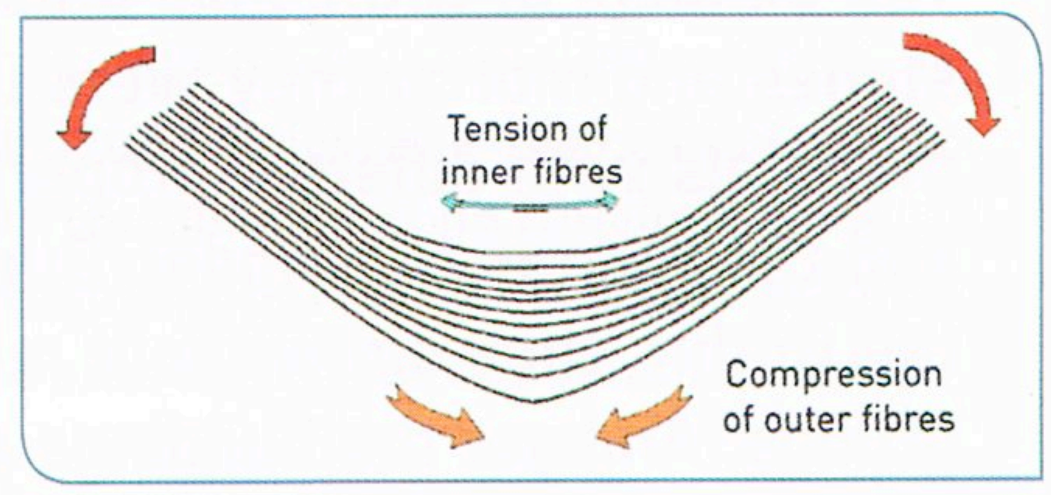
Rod High Mechanical Resistance



Creation: C&T/BTSi/SKF



Problem : Resin shearing



Problem : Unfolding stress in fibers

The resulting connecting rod has a knuckle joint at each end in order to receive 38-mm-diameter axes. The tensile and buckling strength was tested following multiple 90-Joule impacts in the critical areas.

Application to the problem of unfolding

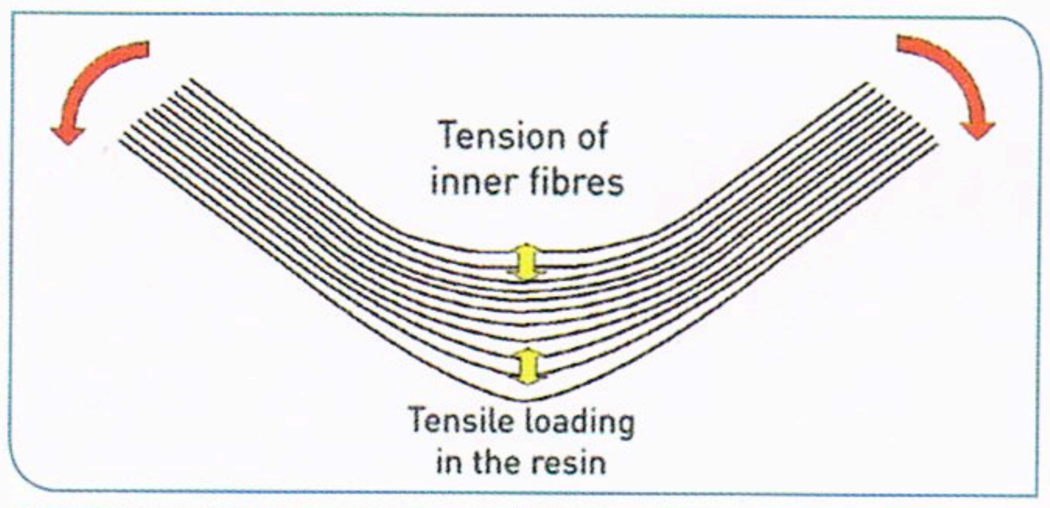
Composite structural parts often have more or less sharp angles that give rise to a complex stress mode called "unfolding", defined as an increase in the angle between walls due to a bending moment.
The plies inside the bend radius are pulled and those outside the bend radius are compressed, subjecting the resin to tensile loading both inside and outside the bend radius.

Rupture is caused by delamination of the plies inside and outside the bend radius and by localized buckling of the plies outside the bend radius.

The part has a weak point that is due to the combined action of tensile loading in the resin and localized buckling of the plies. This unfolding stress does not act alone, however, and the stressed state is almost always compounded by shear loading in the resin at its weak point.

Application to structural parts

The part shape was modified so that the part could withstand a bending moment in the metal fitting's area of unfolding. In this area



The original parts (linking parts between two perpendicular walls)

of unfolding, the new wavy shell design reinforces both the tension on the inner face and the compression on the outer face, while significantly reducing interlaminar shear between the composite plies.

Breaking strength tests were carried out on parts with the new shape. Ruptures occurred at a mean stress of 500 MPa, without any rupturing of the resin by delamination or shear in the critical area. This technology was developed by Conseil & Technique and validated by SKF Aerospace for performance and feasibility. The concept is now patented, and industrialization studies have begun on an application for a primary aircraft structure. When the Conseil & Technique part was compared with a control part at identical weights, there was a clear gain in mechanical strength and stiffness for the C&T part: specifically, a significant increase in resistance to initial damage characterized by the linearity of the load-displacement curves for the redesigned parts. A further gain is possible, and the SKF Engineering et Research Centre is currently optimizing the shape to minimize resin shear and maximize more "desirable" fibre loading. ■

More information:
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