In-plane shear test methodologies for Fibre Reinforced Polymers

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Strength, lightness, stiffness and durability are some of the reasons why Fibre Reinforced Polymers (FRPs) are increasingly being employed in many engineering sectors. As the research for new material configurations, the development of automated manufacturing techniques and the range of applications continue to rise, innovative and improved testing methodologies need to continuously be developed in order to optimise their analysis and design. Therefore, reliable testing methodologies which are able to take into account the complex material behaviour of composites are required.

Together with the tensile and compressive mechanical properties of composite materials, the in-plane shear properties also play an important role. In this case, the loading direction is not along the fibres and, therefore, the anisotropy of these materials is highlighted. The strength of the material decreases when the loading direction is shifted and, consequently, not only depends on the reinforcing fibres, but also on the interaction between the fibre/matrix. Regarding the determination of in-plane shear properties, several test methods are widely used. These generally include the Short Beam Shear (ASTM D 2344), the Iosipescu Shear (ASTM D 5379), the ±45° Tensile Shear (DIN EN 14129), the Torsional Tube Shear (ASTM D 5448), the Two- and Three-Rail Shear (ASTM D 4255), the V-Notched Rail Shear (ASTM D 7078).

The extensive variety of testing methods is due to the difficulty in determining the in-plane shear properties of composite materials by means of a pure and uniform shear distribution throughout the test specimen up to failure. Therefore, each methodology presents its own advantages and disadvantages.

Experimental test program

At Grasse Zur Composite Testing, an experimental comparison between three different test methodologies used in the characterisation of the in-plane shear response of composite materials has been undertaken. These are the ±45° Tensile Shear, the V-Notched Rail Shear and the newly developed shear frame from Grasse Zur (DIN Spec 4885).

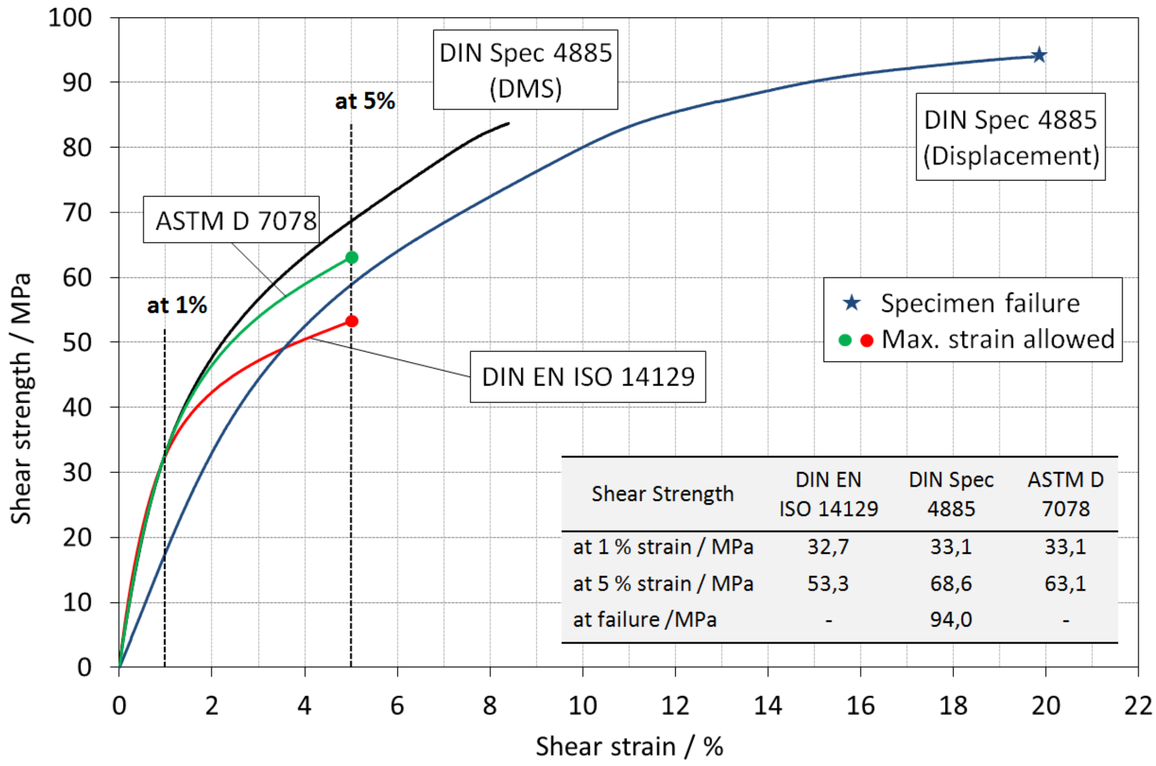
The ±45° tensile shear test is one of the most popular testing methods. It consists of a rectangular and flat specimen, which resembles a tensile specimen, with the specific fibre orientation at ±45° in order to induce the shear loading. Even though it stands out for its simplicity and rapid execution, there are several drawbacks which must be taken into account. It has been reported that the stress state in the specimen can be complex and the results may be dependent on the laminae. Also, the test must be completed at a maximum shear strain of 5% to minimise fibre rotation and undesired effects as the edges of the specimen are not clamped.

The V-notched rail test ASTM D 7078 was developed taking into consideration the advantages of the mentioned Iosipescu Shear and the Two- and Three-Rail Shear. A reasonably pure shear stress state can be introduced at the centre of the specimen through its geometry. However, the V-notches may lead to large standard deviations due to possible stress concentrations and load shifts, especially at high strain ratios. In addition, the test must also be completed at a maximum shear strain of 5%. As composite materials exhibit high non-linear behaviour when loaded under shear conditions and failure due to inter-fibre failure occuring at large deformations, this is a limitation that requires further attention. Accordingly, a new testing methodology based on a picture frame, formerly established at the German Federal Institute for Materials Research and Testing (BAM), has been commercially developed at Grasse Zur Composite Testing. This new fixture offers significant advantages over existing methods and, therefore, allows for a full characterisation of composite materials under shear loading. This testing method has rapidly gained importance and, as a result, has been standardised as

DIN SPEC 4885:2014 and has been recently included into the new DNV GL guidelines for the material characterisation of rotor blades in the wind energy sector (DNVGL-ST-0376 https://rules.dnvgl.com/docs/pdf/DNVGL/ST/2015-12/DNVGL-ST-0376.pdf).

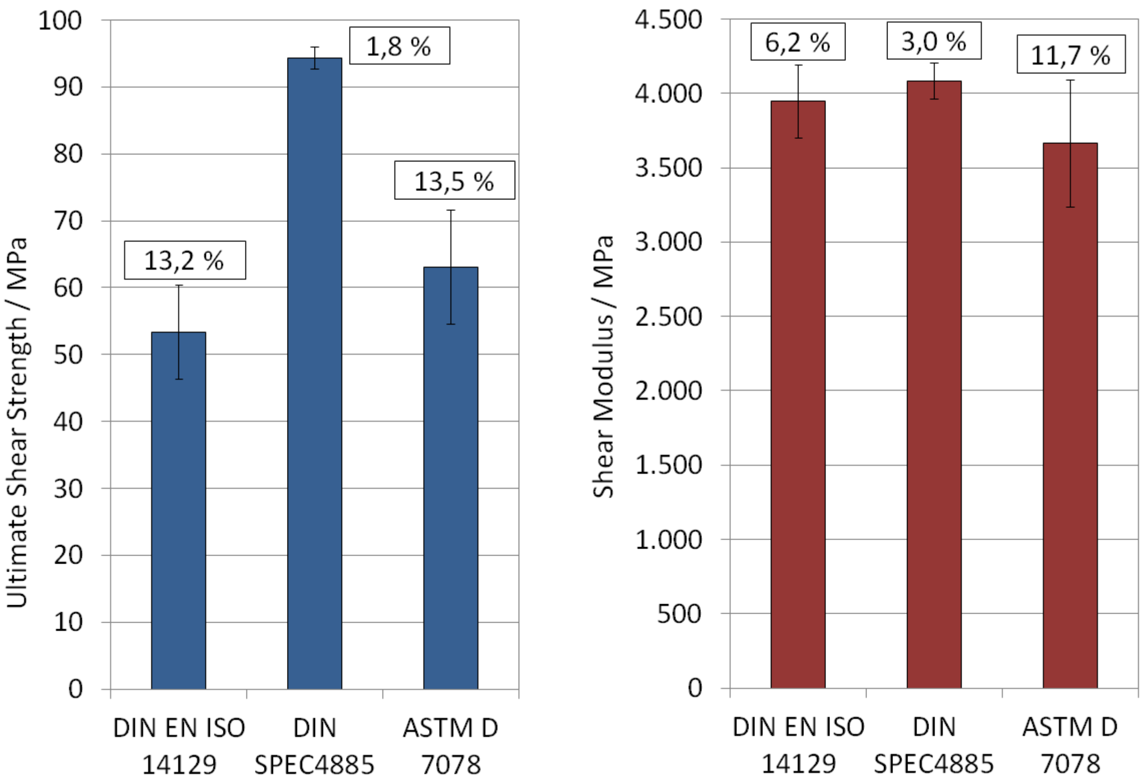
Results and discussion

The material chosen in this particular study was a biaxial glass-fibre reinforced epoxy resin, which is widely used in the manufacturing of wind turbine blades for both small and large wind turbines. Results from the in-plane shear stiffness and shear strength are presented as follows:



Shear Strength	DIN EN ISO 14129	DIN Spec 4885	ASTM D 7078
at 1 % strain / MPa	32,7	33,1	33,1
at 5 % strain / MPa	53,3	68,6	63,1
at failure /MPa	-	94,0	-

Experimental average in-plane shear stress-strain curves concerning different test methods.



Comparison of shear strength and shear stiffness obtained through different test methods.

In all three test methodologies, the shear strain was measured by means of strain gauges which were placed on the specimens following the specifications of each standard. Only when the shear frame method was used, the shear strain was also calculated through the displacement of the moveable crosshead of the testing machine as the maximum physical elongation of the strain gauges was reached (above 8%) before the failure of the specimens.

It was experimentally observed that the shear-strain curve was very similar for all methods up to the point of 1 % shear strain. As the shear modulus is frequently studied between 0,1 and 0,5 % of the shear strain, these methods allow the shear modulus to be reasonably obtained.

Nevertheless, dissimilar behaviour can be observed from 1 % of shear strain, particularly when analysing the composite material at higher strain values. It is worth mentioning that the specimens tested according to the ±45° tensile shear test and the V-notched rail test where limited to a maximum of 5% of shear strain as it is specified in their respective standards, although failure was not reached. At this point, great differences can already be observed where the drawbacks of each method mentioned before may lead to a distortion of the results. On the other hand, the ultimate shear strength can be reached through the shear frame method as it allows a pure shear stress distribution in the specimen. This stress distribution is mainly uniform with a maximum peak located at the centre of the specimen, avoiding a specimen failure in the clamping region.

General conclusions

As the inter-fibre failure for composite materials presents high nonlinearities, a proper characterisation of these materials must be undertaken through testing methods which are able to describe their response, even at large deformations.

The results of this study and the experience of Grasse Zur Composite Testing show that the shear frame test apparatus offers significant advantages over existing methods when determining the shear response of composite materials, especially at high strain ratios. Its main benefits are shown as follows:

- High quality results with low standard deviations.
- No notch or free-edge effects.
- Pure shear loading in specimen with a maximum peak at the centre of the specimen.
- Determination of ultimate shear strength/strain at high deformations (>> 5 %)

Further information regarding the characterisation of composite materials under static and dynamic loading can be found on http://grassezur.de/en/

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