AN APPROACH TO MINIMIZE INHOMOGENEOUS STRESS DISTRIBUTION IN COMPRESSION TESTING OF CFRP

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Abstract

To measure the compression strength of unidirectional Carbon Fibre Reinforced Plastics (CFRP) is difficult. Various compression tests show significant inhomogeneous stress states, leading to a multiple failure mode. In the new approach different lubricants between specimen and loading equipment were tested to reduce multiaxial stress state in the loading area. The test method was modelled by Finite-Element Analysis (FEA) using a multiple body contact model including different coefficients of friction between the bodies as well as plasticity. The unidirectional cylindrical specimens were tested under compression. The model predictions and the tests show good agreement in the deformed shapes under loading. Depending on the lubricant the failure changes from fibre buckling to a pure cross tensile failure. However, the compression strength is not highly dependent on the edge modification, whereas deviation and failure are.

1 Introduction

Today large composite structures are used in high performance applications e.g. wind turbine blades. The compression strength is one parameter necessary for the design of these structures. In praxis the design often is too conservative, due to experimental data which gives too low values for the compression strength of unidirectional composites.

The compression testing of CFRP unidirectional laminates is a difficult task. The established compression tests like ITRII, Celanese or Sendeckyj-Rolfes are based on shear loaded tabs turning into compression along the gage length. Problematic are the peak stresses induced at the borderline of gage and tab leading to an inhomogeneous stress state [1]. Hence the laminate is restricted by the tabs, and the clamping failure occurs in a undesirable way.

Other compression tests are end-loaded e.g. Rockwell (ASTM). This leads often to brooming at the loading surfaces. This brooming origins from a multi axis stress state due to friction between the specimen and loading device. This results in undeformed areas close to the end faces which induce kink band failure. To avoid this stress state we need to allow free extension of the specimen (transverse motion of the specimen between the loading device).

On the other hand other test methods lead to an overestimation of the compression strength when support of the specimen is used to avoid buckling [2]. In this case the transverse extension of the compressed specimen is often prevented and transverse tensile failure can not occur.

The specimen geometry used in this work is a cylinder with a diameter to height ratio of 0.5. Therefore no side support during the test is necessary. In addition a lubricant (grease), a thermoplastic (polyethylene LD-PE) and an eleastomeric (rubber) sheet were tested as a separator between specimen and load device to allow free extension of the specimen over the full gage length. To validate the results tests were also performed using unlubricated end faces.

2 Test configuration

The FEA model were performed using the Marc/Mentat™ code. The element type was a 3-dimensional Hex_8. The lubricant was modeled by applying different coefficients of friction between the specimen and loading device, whereas the plastic separators were modeled as an elastic-plastic body.

The test was designed for thick laminates. The material used in this test was IMS carbon fiber (Toho Tenax) with 977-2 matrix system. The fiber volume fraction was 65 % respectively. A laminate with 12mm thickness was autoclave cured and cut in sections of 12 x 40 mm. In a commercial turning lathe the cross section was reduced leading to a specimen dimension of 10x20mm.

The test was performed in a standard quasi-static testing machine at a testing speed of 1mm/min. The specimens were placed with the lubricants on each side between flat parallel polished steel plates. The deformation was observed by a digital camera connected to a microscope. The shape difference observation was done by subtracting a picture of the loaded and the unloaded state.

3 Results

3.1 FEA

The FE-Analysis showed a convex deformation of the non lubricated specimen under loading. The analysis of the separator modified test predicts a homogenous cylindrical deformation over the specimen length.

The separators react in a particular way. The LE-PE sheet deformed highly plastically while the rubber showed an elastic deformation. The plastic deformation and the lubricant on the end faces exhibited a cylindrical deformation and a free extension of the specimen at the loading surface.

3.2 Testing

During the tests the lubricant squeezed out of the specimen/device interphase leaving a thin film behind. The PE and rubber separators behave like predicted in the FEA. Therefore a homogeneous compression for the tests modified by lubricant or polymeric film is assumed.

The deformation of the specimen showed a behaviour as predicted by the FE-analysis. The unmodified test showed a convex deformation of the specimen, while the modifications led to a cylindrical deformation.

The investigation of the final fracture surfaces showed pronounced differences in the failure mode. While the unlubricated specimens showed kink band formation under 45° along the shear bands forming a cone at both end faces, the specimens using LD-PE or lubrication failed in transverse tensile failure along the whole specimen length.

The average compression strength values are given in table 1.

While rubber as separator material did not increase the measured values, a light improvement was observed for LD-PE. Lubrication resulted in the highest strength values measured. The scatter of the values was minimized by grease and LD-PE.

Table 1. Compression strength of unidirectional CFRP using different separators.

Separator	average compression strength [N/mm²]	min. max. [N/mm²]
non	756	573 915
grease	861	783 1045
LD-PE	771	600 885
rubber	748	454 972

4 Discussion

The separators between the loading device and the cylindrical specimen lead to a more homogenous stress state at the loading edges. However the final failure of the relatively thick specimens reaches about the same values as the unmodified test. The scatter of the results decreased by using a separator like LD-PE, whereas rubber shows higher scatter. The best performance shows the grease where greater compression strength with relatively low variation could be observed.

The unchanged compression strength due to the modification can be connected with a similar failure initiation but differences in further failure process. Also a cross tensile fracture instead of kink band failure is observed. This leads to the theoretical maximum value of the compression strength in case of free deformation. Where the failure mode is guided by the transverse tensile strength of the laminate.

5 Conclusion

The new approach for the determination of the compression strength of unidirectional laminates shows good agreement in the elastic modeling and the testing. A more homogenous stress distribution is achieved by using lubricants or separators. However the ultimate compression strength increased by >10% with the modification.

References

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