Research Project

A new connection technique for fiber composites

Executive Report

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Content

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Parts of this report are an approved prior printed publication of the PhD-Thesis of Jürgen Denonville [1] and are coincide with it in word and content.

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1 Research objective

1.1 Problem Statement

Fiber Composite Elements which are used in the structural engineering segment are usually pultruded profiles. Because of the manufacturing process the fibers are unidirectional (UD) arranged in the longitudinal direction of the elements. Their lightweight potential could be used very well for tension elements or truss elements. But in the load transition zone or connection zone the orthotropic material behavior is adverse. Because in these areas there are multidimensional stress conditions which have to be carried by the weak polymer matrix. Stress concentrations in the elements are dependent from the kind of and execution of the connection. In addition they are higher for anisotropic materials like the unidirectional composites then for isotropic materials [2].

The connection technique is very important for the use of UD-Composites as structural elements.

The state of the art technologies are not adaptive to the boundary conditions of a structural site (e.g. adhesive bonding) or need more space than connections of conventional materials (e.g. loop or clamping) or are not efficient (e.g. bolted connections).

So the aim is to develop a connection technique, which keeps the high performance of the material and is easy to execute on a construction site and compatible with the conditions on it.

1.2 Solution Statement

The solution approach which was investigated in this project and in [1] and which was developed at the institute of lightweight structures and conceptual design (ILEK) is to substitute the polymer matrix by a more efficient metallic matrix in the area of load transition.

On the assumption of a constant fiber volume the following modifications could be postulated:

- The fibers will be unloaded because of the higher stiffness of the metallic matrix.
- The ratio of the Young Moduls longitudinal and orthogonal (E_1/E_2) to the fiber direction will be reduced. This will have a positive effect to the stress concentrations.
- The inelastic deformation behavior of the metallic matrix could reduce the stress concentrations.
- Because of the higher shear stiffness pointed loads could be distributed in short distances.
- The bearing resistance of a bolted connection could be increased.
- The metallic matrix gives the possibility to connect the composite element with other metallic elements with suitable welding methods.
- The usage of pretension connections will be optimized.

Because of these positive effects it can be assumpted that bolted connections can be more efficient than with the polymer matrix.

Picture 1-1 shows this idea for three different structural glass fiber profiles.

In opposite to existing solutions this idea uses the main advantages of composite materials, the possibility to combine two or more under consideration of the requirements.

Picture 1-1 Rendering of the solution idea for three different structural glassfiber profiles; *left:* I-Profil; *middle*: U-Profil; *right:*flat profile

1.3 Execution

To realize the solution approach it is necessary to combine the endless long carbon or glass fibers with the metallic matrix without losing their properties. For the production of metall matrix composites are various methods are established.

At the institute for Forming Technology (IFU) semi solid metal forming methods were investigated since 1998. This methods use the thixotropic properties of semi solid alloys [3]. Thixotropy is a rheological term for a time dependent behavior of the flow properties of a non-Newtonian fluid, whose viscosity decrease with increasing mechanical loading [4].

The advantage of this semi solid forming is that the required process temperature and pressure are less in comparison to other casting and forging methods. Both effects should have a positive influence on the preservation of the fiber properties.

To use this method for our application it is necessary to generally modify the process which was used in [3], because we want to use endless fibers. Therefore it must be possible that the fibers go through the forming tool.

1.4 Objective

The aim of this project is to proof the feasibility of the solution approach and to quantify the reached results. The example structural element is a truss element under tension load out of carbon and glass fiber composite (Picture 1-1 right).

In cooperation with the IFU we will develop a new method based on the thixo-forming. The influences of the necessary modifications will be investigated, quantified and manipulated during parametrical studies.

If a repeatable quality of the specimens is guaranteed, the mechanical properties will be investigated by test series. After successful tension test the properties of the transition zone will be tested by pullout test and the load bearing behavior of a bolted connection will be tested by tension test of an assembly.

The test results were used to refine and verify the numerical modell for further parametrical studies.

2 Executed Tasks (Task Schedule)

Work Package1: Basics

ILEK
- Analysis of possible applications
- Analysis of existing connection techniques

IFU
- construction of modules for the thixo-forming tool

Work Package2: Concept and Construction

ILEK
- Development and conception of the connection
- Definition of the geometry of the Testspecimens

IFU
- Simulation of the fluid flow and verification of rheological behavior inside the forming tool
- Thermodynamical design of the forming tool

Work Package3: Design Concepts and Manufacture of the Forming tool

ILEK
- Comparison of existing design concepts for bolted connections of fiber-composite elements

IFU
- Manufacture of the thixo-forming tool
- Selection of suitable metallic matrix components and investigation of their rheological and mechanical properties

Work Package4: Process Development

IFU
- installation and initiation of the tool
- forming tests with the matrix material

ILEK und IFU
- Development of a pretension construction to fix the fibers in the tool
- Parametrical studies to determine and to adjust the relevant production parameters

Work Package5: Experimental Investigation

ILEK
- Evaluation of the material properties by tension tests with various fiber types and various fiber volume ratios
- Pull-out tests to evaluate the load bearing behavior in the transition zone for various fiber types and various fiber volume ratios
- Tension tests of bolted connections of complete structural elements for various fiber types

IFU
- Production of the half-finished elements for the test series

Work Package6: Numerical Simulation

ILEK
- Numerical simulation of the bolted connection and parametrical studies

Work Package7: Documentation

3 Results

In the frame of this project we developed a method to bring a metallic matrix partially on endless long glass or carbon fibers.

The production process is based on the semi solid forming technology. The main modification is that we used a lateral open form, which allows us to conduct the endless long fibers through it. The open sides will be closed by the solidified matrix itself. Therefore we systematically cool down the form in the near of the openings.

The relevant influencing factors could be identified, quantified and modified during a parametrical study. The influence of the fiber type, the amount of fibers, the position of the fibers in the forming tool, the height of pretension, the insertion of the melted aluminum, the alloys and the temperature distribution in the form were investigated.

When the feasibility was demonstrated and we reached a product quality which is for this stage of development acceptable, we investigated the material properties of the MMC by tension test, the breaking load of the transition zone by pull-out test and the load bearing behavior by tension test of a one bolt connection.

We could show that it is possible to produce MMC by the new production method, which is able to bear load. The material properties and the load bearing capacity are dependent from the effectivity of the self-closing mechanism. This mechanism is dependent for example from the amount of fibers. That is the reason why the test results are scattered over all experiments.

The tension strength of the tension specimens were much lower than expected. The detailed discussion of the results shows, that the quality of the aluminum matrix is the reason for the less ductility and low strength. A negative effect of the process on the fiber properties could not be detected.

The pull-out test shows the dependence of the transferable loads of the formation and amount of the aluminum overrun as well as the quality of infiltration. It could be shown that fibers performance ratios of more than 20 % up to 75 % can be realized in dependence of the fiber type and amount of.

The tension test of the selected bolted connection give an idea of the real breaking loads. Because of the aluminum overrun the fibers are curved at the transition zone and break before the maximum load of the connection was reached. The reached loads have been higher than the comparable loads of unidirectional composites with polymer matrices and higher than the theoretical breaking loads of a standard forging aluminum alloy.

Another advantage is that the transferable loads could be realized with a smaller fiber volume than for standard composites generally used. That is the reason why the fiber performance ratio with 19 % to 25 % is much higher than for standard pultruded composites (5 %). Based on this test results it is possible to increase the performance if the transition zone will be optimized.

Because of the test result of the tension specimens we did not investigate all properties for a complete material model like the model of puck. The numerical parameter studies are based on simplifying assumptions and should show the reachable limits of a selected connection. The assumptions could be verified by the test result in a satisfactory manner.

With the numerical simulation it was possible to show the potential of the new connection technique. The maximum loads of F_{max} = 103 kN bis 110 kN should be possible.

In the authors opinion this new technology is a promising technique.

Literature

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