Mechanical Characterisation of FRP-Tubes

Comparison of different fiber composite technologies

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***Abstract*— This publication deals with the mechanical characterization of tubular parts which have been manufactured using different fibre composite manufacturing technologies. Tubes with high UD and tubes with high torsional properties were manufactured and compared in different manufacturing technologies by different manufacturers. The tubular parts manufactured with the wet filament winding process show the best tensile, compressive and torsional properties.**

***Keywords*— Fibre composite, CFRP, stabiliser bar, FRP-tube, hollow profile, FilaWin®, ondulation, heavy tow roving**

I. Introduction

The project dealt with the production of thick-walled fibre composite hollow profiles for the use in automotive mass production. In cooperation with various profile manufacturers, the actual profile manufacturing process should be optimized in such a way that the mechanical properties on the one hand and the economic efficiency of the process on the other hand can be increased [1]. Due to the excellent mechanical properties fibre-reinforced composites are becoming increasingly important for the future as lightweight construction materials in the automotive industry [2]. A high degree of resource efficiency is achieved by reducing the amount of material used with optimum fibre utilisation (fibre directed as far in the direction of the load as possible) and reduced weight during operation of the vehicle [2].

Specifically, the project deals with a CFRP stabiliser bar (as described in patent [3]) for the automotive industry (see Fig. 1).

Fig. 1: Chassis stabiliser as a driving dynamics component for influencing the roll and steering behaviour of the vehicle (Source: Audi AG)

II. Manufacturing Processes Applied

The following manufacturing processes are investigated for the production of fibre-reinforced composite hollow profiles (FRP hollow profiles):

1. *Thermoset-Filament Winding:* The CirComp FilaWin® technology is used here. The materials used are rovings (50k heavy-tows and 12k rovings) in combination with epoxy resin.
2. *Non-Crimp Fabric (NCF) with Thermoset-RTM (Resin Transfer Moulding):* The materials used are dry fabrics (12k fibres) and epoxy resin.
3. *Braiding with Thermoset-RTM:* The materials used are dry rovings (12k rovings) and epoxy resin.
4. *Thermoset-Prepreg-Winding:* Prepreg semi-finished products with epoxy resin (50k heavy-tows) are used in this process. For example, a prepreg fabric mat is wrapped around a steel mandrel.
5. *Thermoset-Pultrusion:* With the pultrusion process and the existing machine concept it was not possible to produce thick-walled hollow profiles of sufficient quality.
6. *Thermoplastic-Winding (AFP-Process; Automated fibre placement):* For the production 50k semi-finished products (tapes) were used.

Fig. 2 shows the manufacturing processes according to the list above.

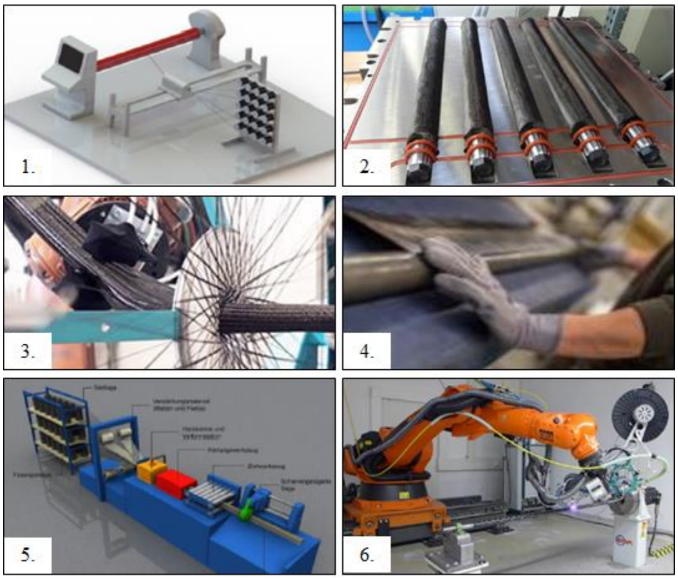

Fig. 2: Illustration of the six manufacturing processes (1. Wet filament winding technology, 2. Fabrics with RTM, 3. Braiding with RTM, 4. Prepreg winding, 5. Pultrusion and 6. Thermoplastic winding technology) [4]

The initial idea was that each production process should work with 50k heavy-tows to reduce material costs and increase output. However from a manufacturing point of view this could not be implemented in every technology. Furthermore at that time the processes thermoplastic winding technology and the technology fabric with RTM were in a testing stage [4].

III. Samples

For the mechanical evaluation of the FRP hollow profiles test specimens with a length of 350mm, an inner diameter of 30mm and an outer diameter of 37.75mm are manufactured. Each technology provides test specimens with a lay-up of 0° (maximum UD properties) and a lay-up of 45° (maximum torsion properties). Fig. 3 shows an example of 50k test specimens with a ±45° lay-up (manufactured by FilaWin® technology).

Fig. 3: FilaWin® 50k samples with a ±45° lay-up

For the CFRP stabilisers, prototypes in wet filament winding technology, prepreg winding technology and braiding with RTM are produced. The lay-ups are manufacturer-specific whereby the following properties are specified for the stabiliser [1]:

- Length 1003,5mm
- Max. outer diameter D_{max} = 37,75mm
- Minimum bending stiffness $EI > 3{,}6 \cdot 10^9$ Nmm²
- Minimum torsion stiffness $GI_T > 3{,}8 \cdot 10^9$ Nmm²
- Minimum weight

IV. Tests

In the first step the profiles are evaluated with regard to their fibre volume content. Either the image analysis method, incineration or the density method is used for this purpose.

For the mechanical characterisation of the 350mm profiles tensile, compression and torsion tests are carried out at room temperature (RT, 23°C) and 80°C (high temperature, HT). For the tests at higher temperatures the profiles are equipped with an external silicone heating mat. The heat-up time to 80°C is 10 minutes.

The profiles with the maximum UD properties are used for tensile and compression testing and the profiles with the maximum torsion properties (45°) are used for torsion testing.

The tensile-/ compression test is performed using a Zwick Z1200 (see Fig. 4). The test speed is 5 mm/min for RT tests and 2 mm/min for HT tests (80°C). The elongation is determined by an extensometer. In both cases a pre-force of 500N is selected. To calculate the stiffness, the strain intervals of 0.05% or -0.05% and 0.1% or -0.1% (tensile or compressive stiffness) are used [1].

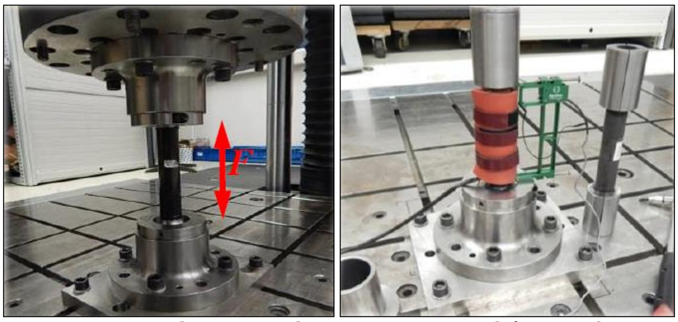

Fig. 4: Experimental set-up tensile-/ compression test (left RT, right HT at 80°C) [4]

The load application is achieved by a frictional connection via a transverse compression joint with steel couplers. The CFRP tubes are supported on the inside by a steel mandrel in the load application area [1].

The torsion test is carried out on a torsion test rig developed by the Bundeswehr University of Munich (see Fig. 5).

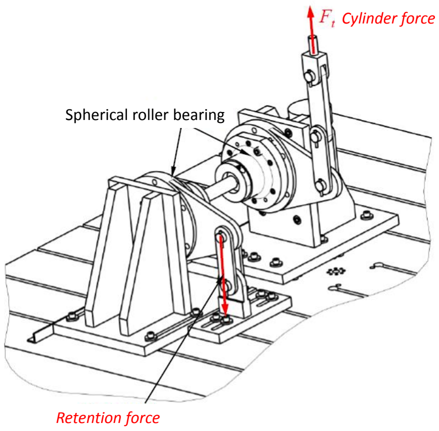

Fig. 5: Torsion test rig [5]

No transverse forces or bending moments are applied to the tube due to the articulated bearings on both sides. The twisting of the tubes is determined by strain gauges and/or an extensometer. The load is applied by means of a frictional connection via a transverse compression connection with glued steel couplers. The CFRP tubes are supported on the inside by a steel mandrel in the load application area [6].

The following tests are carried out for the CFRP stabilisers:

- Quasi-static torsion test (for the tubes) at RT and HT (80°C); angle of rotation controlled with 5°/min (load application via internal mandrel and two toothed half shells which are clamped)
- Quasi-static torsion test on the assembly with aluminium blades (like Fig. 1) at RT and HT (80°); displacement controlled with 20mm/min.

The tests at higher temperatures are carried out in a temperature chamber.

V. Test Results

The tests with regard to the fibre volume content of the 0° or 5° and 45° profiles result in the following values:

TABLE I. Fibre volume content of various manufacturing technologies for tubular parts [4]

Technology	**Fibre volume content for max. UD lay-up (0° or 5°) [%]**	**Fibre volume content for max. torsional lay-up (45°) [%]**
FilaWin® (50k)	61,8*	48,6
Fabric with RTM	44,5	45,6
Braiding with RTM	42,7*	53,3
Prepreg winding	39,9	40,5
Thermoplast winding	49,0	49,0

*Lay-up 5°

On average, FilaWin® technology achieves the highest fibre volume contents.

The results of the mechanical tests are presented below:

A. *Tensile-/ compression test of samples with maximum UD properties*

Fig. 6 shows the results of the tensile tests.

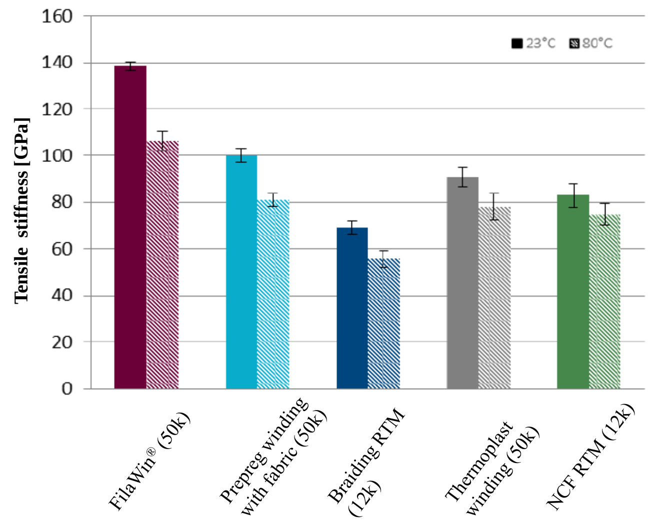

Fig. 6: Tensile stiffness of the test specimens with max. UD properties [4]

In general testing at higher temperatures leads to lower stiffness values [1].

The highest tensile stiffness is achieved using FilaWin® technology for the manufactured components.

Fig. 7 shows the results of the compression tests.

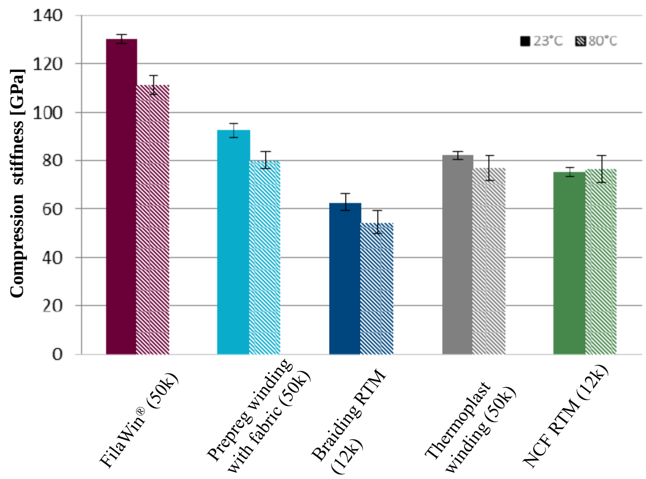

Fig. 7: Compressive stiffness of the test specimens with max. UD properties (0° or 5°) [4]

In this case the decrease in stiffness is lower at 80°C [1]. The samples manufactured using FilaWin® technology achieved the highest tensile and compressive stiffness values.

B. *Torsion test of the 45° samples*

Fig. 8 shows the results of the torsional stiffness tests.

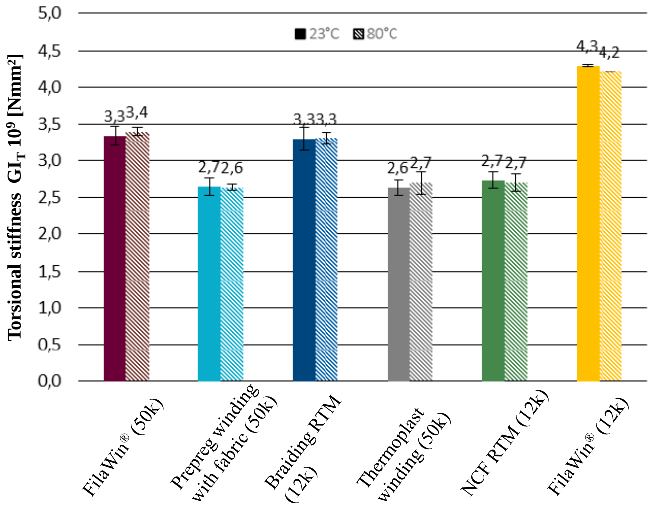

Fig. 8: Torsional stiffness of the ±45° test specimens [4]

The results show that the higher temperature has no significant influence on torsional stiffness. Furthermore it is evident that the use of a 12k fibre results in significantly higher stiffness (especially in FilaWin® technology). This could be explained by the fact that there are less undulations through the use of a 12k roving [1].

Fig. 9 shows the results of the fracture examination under torsional load.

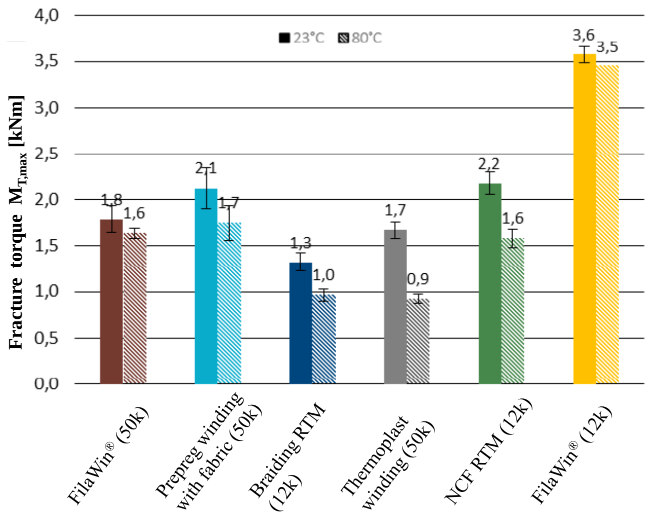

Fig. 9: Fracture torque of the ±45° samples [4]

The 12k samples manufactured by the FilaWin® technology show significantly higher fracture torque than the specimens of the other manufacturing processes do.

The fracture test shows that the temperature influence is not negligible in contrast to the stiffness test. The fracture torques are reduced under temperature by approx. 10-20% [1].

C. *Torsion test of CFRP stabiliser tubes*

Fig. 10 shows the torsional stiffness test of the stabiliser tubes.

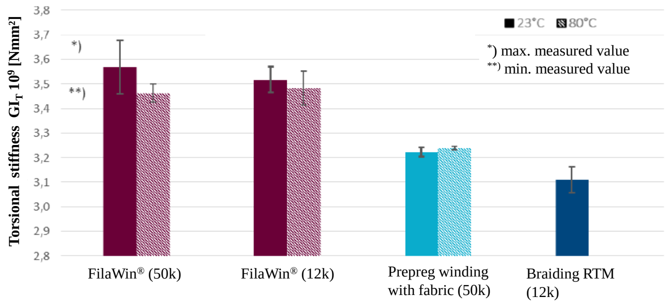

Fig. 10: Torsional stiffness of the CFRP stabiliser tubes [4]

Similar to the tests on the 45° test specimens the results of the stabiliser tubes show that the highest stiffness is achieved with the FilaWin® technology. In contrast to the samples there is no significant difference between 50k and 12k for the stabilisers tubes [1].

D. *Fracture analysis of the CFRP stabiliser assembly*

Fig. 11 shows the fracture analysis of the CFRP stabiliser assembly at 80°C.

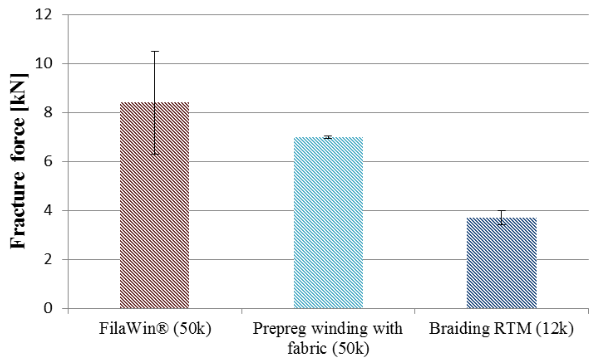

Fig. 11: Fracture force of the CFRP stabiliser assembly at 80°C [1]

The results show that the stabilisers manufactured using FilaWin® technology achieve the highest fracture force at 80°C compared to other technologies.

VI. Conclusion

Within the scope of the project a mechanical characterisation of hollow profiles which are produced in different fibre composite manufacturing processes takes place. The following technologies were examined: FilaWin® filament winding technology, fabrics with RTM, thermoset pultrusion, braiding with RTM, prepreg winding with fabric and thermoplastic winding. As a result of the project the pultrusion process was not suitabel to produce thick-walled hollow profiles of sufficient quality. All other profiles were subjected to tensile, compression and torsion tests. Essentially profiles manufactured using FilaWin® technology achieved the best results in terms of tensile, compressive and torsional stiffness. Furthermore it was found that reduced mechanical properties are measured by using 50k fibres for the tubes. By using a 12k fibre in the FilaWin® technology it was possible to achieve a 23% higher torsional stiffness and a 50% higher torsion fracture torque compared to tubes with a 50k fibre (manufactured by FilaWin® technology). The overall result shows that FilaWin® technology leads to higher mechanical properties of the tubes and it is a suitable manufacturing technology for such FRP tube applications.

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