CUSTOMIZED POLYMER MATERIALS

Screwing into carbon fiber thermoplastic components - always a (corrosion protection) challenge?

In cooperation with baier&michels

LEHVOSS Group

Plastics of all kinds surround us in everyday life. Be it in the form of sophisticated technical parts or assemblies inside devices and machines or as visible parts, for example as housings. In many cases, components have to be connected and connection techniques used for this purpose, which enable the components to be separated non-destructively. On the one hand, in order to be able to carry out necessary repair tasks and, on the other hand, to take into account the basic idea of sustainability by separating different materials as cleanly as possible. Bolted connections make it possible to achieve both goals, but in some cases also entail technical challenges.

Embedded or overmoulded threaded inserts in plastic parts are often used for multiple disassembly and reassembly. These allow the use of metric screws and the loosening and re-screwing of the connection is theoretically possible as often as you like. This can be implemented in a similar way with inserted nuts, which, however, are often not captively placed in the component. In both cases, two screw parts have to be assembled.
A nut that is only inserted is a source of error (lost), embedded components must be separated for the material recycling of the plastic. The embedding of threaded elements as a downstream operation is always associated with increased costs. To some extent, the tolerances to be observed in downstream processes also have a limiting effect. For this reason, plastic-compatible screws have been established over the decades that allow direct screwing into a pre-formed hole. As a rule, it does not matter which substances the plastic is filled with and/or reinforced with. With one important exception: high-strength materials with carbon fiber reinforcement cannot usually be screwed together with conventional, plastic screws! At least such screw connections do not meet the usual requirements with a C-fiber content of approx. 15% or more.

The LEHVOSS Group is a leading developer and manufacturer of carbon fiber reinforced (CF) thermoplastics and is repeatedly confronted with questions about direct plastic screw connections. Designers regularly come up against technical limits. Connection solutions in materials with a high carbon fiber content of up to 50% are considered to be unreliable using plastic direct screw connections. The present study, which was carried out in close cooperation with baier & michels, now impressively refutes this.
For the designers in the premium automotive segment, the aviation industry, machine components, but also in sports and outdoor applications, there were sometimes considerable technical challenges. For example, bicycle components and accessories, parts for water sports equipment and model sports (e.g. vehicles and airplanes), drones, and components for photo and film equipment should have maximum strength and be weight-optimized at the same time. In many cases, the carbon fiber compounds of the product lines LUVOCOM® CF and LUVOCOM® XCF from LEHVOSS are used. Screw connections are mandatory in many cases. Of particular importance here are the LUVOCOM XCF materials, which achieve significantly higher strength, rigidity and impact strength at the same time than conventional carbon fiber compounds.

From the user's point of view, a direct screw connection is also the first choice for CF materials. However, significant challenges emerge here:

1. Carbon fiber compounds are often more abrasive than glass fiber reinforced polymers due to higher volumetric filling levels. The screw thread must survive the screwing process.

2. Electrochemical corrosion of metals in contact with carbon fibers can destroy conventional screws within a very short time (contact corrosion). This effect is significantly accelerated by the presence of electrolytes (e.g. salt water). Even connecting elements made of high-alloy steels A2 and A4 only offer insufficient protection against corrosion.

3. Any application of anti-corrosion screw coatings is ineffective. The rubbing C-fiber would destroy it when screwing it in.

4. The screw used must be sufficiently strong to withstand the usually high tightening torques. Fasteners made from "more precious" materials, such as titanium, would often be the only solution here. However, in addition to an extremely high price (factor 100 compared to steel), these also have another disadvantage. Due to a comparatively low strength compared to steel, larger dimensions are required. Ultimately, screws made of this material are not suitable for direct screwing into CFRP components, since the thread tips are not sufficiently strong. In the cross-section of the b&m CARBONPLAST® screw [Image 1a, 1b] it can be seen that the thread is completely present after the screwing process.

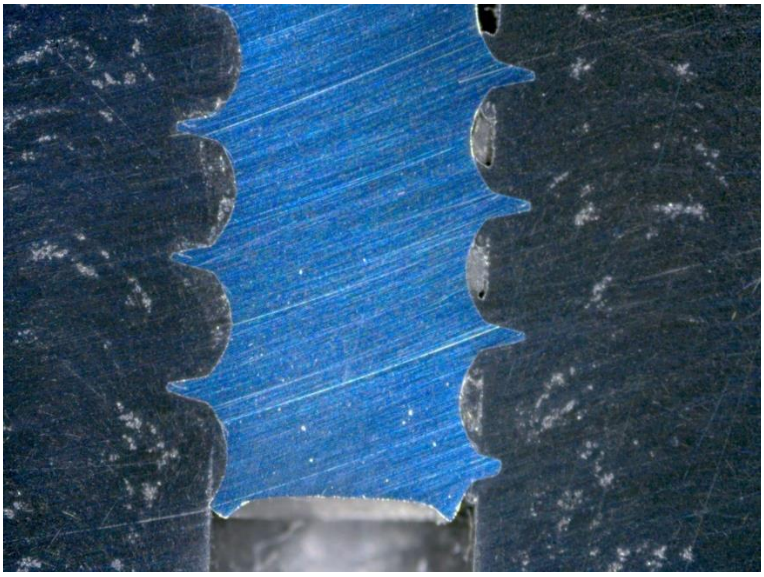


Figure 1a Screw end: b&m-CARBONPLAST® 5x20 in PEEK-XCF30 with core hole Ø4.0 mm (1° conical – thread-tapping area)

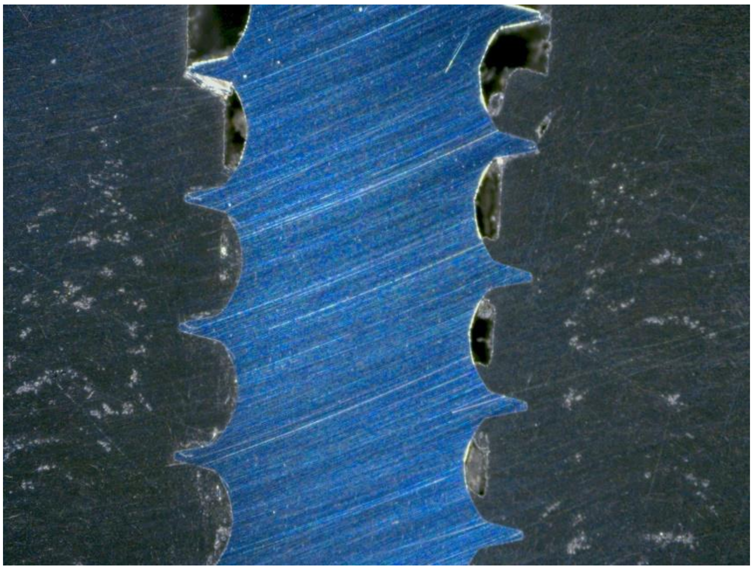


Figure 1b Head area screw boss: b&m-CARBONPLAST® 5x20 in PEEK-XCF30 with core hole Ø4.0mm (1° conical – load-bearing area)

In order to be prepared for such cases, three LUVOCOM CF high-performance compounds [Table 1] were examined with regard to their screwing properties. A b&m CARBONPLAST® screw was used as the screw.

It is crucial that the character of the screw connection is initially only changed by varying the polymer, since the sliding of the screw surface on the contact surface with the plastic can change depending on the polymer. With a selected carbon fiber content of 30% by weight, corrosion effects would have to be expected in the joint in any case. The materials examined are representative of many end uses.

ISO Type	Product	Description
PA 66-CF30	LUVOCOM 1/XCF/30	PA 66 with eXtra high strength CF
PPS-CF30	LUVOCOM 1301/XCF/30/EG	PPS with eXtra high strength CF
PEEK-CF30	LUVOCOM 1105/XCF/30	PEEK 66 with eXtra high strength CF

Tab.1: Carbon fiber materials used

Experimental setup and execution:

- First, a series of tests with molded tubes with core hole Ø4.0mm (1° conicity) were examined.
- In the second test series, the plastic tubes were reamed with a conical reamer (1°) to Ø4.2mm (largest diameter).
- All screws were measured before the screwing tests and corresponded to the tolerance specifications.
- Tubes with core hole Ø4.0mm and 4.2mm (each conical) were screwed in until the connection failed (MV).
- The screw-in depth was approx. 12mm in each case.
- The b&m-CARBONPLAST® Ø5x20 and Ø5x27 screws were used.
- A screwing speed of 200 rpm was selected for all tests.
- Furthermore, preload forces were determined in the event of failure and with a defined tightening torque MA = 5.5Nm / 4.5Nm.

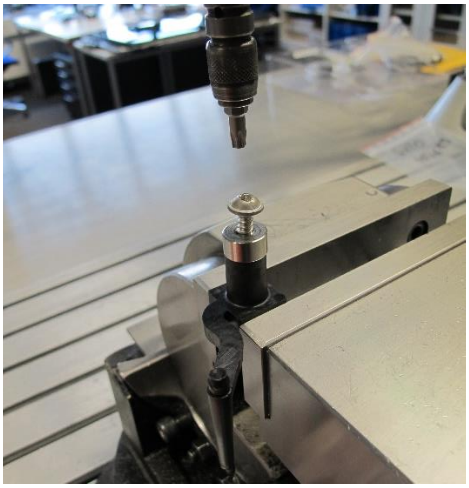


Image 2: Experimental arrangement with screw before screwing in and washer

As a general finding from all tests, it can be stated that, as with every design of a plastic direct screw connection, the dimensioning is decisive. In order to achieve the best possible screw connection characteristics, an optimal pilot hole diameter must be determined so that a favorable ratio between the forming torque (MF) and the failure torque (MV) can be achieved and the value scatter remains low. The greater the distance between MF and MV, the greater the safety within the screw connection. Of course, a maximum failure moment should always be aimed for. For the best possible design of the screwing parameters, close cooperation with the screw manufacturer is recommended in any case. The assembly parameters can be determined in the application laboratory of the screw manufacturer.

In the tests with the PEEK and PPS compounds, the larger pilot hole proved to be advantageous. The tapping torque decreases with a larger pilot hole diameter. At the same time, it can be observed that the spread of the values decreases. The process-typical fluctuations in the screw diameter no longer appear.

Even if higher failure moments can be achieved with the PEEK compound with smaller pilot holes [diagram 1a], the value scatter for MF is significantly higher. Thus, a clear technical uncertainty in the screw connection would have to be assumed. With comparable tolerances at MV, the test series with the enlarged pilot hole diameter can be rated as unreservedly advantageous. In the limit positions of the measurement deviations (upper limit MF to lower limit MV), the safety margin MF/MV is significantly larger.

With the evaluation of the achievable preload forces with a calculated or defined tightening torque, a very interesting picture emerges [diagram 1b]! The fact that with a larger pilot hole diameter less forming energy is required to form the thread, more effective tightening torque remains for the generation of the preload force. Although the scatter is slightly larger than with the smaller bore diameter, the overall level is higher. It should be investigated whether a small spread of the preload forces can be achieved with a specific optimization of the bore diameter.

The PPS compound [diagram 2a] shows a very low scatter of the measured values. Similar to the PEEK compound, with a larger pilot hole it can be observed that the forming torque decreases, but here there is extremely little scattering. Slightly lower failure moments are achieved. However, as with the PEEK evaluation, the safety margin MF/MV is very large, and a proper design based on a high tightening torque can be implemented without restrictions.

The preload forces that can be achieved with the PPS compound examined are on a level comparable to PEEK [Diagram 2b]. Here, too, it can be seen that the larger pilot hole diameter has a more favorable effect on the preload force level. The switch-off torques / tightening torques MA(t) measured in the test deviate only slightly from the calculated value (MA(m)). This is due to the somewhat conservative selection of the tightening design factor within the test series (0.65).

Due to the polymer, the PA66-based formulation [diagram 3a] has a greater elongation at break with a lower tensile modulus of elasticity. This is reflected in a significantly better absorption of the forces during the screwing process. The PA-CF combination also seems to have a positive effect on the grooving process in this case (tribology). The tapping torques are subject to only very small scattering with both small and large pilot hole diameters. In the present case, a 16% higher failure moment can be achieved with a smaller pilot hole diameter, even if the scatter is somewhat larger here. With this class of materials, due to the slightly more elastic material behavior when screwing, the entire scope can be used when dimensioning the screw-in hole. Depending on the application, the design should be verified by safeguarding, e.g. in a climate change test, vibration test, etc. An adjustment of the pre-hole diameter is, technically safe, possible at any time.

The PA66 compound shows a special feature compared to the PEEK and PPS compounds. With the enlargement of the bore diameter, there is a slight reduction in the preload force. At the same time, with the pilot hole diameters of 4.0 and 4.2mm, there is almost no difference in the actual tightening torque MA(t) (order of magnitude of the switch-off accuracy). [Diagram 3b] A greater elastic deformation in the plastic probably already occurs while the screw connection is being tightened. The PA compound has a tensile modulus that is around 22% lower than PEEK and PPS.

Conclusion:

With the screwing tests carried out, it was possible to determine that screwing the tested LUVOCOM CF materials with a b&m CARBONPLAST screw is problem-free and process-reliable. As in all cases when screw connections are considered, a proper design of the connection and its protection, in cooperation with the screw manufacturer, is recommended.

In diagrams 1 to 3, a dimensioning factor of 0.75 is assumed for determining the tightening torque MA (MV as the basic dimensioning value, MA = 0.75 x MV).
This is technically possible, since very large distances between MF and MV were determined in all tests. Conservatively, the design of screw connections is also possible with a lower rating factor (e.g. 0.65). This applies in particular to materials that have a lower resistance to creep (lower relaxation modulus or moisture absorption).

Dome ruptures or weld line failures did not occur in any of the tests. The corrosion resistance of the b&m CARBONPLAST® screw was verified in tests in accordance with DIN EN ISO 9227 [image 3a and 3b]. The cuts [1a and 1b] show that there is no abrasive wear on the thread flank and in particular on the thread crest, which would reduce the performance of the screw. The inflow of the plastic in the direction of the screw core is also clearly visible.

Figure 3a: Exemplary CFRP components with conventional steel screw for direct screw connection after a 720-hour salt spray test

Image 3b: Exemplary CFRP components with b&m CARBONPLAST® screw for direct screw connection after a 720-hour salt spray test

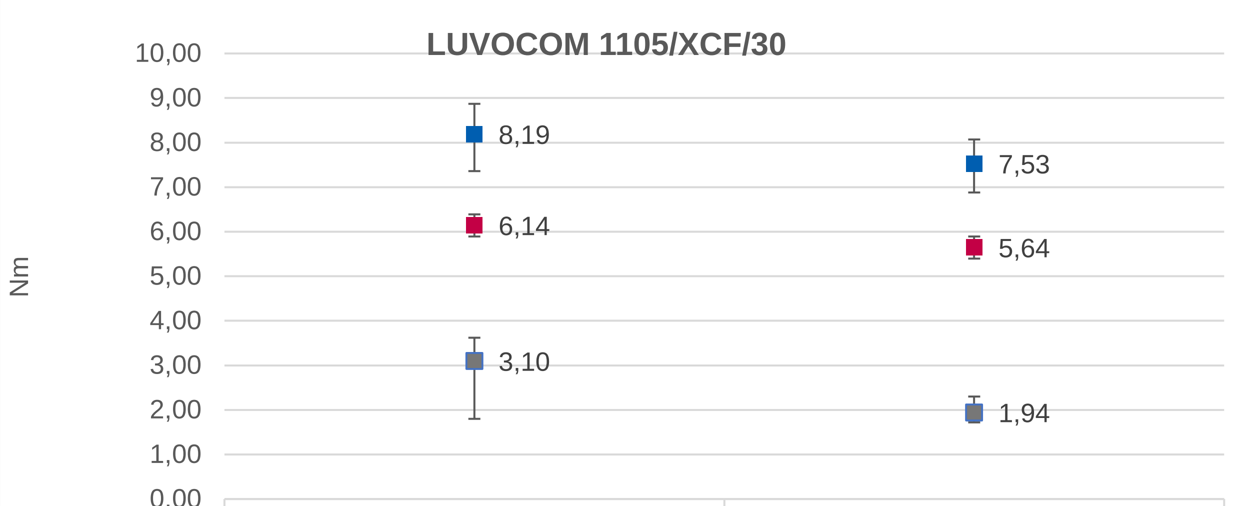
The properties of the materials tested here cover a wide range of applications. The results obtained can also be easily transferred to other LUVOCOM CF materials. Even with higher CF contents, the occurrence of a contact corrosion problem is not to be expected.

Production of electrically conductive contact points

However, the "core problem" of CF materials, the electrical conductivity via the connecting element, can also be used. In addition to the purely technical screw connection, this type of screw connection also allows the production of electrically conductive connections. For example, to implement grounding points using direct screw connections. This means that threaded inserts can also be dispensed with here. In a simple test, the volume resistance was measured across the screw and a contact surface on the base of the dome. The resistances determined were below 1 ohm in each case. Even after ten disassemblies and reassemblies, the values remained at this level. Since different contacts and measuring arrangements have to be implemented depending on the application, this must be examined in a separate test series. An application-related conductivity test is recommended in any case.

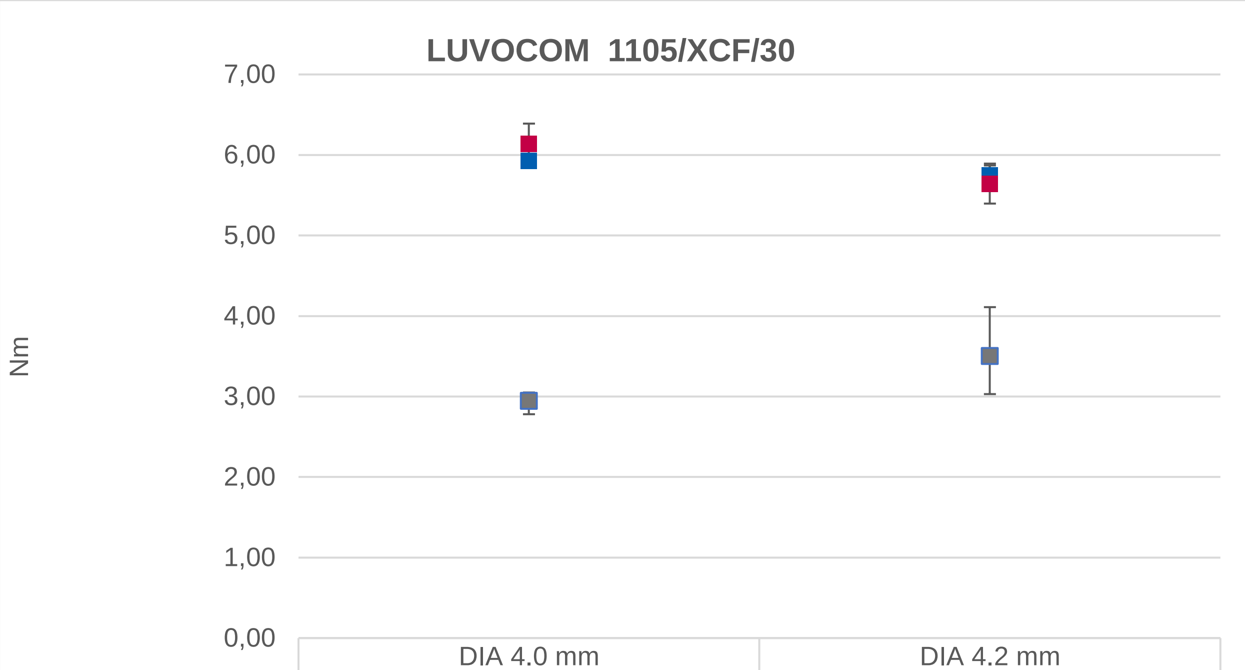
Definitionen / Definitions				
Furchmoment	MF	Grooving Torque	Tg	MF / Tg (Nm)
Anziehdrehmoment	MA	Tightening Torque	Tt	MA / Tt (Nm)
Versagensmoment	MV	Failure Torque	Tf	MV / Tf (Nm)
Anziehdrehmoment (Test)	MA(t)	Tightening Torque (Test)	Tt(t)	MA(t) / Tt(t) (Nm)
Anziehdrehmoment (Berechnet)	MA(m)	Tightening Torque (Math.)	Tt(m)	MA(m) / Tt(m) (Nm)
Vorspannkraft	FV	Preload Force	Fp	FV / Fp (kN)

Diagrams



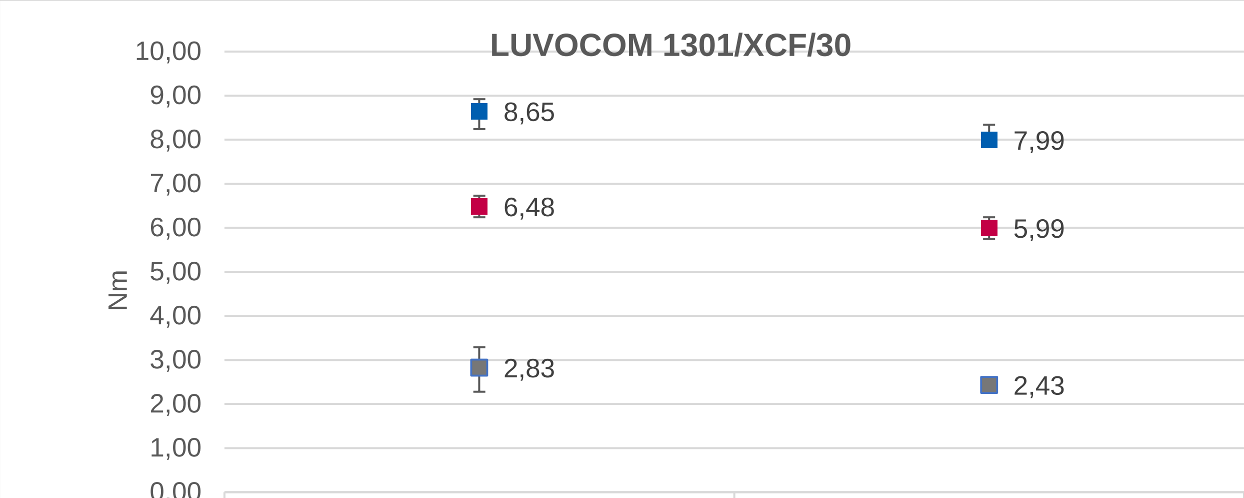
	DIA 4.0 mm	DIA 4.2 mm
MV / Tf (Nm)	8,19	7,53
MA / Tt (Nm)	6,14	5,64
MF / Tg (Nm)	3,10	1,94

Diagram 1a: Screw connection parameters PEEK-XCF30



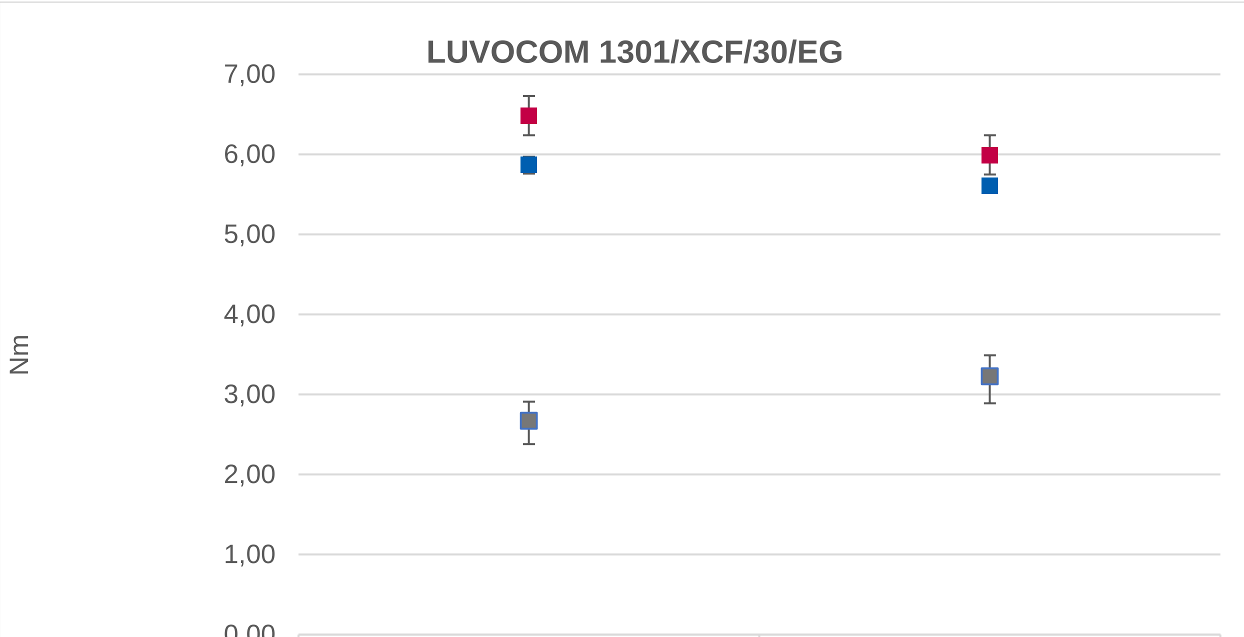
	DIA 4.0 mm	DIA 4.2 mm
MA(t) / Tt(t) (Nm)	5,93	5,75
MA(m) / Tt(m) (Nm)	6,14	5,64
FV / Fp (kN)	2,95	3,50

Diagram 1b: Preload forces PEEK-XCF30



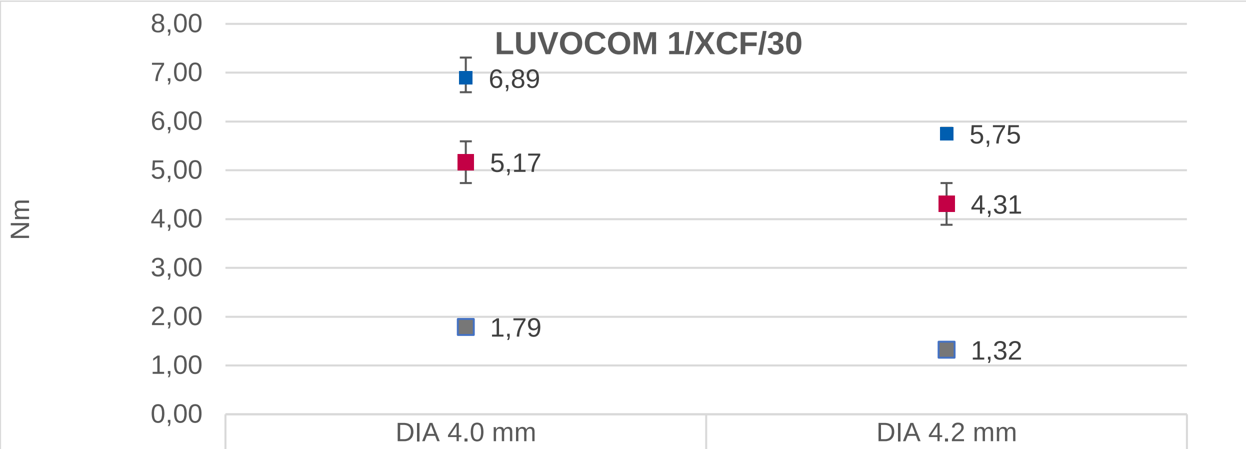
	DIA 4.0 mm	DIA 4.2 mm
MV / Tf (Nm)	8,65	7,99
MA / Tt (Nm)	6,48	5,99
MF / Tg (Nm)	2,83	2,43

Diagram 2a: Screw connection parameters PPS-XCF30



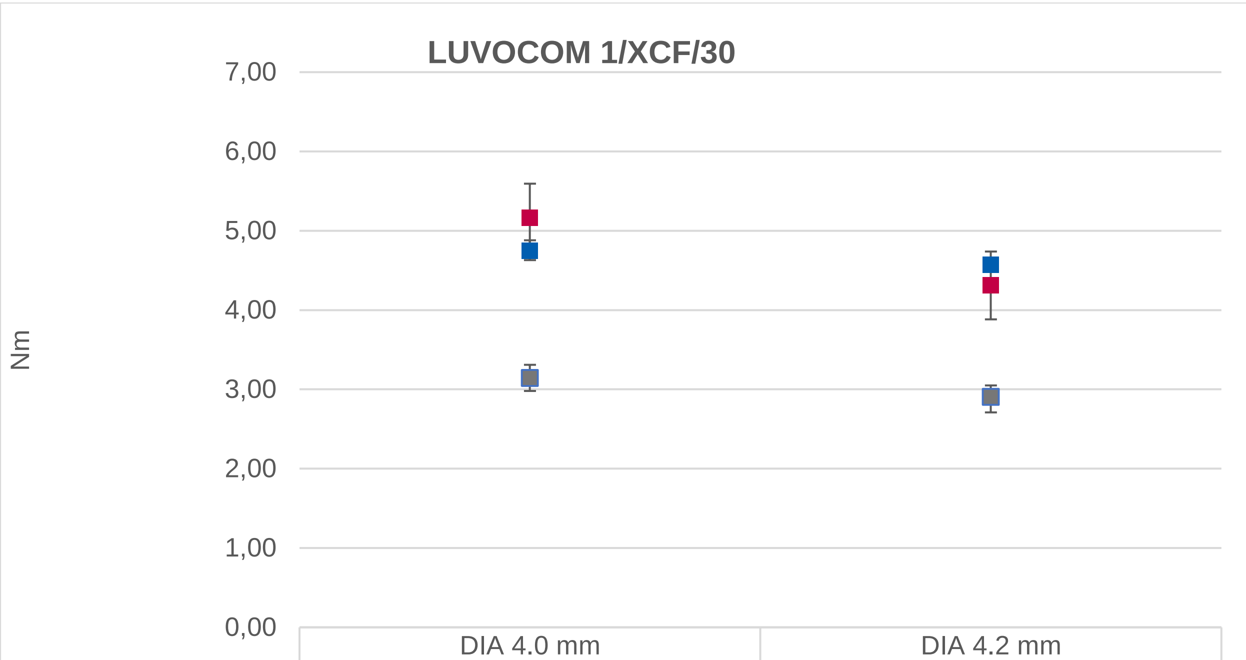
	DIA 4.0 mm	DIA 4.2 mm
MA(t) / Tt(t) (Nm)	5,87	5,61
MA(m) / Tt(m) (Nm)	6,48	5,99
FV / Fp (kN)	2,67	3,23

Diagram 2b: Preload forces PPS-XCF30



	DIA 4.0 mm	DIA 4.2 mm
MV / Tf (Nm)	6,89	5,75
MA / Tt (Nm)	5,17	4,31
MF / Tg (Nm)	1,79	1,32

Diagram 3a: Screw connection parameters PA66-XCF30



	DIA 4.0 mm	DIA 4.2 mm
MA(t) / Tt(t) (Nm)	4,75	4,57
MA(m) / Tt(m) (Nm)	5,17	4,31
FV / Fp (kN)	3,14	2,91

Diagram 3b: Preload forces PA66-XCF30

The project partners:

The globally oriented **b&m** group, headquartered in Ober-Ramstadt in southern Hesse, has established a strong position as an innovative partner of the manufacturing industry in the field of cold forming. The basis for this are high-quality connecting elements as well as closure and sealing systems from our own development and production. Our customers include OEMs and suppliers from the automotive, electrical and medical technology sectors.

Baier & michels is not only at your side as a producer, but also as a problem solver: in addition to application-related advice and connection tests in our laboratories, we offer specialist training and a unique standardization tool that industrial companies can use to massively reduce the variety of C-parts. Our currently around 500 employees are our greatest asset. With their know-how and experience, we are always able to meet the highest demands of our customers. You can build on that!

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The Customized Polymer Materials business unit is a partner to industry in material selection, development and production, application-related advice and support, from design to production. The materials with precisely defined properties are based on almost all available thermoplastics and are tailored to individual customer and application requirements. www.luvocom.com

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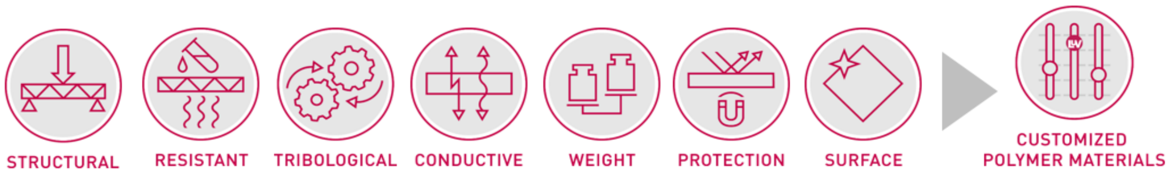
Our Competences



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