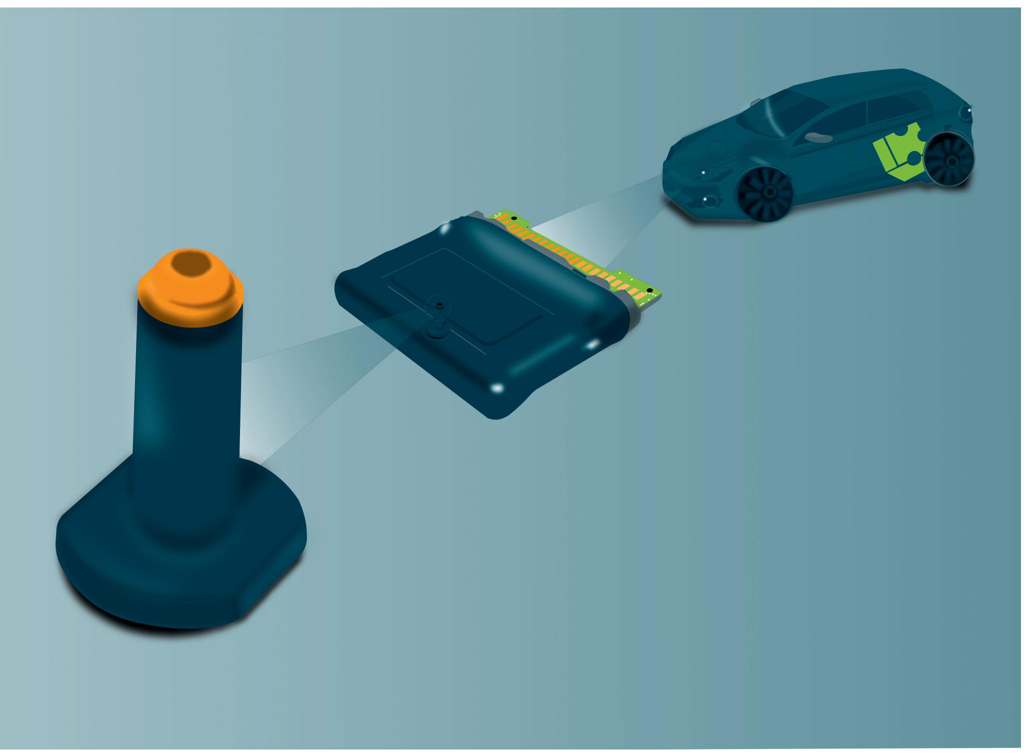
Higher Process Quality through Adjustment of the Production Parameters

Achieving a More Secure Connection with the Correct Design

In a research project being carried out by the IKV and KTP, the influence of geometric and process parameters on the quality of the screw connection in the direct assembly of thermosetting plastics has been analyzed. The research results show that, in addition to the geometric design, the production parameters offer additional optimization potential for the reliability of the screw connection. The compactness and curing degree of the parts exert the largest influence.



Encapsulation protects the sensitive sensor technology from external influences. The direct screw connection enables secure mounting of the module. © IKV

Thanks to their property spectrum, thermosets are becoming ever more popular in car production due to increasing electrification and power density. This is above all because, thanks to the curing, they have virtually constant mechanical properties over a wide temperature range and also have very good electrical insulation properties [1–3]. The frequently high filler contents of approx. 80 % by weight also result in very low shrinkage, so that narrow tolerances can be adhered to [4–5]. Furthermore, unlike thermoplastics, thermosets have a similar coefficient of thermal expansion to steel, and do not display any creep, making them especially suitable for screw connections [6].

As a joining process, screwing has the advantage not only that it is possible to design the process fully automatically and thus economically, but also that the connection is reversible. Apart from that, a pre-loading force can be built up, making it possible to secure the two parts against slipping. From an economical point of view, the use of thread-cutting screws for direct screwing is recommended because the additional step needed to position a metal insert becomes superfluous and the accompanying risk of mold damage is avoided.

Until now, however, no guidelines exist for designing screw-in tubes and direct screw connections for thermoset molding compounds [7]. For this reason, the design is currently oriented to the guidelines for thermoplastics, even though their material behavior differs fundamentally from that of thermosets [8]. There are, for example, significant differences in processing, in the thermomechanical behavior and in chip formation. This means that more extensive test series are needed to ensure adequate process reliability.

The aim of the joint studies at the Institute for Plastics Processing (IKV) in Aachen, Germany, and Kunststofftechnik Paderborn (KTP), Germany, is to draw up an optimized geometry of the screw-in tube for direct screwing into thermoset components, and to obtain further knowledge about the material behavior and failure characteristics. Based on systematic studies, design recommendations are being developed to enable users to better safeguard their development (**Fig. 1**).

Measuring the Torque Guarantees a Reliable Screw Joint

For direct screwing into brittle plastics such as thermosets, special screws are used with cutting elements [8]. The thread is produced by cutting during assembly. In order to make the screw connection reproducible, the assembly process is regulated via the torque. From the installation torque necessary for cutting the thread and the stripping torque occurring on failure of the screw connection, a differential torque can be determined. To guarantee a secure screw connection, a high differential torque is required because only then is there sufficient space before failure of the screw joint.

The screw-in tube specimens are produced from a phenolic resin (type: PF 1110; manufacturer: Bakelite GmbH) with a filler content of 80% wt.% glass fibers and glass spheres. The screws with cutting groove (type: Delta PT-DS; manufacturer: Ejot GmbH) are screwed in with a screwdriver (type: ERS12EL; manufacturer: Desoutter GmbH). For this, a constant screw contact force of 75 N and a constant installation torque of 50 rpm is set. The reliability of the screw joint is evaluated with the aid of the screw-in values (installation torque and stripping torque) and the pull-out force, which is determined via a tensile test. In order to determine the installation torque and stripping torque, five specimens were tested for each testing point, and for the tensile test, three specimens were tested.

Geometry Influences Flank Coverage and Quality of the Screw Connection

In order to establish the influence of the screw-in tube geometry on the torques and to measure the pull-out force, the outer diameter d_O, the core hole diameter d_C, the relief bore depth t_R and the screw-in length l_S are varied, each in three stages (**Fig. 2**). In preliminary trials, these parameters showed the biggest influence on the screw-in data. The results of the analyses were subsequently evaluated (**Fig. 3**).

Varying the outside diameter does not show any influence on the installation torque. A look at the differential torque shows that a larger outside diameter results in higher values and that the standard deviation for the mean outside diameter is the lowest. This corresponds to better reproducibility of the screw joint. For the larger outer diameters, the pull-out force is lower: 3.9 kN at 9 mm and 4.0 kN at 10 mm compared with approx. 4.2 kN at 8 mm. The reason for this could be the higher degree of curing of the screw-in tube at the smallest outer diameter, because here, the wall thickness is at its lowest and thus a higher degree of curing is achieved at constant curing time.

With increasing core hole diameter, both the installation torque and the pull-out force decrease. Both observations can be due to the declining flank coverage of the screw in this series of tests. The influence on the differential torque shows a non-linear relationship. With both the smaller and the larger core hole diameters, significantly lower differential torques (2.7 and 3.1 Nm) are attained than with the medium size (4.5 Nm). The reason for this is the low flank coverage with a large core hole diameter. A small core hole diameter, on the other hand, causes, because of the high flank coverage, larger radial »

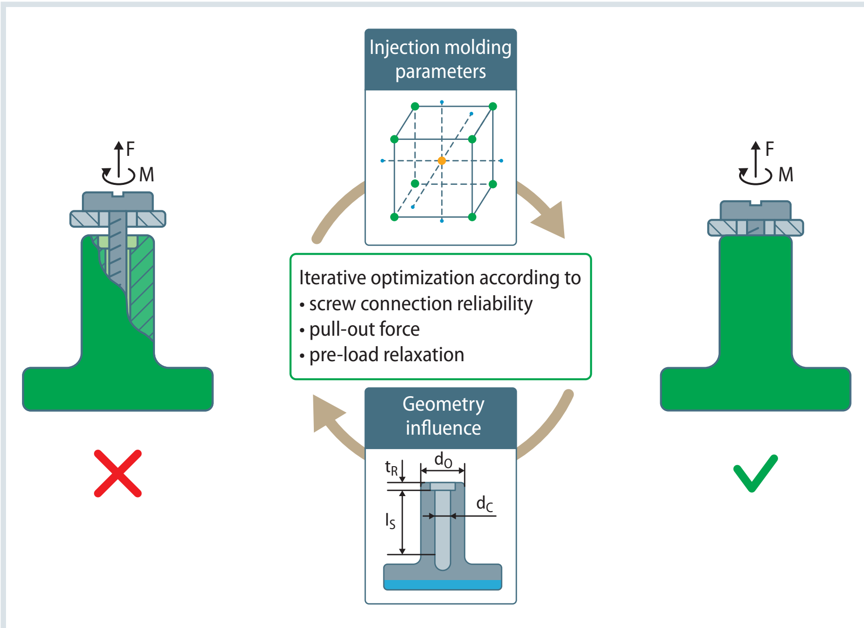


Fig. 1. In order to better understand the influences exerted on direct screwing processes in thermoset molding compounds, the screw connection is designed and optimized in an iterative process. Source: IKV; graphics: © Hanser

Parameter		Step		
		–	0	+
Outer diameter	d_O [mm]	8	9	10
Core hole diameter	d_C [mm]	3.4	3.6	3.8
Relief bore depth	t_R [mm]	1.2	1.6	2.0
Screw-in length	l_S [mm]	6	8	10
Screw-in tube height	h [mm]		20	
Base thickness	s [mm]		5	
Screw diameter	d_1 [mm]		4	
Screw length	l [mm]		16	

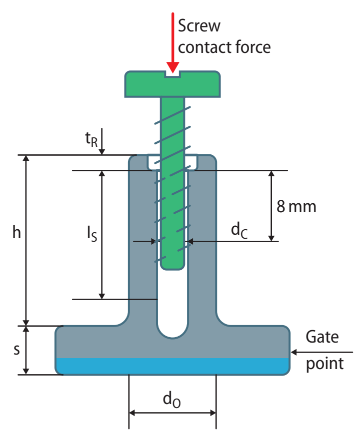


Fig. 2. Sketch of the screw-in tube with the varied geometry parameters. A modular mold structure allows an analysis of the different tube geometries. Source: IKV; graphics: © Hanser

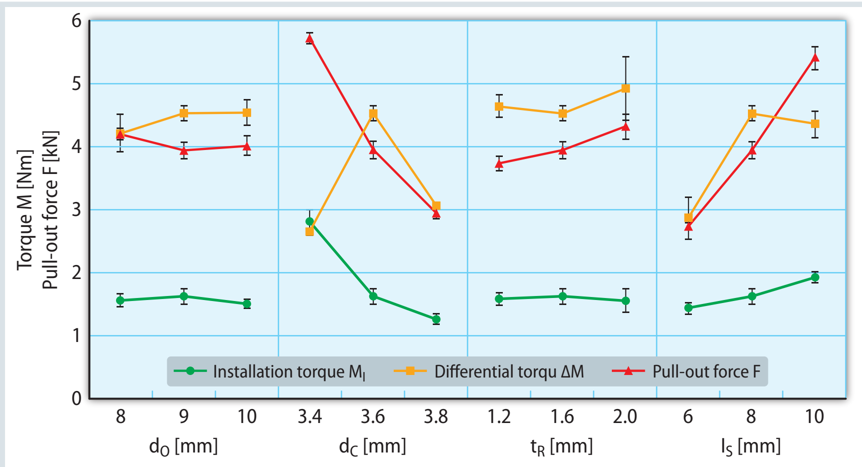


Fig. 3. Influence of the geometry parameters: a high differential torque provides for adequate space before failure of the screw connection and thus ensures a higher quality of the joint.
Source: IKV; graphics: © Hanser

tensions that lead to a lower differential torque.

The depth of the relief hole does not have any influence on the torques. Only the deepest relief hole has a higher differential torque. On the other hand, a higher standard deviation occurs, so that the reproducibility of the screw joint is reduced. The pull-out force increases slightly with the depth of the relief hole.

The screw-in depth has only a minor influence on the installation torque. The highest differential torque with the lowest standard deviation is attained with a screw-in length of 8 mm. Since, with increasing screw-in length, more thread turns can absorb the force, the attainable pull-out force of the screw connection increases significantly – almost linearly.

Injection Molding Parameters further Optimize the Quality of the Screw Joint

Overall, the process of varying the geometry shows that the best screw connection is achieved in each case for the middle stage, which is why this is then used for the subsequent part of the study in which the injection molding parameters are varied. With the aid of a full-factorial 2^6 experimental plan, tests are carried out to see whether the curing and the filler orientation influence the quality of the screw joint. For this purpose, the process parameters that have a large influence on the material behavior in thermoset injection molding [9] are varied (**Table 1**). The values for the parameter steps are selected on the basis of the datasheets and preliminary trials.

The results of the significance analysis for the influence of the injection molding parameters on the installation torque, differential torque and pull-out force are summarized graphically in **Figure 4**. The installation torque increases significantly with rising mold temperature. Because of the higher curing level, a larger torque is needed to cut the thread. As a result, the radial tensions during the screw-in operation increase, raising the risk of splitting. Stronger compaction of the material through a longer holding

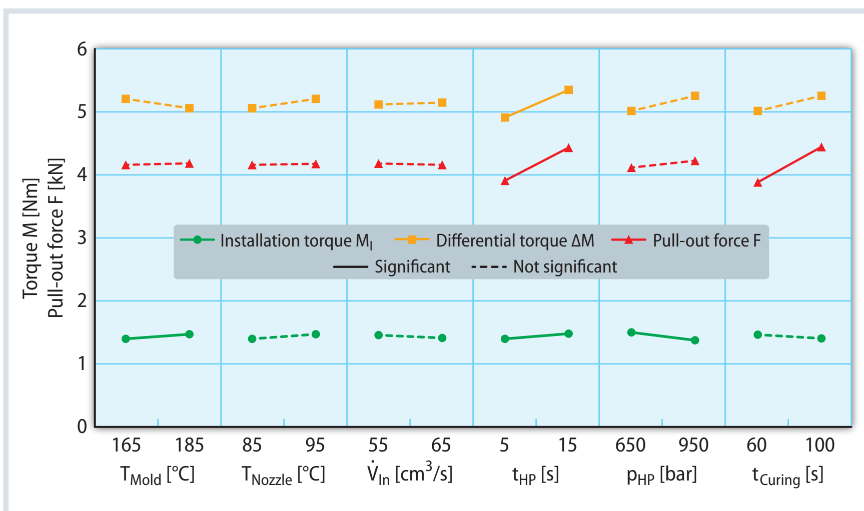


Fig. 4. Evaluation of the significance analysis: the largest influence on the quality of the screw connection comes from the holding phase and the subsequent curing time.
Source: IKV; graphics: © Hanser

Info

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References & Digital Version

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pressure time also brings about a higher installation torque.

Further analysis shows that simply extending the holding pressure time by a significant amount will increase the differential torque and thus the quality of the screw joint. Through the effect of the longer holding pressure, the material at the end of the flow path is also compacted more strongly and can, at this point, withstand higher torques. Accordingly, higher differential torques are achieved.

A longer holding pressure time and, resulting from this, improved compaction of the material, leads to a significant increase in the pull-out force. Equally, extending the curing time leads to higher pull-out forces. The reason for this can once again be attributed to the curing behavior of the thermosetting plastics. A longer curing time at the end of the holding pressure means that a higher level of curing is achieved, which, in turn, results in higher strength data.

Factor		Unit	Step	
			–	+
Mold temperature	T_{Mold}	[°C]	165	185
Nozzle temperature	T_{Nozzle}	[°C]	85	95
Injection volume flow	$\dot{V}_{In}$	[cm³/s]	55	65
Holding pressure time	t_{HP}	[s]	5	15
Holding pressure	p_{HP}	[bar]	650	950
Curing time	t_{Curing}	[s]	60	100

Table 1. Factors and steps for the injection molding tests. Source: IKV

Conclusion

Designing the screw-in tube to suit the material and the injection molding process also significantly influences the component design. The analysis of the geometric parameters shows that the core hole diameter and the screw-in length of the screw-in tube exert the largest influence on the quality of the screw joint. For this, the outside diameter should be increased by reducing the core hole diameter in order to withstand the increasing radial stresses in the screw tube.

By manufacturing the screw-in tubes to suit the material, it is also possible to increase the quality of the screw connection, and this can be further improved by adjusting the mold temperature, holding pressure time and curing time. In further tests, the focus should be placed on the long-term strength of the screw joint. For this purpose, the influence of the injection molding parameters and the formation of the weld line on the dynamic behavior of the connection will be examined. ■