Rigid/flexible composites
Specifics of processing and testing adhesive strength – standard VDI 2019

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Summary
Rigid/flexible composites are material combinations of thermoplastics (rigid component) and elastomers or thermoplastic elastomers (flexible component). Their functionality focuses mainly on damping and sealing properties as well as a comfortable feel. Because of the long-term importance of these plastic material composites for new products, there is a need to build on our understanding of the fundamentals of these composites and their application characteristics in terms of adhesive strength. In order to give an up-to-date overview, this article therefore covers the following topics: interfacial effects and compatibility principles, specifics of processing, test methods for rigid/flexible plastic composites and flexible plastic/metal composites and the standard VDI 2019, including a discussion of adhesive strength test results.

Introduction
Multi-component injection moulding or in-mould assembly processes [1 – 3] offer excellent technological solutions for the cost-effective joining of plastics to one another or to other materials. The possibilities for arranging different functionalities within a product are almost endless. In the majority of cases, different mechanical properties are required and therefore rigid/flexible composites consisting of thermoplastics (TP) and thermoplastic elastomers (TPE) have been firmly established on the market for decades [1 – 5]. Sophisticated products can be found not just in technical applications but in everyday life, and therefore in practically every area of application [3 – 6]. For the assembly of components in an injection-moulding process, the rigid component is first shaped and cooled in a complete cycle (Figure 1). In a second process step, the molten flexible component is bonded to the relevant surfaces by flowing on to, around or over parts of the rigid component in the same mould. In this variant of joining technology, either the cavity areas for the second component are opened up by a slider/core puller in the closed mould or the mould is opened and rotated to a new position where the second component is formed in a larger cavity. Another option is to insert the rigid component into the mould and then to bond the flexible component on to it. Since the adhesive strength of the bond depends partly on time management in bringing the components into contact with one another, the first two variants (slider/core-back and rotating mould technology) are preferred [1, 2].

The chemical and/or physical adhesion mechanisms initiated in the process should lead to a material bond between the components, if at all possible. Despite many years’ experience with different combinations of materials and countless successful products, there is still a need for greater understanding of these adhesion mechanisms. There are a number of basic scientific publications that describe relationships between structure, process and properties, prediction capabilities and a wide variety of test methods [7 – 13]. These suggest that the quality of the bond, its functionality and its durability depend on complex interactions between material, process conditions, design and stresses during production and use (Figure 2).
Furthermore, typical interfacial effects play a significant role in the long-term durability of the bond in use [14, 15]. A brief insight into these interrelations is given below to allow better estimation of the potential adhesive strength of a selected material pairing and of the requirements that have to be met in terms of materials and processing.

Interfacial effects, compatibility principles and processing

A basic understanding of interfaces created by injection moulding requires, among other things, knowledge of the thermo-rheological history of their formation, which results from shear-thinning flow behaviour, flow channel dimensions and process parameters. Basic effects such as specific molecular and filler orientation, associated faults in the development of adhesion mechanisms and surface defects can also be derived from the weld lines known in conventional injection moulding (Figure 3) [14, 15]. Weld lines are formed when two or more melt streams meet, and they can constitute both mechanical and optical flaws. The causes of interfacial defects in a product can be summarised as shown in Figure 3 [14, 15]. There are very good solutions for eliminating surface defects already available on the market, in the form of variotherm technologies. However, there can be a huge reduction in mechanical properties compared with the initial level in the area of a weld line or an interface between two components [15].

For unfilled thermoplastics, promising results have been obtained from adjustments to processing temperatures. In contrast, only process variants such as cascade injection moulding can have a positive effect on orientation in filled polymer components through targeted flow control in the area of the weld line [16].

It is assumed in the literature [e.g. 7, 8, 11, 12] that a complex mix of mechanical, physical and chemical bonding mechanisms can occur in plastic composites as they are formed. In the case of rigid/flexible composites, however, provided that the materials are compatible (miscible), optimum conditions for the adhesion mechanisms can be achieved by means of appropriate adjustment of the processing window.

The definition of the principles of compatibility [1, 3, 11, 17] can be summarised as follows:

- compatibility of materials or of adhesion: the ability to form adhesive bonding forces, possible adhesive modification of a component
- processing compatibility: ability to be shaped at the same mould temperatures, second components having higher melt processing temperature
- compatibility of properties: moderate property differences of the combination to avoid excessive stress in the contact area

Figure 4 illustrates the morphological effects caused by the high cooling rates at the cold mould wall, which are typical of injection moulding, using the example of a monomonomer rigid/rigid model composite made of a polyoxymethylene. The extent to which the first component can initially crystallise at the surface is shown to be important, together with the way in which a state of molecular mobility can be achieved again when the second, hot component is injected over the first. It is therefore advantageous if the surface layer can be suitably mobilised with the lowest possible energy input and effects of e.g. recrystallisation can be reduced. Depending on the structure size and density, brittle
properties and stresses in the composite interface can cause problems in terms of durability.

There are still a number of approaches to the methodology for quantifying adhesive strength [18-21]. Current publications [23-25] already refer to studies that take account of VDI standard 2019 [22], which was introduced a few years ago, or take a critical look at this standard in comparison with well-established company test procedures [26]. The second part of this introductory section will therefore give a brief presentation of the state of the art in testing rigid/flexible composites and the current state of activity on standards.

Specimens and test methods for rigid/flexible plastic composites

Figure 5 shows the relevant material properties of flexible components in relation to possible partner materials as an initial guide in selecting suitable test methods and specimens. Because there is such a broad distribution of mechanical properties of thermoplastic elastomers, the extent to which they, as the flexible or soft component, can be deformed and peeled at a defined angle in a peel test is crucial. If a critical Shore hardness is exceeded, cracking and premature failure may occur. For TPEs with higher Shore hardneses, therefore, alternative test methods can be found in international standards (DIN, ASTM). By way of example, Figure 5 shows diagrams of the DCB (Double Cantilever Beam) test used for laminates, the compressive shear test and specimens for tensile and tensile shear tests.

Studies and findings relating to the influences of processing parameters in specimen production, specimen geometry (thickness), bond geometry (length and width of overlap) and test conditions (loading rate) on adhesive strength and on adhesive strength test results have been published by both industrial organisations and institutes [15, 17-21, 23-25].

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As already mentioned, the procedure for characterising bond strength is somewhat controversial [20, 26-28]. In principle, it is generally agreed that the results of a peel test on rigid/flexible...
Composites may be expected to provide meaningful information allowing a suitable combination of materials to be identified for a particular product. It is clear from the specialist publications that, apart from the test standards for adhesively bonded and welded joints, there was no uniform standard for composites produced by injection moulding. The VDI standard 2019 initiative filled this gap. The aim of this standard was to create a basis for suitable specimen geometry and test methodology and to enable the adhesive strength of TPE/thermoplastic composites to be assessed and compared. In order to ensure robustness and comparability of the data, it must also be possible to give a precise description of the observed failure behaviour. The new document (2014) therefore offers a classification of failure patterns. In evaluating findings and applying them to the relevant loading on a bond in a particular application, it is essential to take account of the product-specific situation. Additional composite geometries/dimensions may be needed and adjustments may have to be made for special loading situations. In particular, there is currently no provision for evaluating dynamic and long-term behaviour in a composite – an area that this VDI standard also fails to cover at present. There may be a great deal of practical experience among those working in the field providing them with a feel for the durability of a bond, but there is very little experience-based data freely accessible for consultation. A standard-based procedure at least constitutes a first step in making comparable experimental data available.

In the context of a uniform procedure for rigid/flexible composites containing a flexible component in the lower Shore hardness range, collaborative studies among the members of the VDI Standard Committee during the revision phase have led to a meaningful consensus on specimen dimensions and recommendations for testing and describing the results. Taking comments from science and industry into account after the first version of the standard [22], the new, extensively revised “greenprint” document [29] has been available since October 2014. Figure 6 shows key points from the contents of the standard VDI 2019, providing an overview of its use.

CONCLUSIONS

To summarise, then, both pragmatic application tests and detailed scientific investigations may initially allow a relative comparison to be made of the boundary conditions prevailing at a particular location. Based on the component properties, which are specific to the plastics and are highly sensitive to the processing history, individual approaches to characterisation are a possible way of generating locally comparable data for a new product in the future. However, it is important for institutes and industry to be guided by a uniform standard and therefore to follow a strict procedure for the production and testing of TPE/thermoplastic composite specimens. Future work on the standard will address the specific boundary conditions for testing plastic/material composites, such as hybrid plastic/metal composites.

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REFERENCES


