Holistic Evaluation of Industrial Adhesives

The selection of complex adhesive systems is still a challenging task. Industrial practice shows that technical data sheets provided by manufacturers alone do not allow an assessment of adhesive performance and failure behavior. A holistic assessment based on empirical-valid data might help here.

Martin Brandtner-Hafner

Introduction

Adhesives have become indispensable in today's world. Their broad and varied use in industry declares this type of joining to be the key technology of the 21st century. However, the lack of meaningful performance, risk, and quality figures often means that empirical-valid comparability and transparency is not possible. It is up to the user to work his way through a jungle of datasheets, sales prospectuses and reviews. The lack of resources, be it time or money, allows only limited effort in the selection process. Therefore, the price is usually used as the decisive selection criterion, which can be fatal for the successful implementation of an adhesive project.
There are already practicable approaches using online search engines, such as the Substratec adhesive navigator [1] to provide initial constructive insights into the vast range of possibilities.
However, decision-makers are still missing an authentic ultimate benchmark and metric for evaluating adhesive bonding performance. Having such a metric would greatly simplify and focus the selection process. Providing such a metric is the goal of this article.

A novel assessment methodology

The selection of complex adhesive systems is a challenging task for the user. Since resources are scarce and precious, one is often dependent on the information that is available. The easiest way is to take a look at the technical data sheet provided by the manufacturer. Similar to the package insert for medicines, the basic technical and chemical properties are listed there. This is usually accompanied by safety data sheets and application aids. However, a look at industrial practice shows that there are no meaningful evaluation methods available to assess the failure behavior of adhesive composites by adhesive manufacturers. Both in industry and in research, the existing methods for performance characterization are far from sufficient. Clear statements on the technical and economic performance limits are therefore lacking. Even manufacturers do not allow themselves to make any judgments about the potential and reserves of their systems for ongoing operation by means of disclaimers. For the decision-maker, this is a highly unsatisfactory situation in which clarity is required.
If one turns to the medical sector, it is noticeable that there are corresponding independent and scientifically sound accompanying studies for a great many clinical products. So-called in-vitro studies establish an empirically valid relationship to the approved product, its performance, and the expectations of the user (doctor/patient). This approach has become established as inevitable in an industry in which human lives depend on the proper use of medicinal products (drugs).
When it comes to evaluating adhesives in regard to their performance, there is an almost unmanageable mix of possible parameters that could be considered. On the one hand, there are the chemical parameters, such as toxicity, viscosity, or tack. This bundle of key figures has a decisive influence on the tack quality. *Table 1* shows four examples of this for each category.
On the other hand, there are also technical and economic parameters that are immensely important for evaluation. Now the question arises how these parameters can be compared in a possible evaluation model, so that meaningful indications for the selection can be derived.

Chemical	Technical	Economical
Tack	Strength	Curing time
Toxicity	Damage tolerance	Costs per kg
Viscosity	Crack growth resistance	Consumption per m^2
Biocompatibility	Stiffness	Miscibility (1C/2C)

Table 1 > Classification of the performance indicators of adhesives including examples

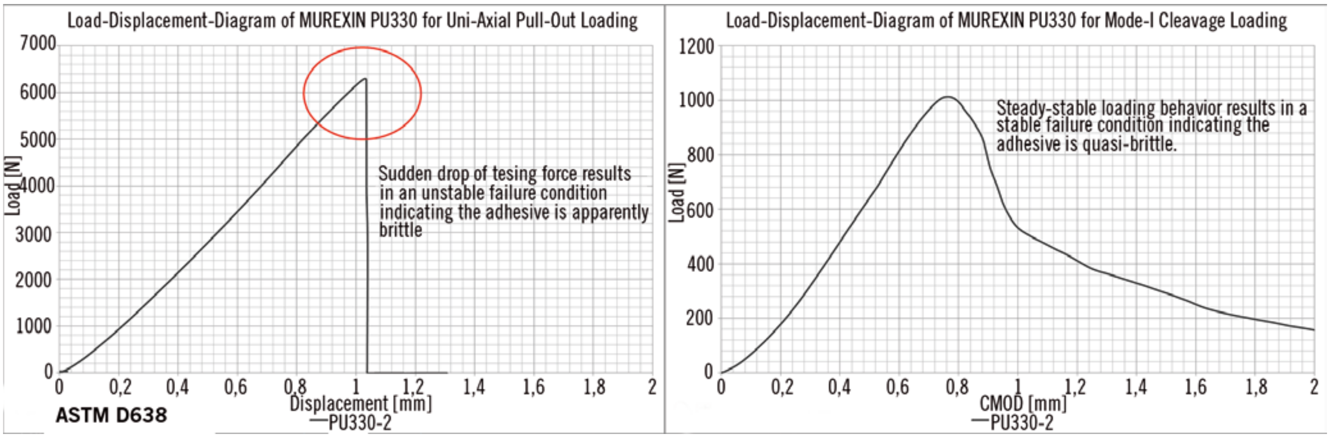

Figure 1 > The same adhesive, but different test curves. The standardized tensile test according to ASTM D638 (left) causes candidate Murexin PU330 to fail unstable, whereas the change to a stable test method according to Fracture Analytics (right) leads to steady curves.

The assessment principle presented here is based on research and developments by Dr. Martin Brandtner-Hafner of Fracture Analytics. The first basic principles have already been published in several industrial magazines [2, 3] as well as in international scientific journals [4–9]. The aim of this novel principle is to evaluate industrial, structural, and high-tech adhesives and is divided into three stages:

1. Testing
2. Assessment
3. Benchmarking

Testing

Adhesive joints have been tested for years by well-established and widely used standard test methods in terms of technical quality. The advantage of these test methods is the simple implementation in the laboratory, the relatively inexpensive production of test specimens, and the comparability of the mechanical quality parameters, such as the adhesive tensile strength. At present, the lap-shear strength according to [10] is used as a standard for characterizing adhesives, and the corresponding values can also be found in the manufacturers' technical product datasheets. For mechanical calculations when dimensioning adhesive bonds, this is used as a strength measure.

In 1990, Manfred Rasche [11] critically reviewed the lap-shear test according to DIN EN 1465 [10]. He came to interesting conclusions, which make alternative test methods necessary. Further details can be found in [2–9]. The test procedure presented in this study enables the generation of empirically valid data for the determination of meaningful performance figures, which allow a qualitative adhesive selection. This methodology is characterized by three clearly defined unique selling points compared to the procedure according to [7] that is currently available on the market:

1. Stable testing even of brittle adhesives *(Figure 1)*,
2. No substrate failure, as for example with PVC in lap-shear tests with cyanoacrylate *(Figure 2)*,
3. Softening processes of the interface are physically characterized and directly measured. They therefore allow statements on the overall structure and numerical simulations using FEM.

Assessment

In the assessment phase (phase two), bundles of key figures are generated based on stable measurement results for corresponding stress modes (*Figure 3*) and mathematically evaluated employing an algorithm. The great advantage of this is that these key figures can be supplemented with existing parameters from, for example, technical data sheets of manufacturers (for example the lap-shear strength). This gives the client a first impression of his adhesive candidate.

Benchmarking

The third step is the holistic linking with a customer-defined set of key metrics, which are subjected to an evaluation process in the sense of "best practice". Chemical attributes (i.e. toxicity, viscosity, etc.)

Supplier	Adhesive	Chemistry
Murexin	D490	Acrylate 1C
Murexin	X-Bond MS K577	MS-Polymer 1C
Murexin	PU330	Polyurethane 2C
Sika	SikaBond T8	Polyurethane 1C
Sika	SikaBond 52	Polyurethane 1C
Sika	SikaBond Lino1	Acrylate 1C

Table 2 > Overview of the tested adhesives

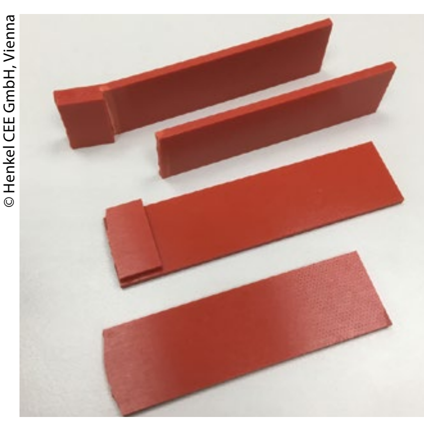

Figure 2 > Visualization of broken PVC joint specimens after lap-shear tests were carried out with cyanoacrylate adhesive. Thanks to a novel testing device, such fractures could be avoided in this study.

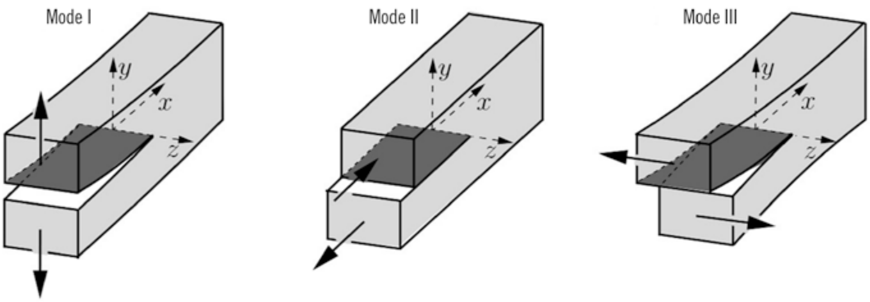

Figure 3 > The three stress modes I (crack opening), II (shearing) and III (torsion) for the fracture analytical creation of performance indicators

as well as economic parameters (i.e. curing time, costs per kg, etc.) can also be incorporated. Finally, a novel API index (adhesive performance index) is created. With this performance index, comparable peer groups can then be formed – independent of manufacturer and customer – from which a rating as well as a ranking can be created. To illustrate this, an independent empirical study of different industrial adhesive systems from two manufacturers (Sika, Switzerland and Murexin, Austria) was carried out. The adhesives indicated in *Table 2* were used for testing and benchmarking.

To empirically characterize the adhesive bonding process, a specifically developed mathematical evaluation algorithm was utilized. It incorporates the relative performance under consideration of the risk and profitability. The resulting adhesive model consists of two selected input variables “bonding costs and bonding time” as well as two selected output variables “bonding integrity and bonding strength”. *Table 3* summarizes these variables, supplemented by their relative properties.

All data, except for the damage capacity, are available from the manufacturers’ technical datasheets. The damage capacity can be obtained directly from Fracture Analytics. For the user, a maximization of the output variables as well as a minimization of the input variables is desirable. The mathematical assignment and optimization of the input and output variables are carried out by means of an algorithmic data model, which sufficiently describes the bonding process (*Figure 4*). The aim of this modeling process is the creation of a distinct performance measure which is not provided by adhesive producers and their technical datasheets. In accordance with the inputs and outputs, the API is a novel, single performance benchmark indicating the adhesive performance compared to its peer candidates.

Results

The results are quite surprising. Among the top two adhesives are those of the Swiss supplier Sika, which is very strongly represented in the automotive sector, closely followed by Murexin from Austria in the third place (*Table 4*). API is the acronym for “adhesive performance index”, developed by Fracture Analytics, a metric between 0 to 1 indicating the relative performance of each adhesive candidate compared to its peer. The rating is described by stars from 1 to 5 and dependent on the API value created from the performance modeling process.

Figure 5 again shows the performance results in the form of color-illustrated bars. The colors represent the risk of uncontrolled failure in the adhesive interface after exceeding the tensile strength – an important criterion for selection. Such specific information is not available in any technical data sheet.

The evaluation of different adhesive systems leads to interesting insights that

Supplier	Adhesive	Input 1	Input 2	Output 1	Output 2
		Costs	Time	Strength	Integrity
Murexin	D490	Low	High	Low	Low
Murexin	X-Bond MS K577	Low	Medium	High	Medium
Murexin	PU330	High	High	High	Low
Sika	SikaBond T8	High	Low	High	High
Sika	SikaBond 52	Medium	Low	High	High
Sika	SikaBond Lino1	Medium	Low	Low	Low

Table 3 > Overview of input and output variables including physical, chemical and economic properties

Supplier	Adhesive	Performance	API	Rating
Sika	SikaBond 52	High	1.00	+++++
Murexin	X-Bond MS K577	High	1.00	+++++
Sika	SikaBond T8	Medium/High	0.98	++++
Murexin	PU330	Medium	0.50	+++
Sika	SikaBond Lino1	Low	0.18	+
Murexin	D490	Low	0.10	+

Table 4 > Results of the adhesive performance study (**Disclaimer:** Results without guarantee. Fracture Analytics assumes no liability for the effects of the results on bonding processes and product performance based on this study.)

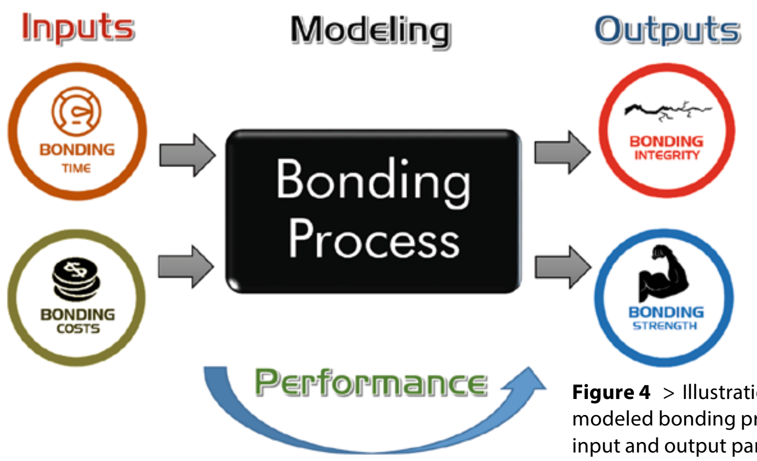

Figure 4 > Illustration of the modeled bonding process with input and output parameters

would not be possible if only the technical datasheets were considered. In this peer, all acrylate-based adhesives show very low-performance levels (Murexin D490 and Sika Lino1). However, one-component polyurethane systems are the clear winners. They include Sika SB52 and Sika T8.

Murexin's only PU candidate in the test – PU330 – only achieved a place in the midfield despite the highest strength values. The reason is the low damage tolerance due to its brittle structure, which means that if overstressed in the bonding zone, the risk of uncontrolled failure in the overall bond is very high. Furthermore, its high unit costs have a negative impact on the overall performance. Other adhesives could achieve better performance at much lower costs. The only MS polymer system in the round, MUREXIN MS K577, however, came in third place. This is a good result considering the technical and economic parameters.

Outlook

This independent pilot study on the bonding performance of industrial adhesives shows that technical data sheets alone do not provide a sound and valid basis for assessment. The reason for this is the lack of independent rating parameters and benchmarks. They can only be obtained from empirically valid data. With Fracture Analytics there is a novel provider on the market offering such data with the corresponding studies. In the coming years several studies on different adhesive systems from various industries will be published. //

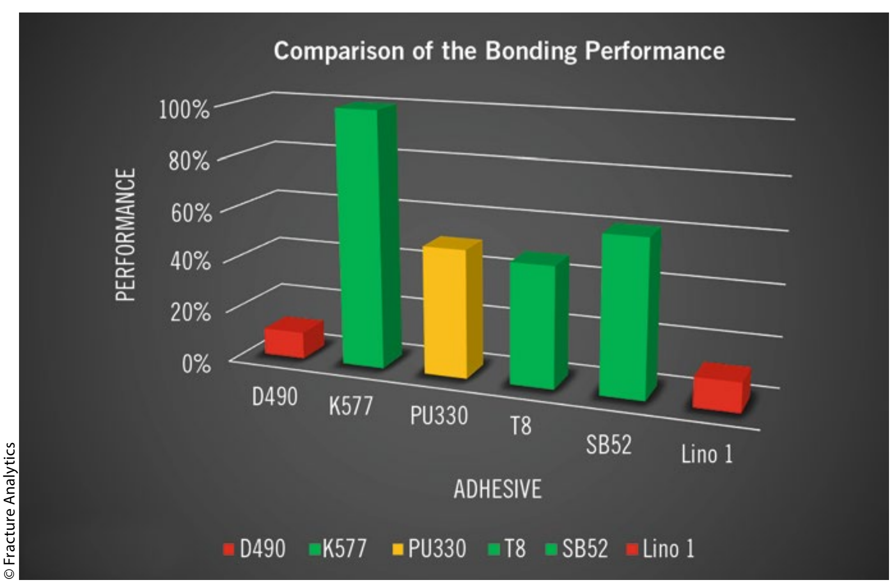

Figure 5 > Comparison of the adhesive bonding performance. Color coding: green – low performance, yellow – medium performance, red – high performance.

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The Author

Dr. Martin Brandtner-Hafner
(info@fractureanalytics.com) is the founder and owner of Fracture Analytics, which focuses on security assessment and performance benchmarking of adhesives and composites.