Technical Article
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Polyurethane technology as applied to the mass production of composite leaf springs using the RTM method

Flexibility and strength for consistent performance

The leaf springs installed in a wide range of vehicles are traditionally manufactured in steel. However, as the issue of vehicle weight continues to gain importance, solutions offering the benefits of lightweight construction are becoming ever more attractive. Although composite materials are the obvious alternative here, the journey from laboratory prototype to mass production is a long one.

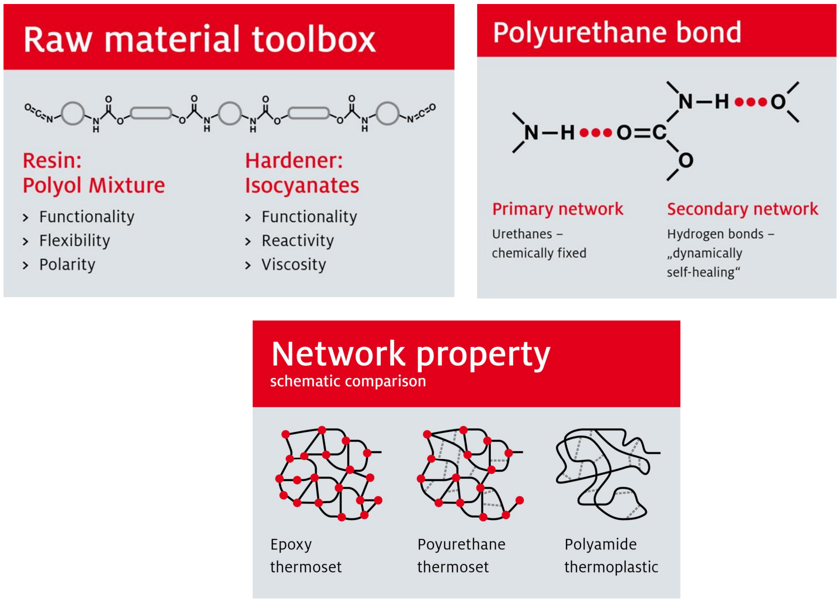
The two main components of a composite are the fiber and the resin. The resin's job is to protect the fibers and ensure efficient force transmission between them. In addition to exhibiting the necessary mechanical properties, the resin must also remain reliably adhered to the fibers in any situation and exhibit a good resistance to a wide range of aging effects.

In automotive suspension applications, excellent mechanical fatigue strength, elongation and resistance to liquids such as water and oil are, of course, also particularly important.

Polyurethanes offer extensive design scope

Polyurethanes provide an excellent basis for satisfying these requirements. Polyurethane chemistry is not only robust but also very flexible. Hence there is an abundance of basic matrix materials with which even complex property profiles can be combined to create a tailored solution. If one analyzes the task of a "spring" in conjunction with the needs of mass production, the aspects of fatigue strength and cycle time immediately come to light as key criteria for selecting the right resin system.

Aside from the purely chemical cross-linked network, polyurethanes also exhibit very strong secondary physical interactions that flexibilize the material without weakening it. By appropriately selecting the resin components, it is possible to specifically vary the two network phenomena in order to achieve a particularly high degree of toughness and thus an extended service life. It also remains possible to retain the high mechanical values and thermal resistance that are particularly associated with chemically cross-linked systems. Of key significance here is the fact that, in particular, many of the disadvantages of the purely physically cross-linked thermoplastic systems, such as creep under thermal stress or susceptibility to moisture, can be almost entirely avoided.



Diagrams 1, 2 and 3: Building blocks of the Loctite MAX 2 matrix resin from Henkel.

In spring applications, high fiber volume contents are essential, so the resin has to be formulated to quickly and effectively penetrate tightly packed fiber bundles. The components primarily selected from the building blocks available are those offering low viscosity and a polarity matched to the properties of the fibers. This ensures that, even with the shortest of injection times, no flaws are induced into the material and full fiber-matrix adhesion is achieved.

High resistance to external influences

The use of low-viscosity systems also enables the satisfaction of a further important criterion: stability in the presence of media such as water or oil. Here it is important both that the components themselves exhibit good resistance values, and that this property is further enhanced by a high level of chemical cross-linking density that limits swelling processes. Here the low-viscosity components in the formulation offer the additional advantage – provided they have been properly selected – of simultaneously promoting high cross-linking density.

As a further benefit, the maximum application temperature is also increased, with embrittlement being effectively avoided through coordinated flexibilization utilizing the physical interrelationships of the urethane groups.

This effect can be very simply illustrated with crack propagation experiments. Comparing an impaired test specimen of the polyurethane resin Loctite MAX 2 with a typical epoxy of similar strength and service temperature shows that, in the case of the former, crack propagation commences at significantly higher loads and progresses much more slowly. This advantage also remains even if the specimens are exposed to extreme moisture loading under water. This shows very clearly that, in the case of polyurethanes, toughness can be regarded as material-intrinsic and controllable, and is thus fully reconcilable with the variables of strength and thermal load resistance.

Such excellent toughness also has a positive effect on fatigue behavior under load. A leaf spring, for example, is exposed to constant dynamic stresses when an automobile is in motion. Therefore, flexible materials with a high fatigue tolerance facilitate substantial prolongation of the service life of a component.

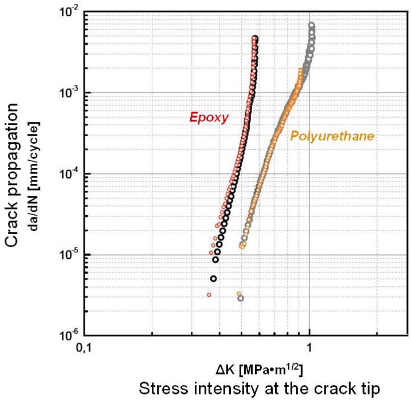


Diagram 4: Typical crack propagation graph showing a Henkel polyurethane compared to a reference epoxy.

Aside from the material properties per se, the speed with which these can be achieved within the process is of significant importance. The relevant variables here are essentially time and temperature. Polyurethane cross-linking is generally characterized by two special features that allow excellent process control: the first is the very low reaction heat, which means there is no danger of highly accelerated formulations reacting in an uncontrolled manner; and the second is that accelerators can be readily added to finely tune the process speed to requirements.

Depending on the desired process and properties window, maximum speeds to demolding can be achieved, for example, at a mold temperature – and thus reaction temperature – of anything from e.g. 70 °C to, say, 110 °C. The change is achieved by simply adjusting the quantities of accelerator added. Thus, it would be possible to use the same resin system to produce – with equal speed – both thermally highly stressed structural components, say, and external bodyshell components in which the emphasis is on achieving good surface quality. For each process and each component design, therefore, it is possible to optimally adjust the resin system to minimize cycle time.

In the case of the automotive suspension spring, the system is formulated for good impregnation, high elongation and extreme resistance to cyclic stressing, while at the same time ensuring sufficient thermal loadability under conditions of moisture exposure.

Mass production of composite leaf springs

Although the resin is key to producing a viable composite component such as a leaf spring, it is just as important to align the design and the overall engineering configuration to the subsequent manufacturing process. Only in this way can it be ensured the component will both perform the function for which it is intended and meet the criteria governing production efficiency.

For transverse leaf springs, the key variables here are, firstly, a boundary parameter such as the amount of installation space available, and secondly, the specified properties profile in relation to stiffness or service life. However, process parameters such as cycle times or hardening conditions also play a central role. The first principle is always to ensure the achievement of economic and technical customer benefit. At around 6 kilograms, the composite spring is 9 kilograms lighter than the conventional steel version for this application, giving the technical benefit of a 65 percent saving in weight. And economically, the availability of an efficient process means more tailoring scope.

It is important when embarking on the mass production of series components that all these essential factors and parameters are accommodated within a smoothly interlinked process chain. Through its work on the development and commercialization of a transverse leaf springs manufactured using resin transfer molding (RTM) technology, Benteler-SGL has made pioneering inroads into a number of new fields.

Photos 1 and 2: Composite leaf springs as manufactured (left) and as installed (right).

The first step in guaranteeing product quality is to introduce automated preforming. Layer by layer, the unidirectional (UD) glass fiber material is checked in-process for quality and placed in stacks into the mold. This means that, for each individual spring, there is a guarantee that the material parameters for the component are always compliant with the specification, even in the event of minor variations in the starting material.

The preforms of several leaf springs are simultaneously impregnated in the multiple cavities of a shuttle press mold. The system is designed for a production output of over 100,000 pieces per year. Aside from the above-described resin parameters, major aspects in this regard are an appropriate mold design and handling concept with the leaf springs being separated once they are removed from the cavities.

The last stages in the process are the heat treatment aligned to ensure the uniform hardening of all the leaf springs produced, and a final mechanical QA check to ensure that any concealed defects can be reliably detected.

Hence, with a high level of automation, extensive process design expertise and continuous quality control, together with a functionally stabile, process-compatible resin, it is indeed possible to create and maintain an efficiently interlinked process chain.

Outlook

The sections above discuss the fundamental features of polyurethane resin systems and the specific application of leaf spring production. However, this by no means exhausts the possibilities of polyurethane technology. The building block system inherent in the chemistry means that the combinations available in the creation of specifically tailored solutions are almost infinite.

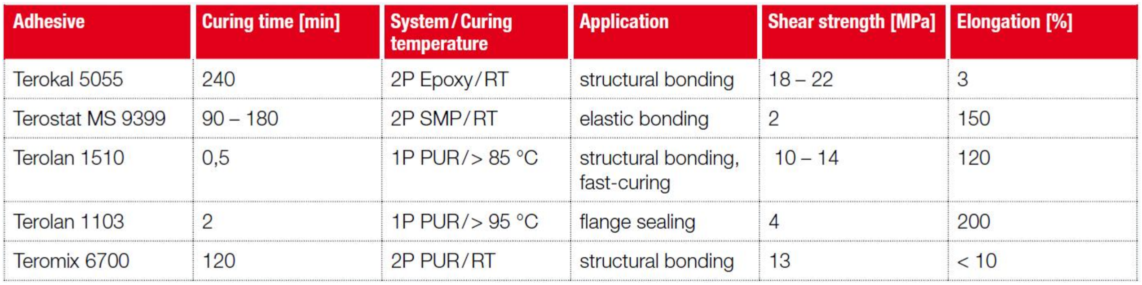
It will certainly be vitally important for the future applications of composites – within integrated modular solutions or as finished components – that solutions will be found for the combination and integration of often disparate materials.

Looking at the use of composite materials in automobile construction, interfaces are constantly surfacing where different materials have to be joined together. Here, a lot of time is currently being spent employing integration techniques that require complex pretreatment processes. Thanks to its versatility, polyurethane in particular offers the basis for the formulation of resins in which a smart release agent function is already integrated. This would serve to separate molding from mold while also being sufficiently well incorporated within the system to allow subsequent bonding or even painting without the need for major pretreatment processes.

GRP test substrates uncleaned	**Teroson PU 1510 1K microencapsulated PU**
Without release agent	9.8 MPa 100 %cf
External release agent	4.2 MPa 100 %af
Internal release agent	9.5 MPa 100 %scf

Table 1: Bonding test on composite specimens made with Loctite MAX 2 with internal release agent.

For the automotive industry particularly, integration within an overall package is essential for this technology to be regarded as a complete application solution. Henkel is therefore working hard on further developing resin components that can be incorporated within the system and thus contribute to optimizing the production process. Similarly, Henkel also offers individually formulated adhesives designed to ensure the reliable integration of the different component materials within the framework of advanced multimaterial concepts.



Adhesive	Curing time [min]	System / Curing temperature	Application	Shear strength [MPa]	Elongation [%]
Terokal 5055	240	2P Epoxy / RT	structural bonding	18 – 22	3
Terostat MS 9399	90 – 180	2P SMP / RT	elastic bonding	2	150
Terolan 1510	0,5	1P PUR / > 85 °C	structural bonding, fast-curing	10 – 14	120
Terolan 1103	2	1P PUR / > 95 °C	flange sealing	4	200
Teromix 6700	120	2P PUR / RT	structural bonding	13	< 10

Table 2: Henkel adhesives portfolio for the bonding of composites.

Is this vision or reality? The advancements made to date show that this approach can indeed be adopted with products such as Loctite MAX 2. The components are available and the art now lies in utilizing this potential in the creation of solutions tailored to each specific application.

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Loctite is a registered trademark of Henkel in Germany and elsewhere.

About Henkel

Henkel operates worldwide with leading brands and technologies in three business areas: Laundry & Home Care, Beauty Care and Adhesive Technologies. Founded in 1876, Henkel holds globally leading market positions both in the consumer and industrial businesses with well-known brands such as Persil, Schwarzkopf and Loctite. Henkel employs about 47,000 people and reported sales of 16.4 billion euros and adjusted operating profit of 2.5 billion euros in fiscal 2013. Henkel's preferred shares are listed in the German stock index DAX.

About Benteler-SGL

Benteler-SGL GmbH & Co. KG was founded in 2008. It is a joint venture of Benteler Automobiltechnik GmbH with headquarters in Paderborn, Germany, and SGL Group with headquarters in Wiesbaden, Germany. The core competencies of SGL Group in material sciences and carbon fiber-based preliminary products are complemented by the market and engineering technical competence of Benteler, a tier 1 supplier to the automotive sector for many years. At the beginning of 2009, the joint venture company additionally took over the automobile business unit of Composite Technology GmbH in Ried im Innkreis, Austria, from the Fischer Group. The production operation has been systematically built up since that time. Today, Benteler-SGL employs 150 people in Austria, twice as many as in 2009. More information can be found at www.benteler-sgl.com.

Photo material is available at http://www.henkel.com/press

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Henkel AG & Co. KGaA

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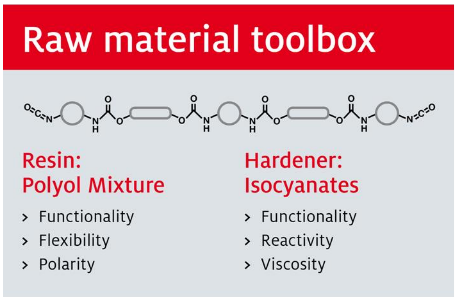

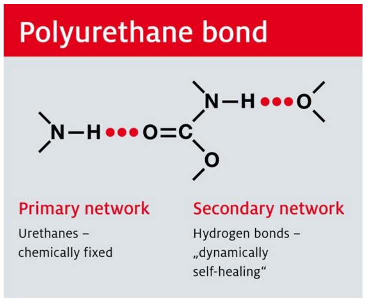

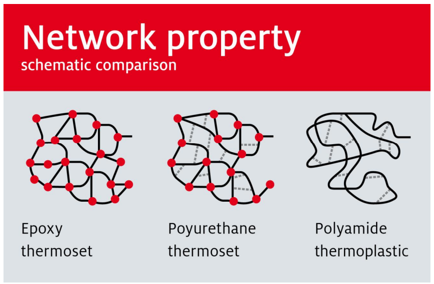

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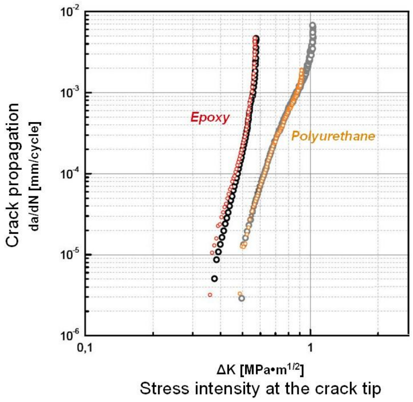

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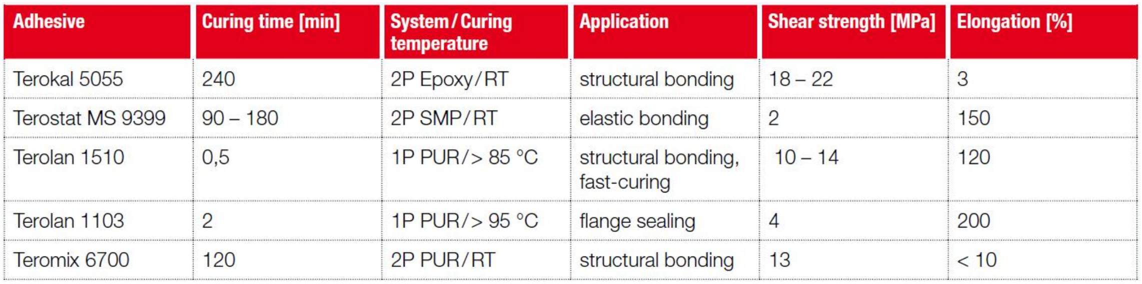

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