Toughened 2K-Epoxy Adhesives: From Automotive and Wind towards Construction

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ABSTRACT: The toughness of 2C epoxy adhesives is a decisive factor of today's high performance adhesives used for crash-zone repair in automotive or the bonding of wind turbine blades. Adhesives using Sika's patented PU-rubber toughener are used for applications, where high impact engergies or high fatigue cycles have to be resisted without bond failure during the entire life-time. Different toughness measurements are shown and its potential for construction applications outlined.

1 INTRODUCTION

Nowadays top performance, toughened epoxy adhesives are primarily hot curing 1C epoxy systems used for bonding metals in modern car bodies. Sika introduced their new toughened 1C epoxy adhesive for automotive lightweight structures 2009 to the market [1] which are based on an in situ formed PU-rubber epoxy toughener. Based on this concept a patented PU-rubber toughener for 2C epoxies was developed and introduced for automotive repair and wind, where till then rather classic, brittle or flexibilized, 2C Epoxy solutions were available.
To achieve a high level of toughness, different solutions are possible. All aim at high amounts of elastic domains resp. particles, as small as possible in size and well connected with the primarily stiff matrix. Here prefabricated or in situ formed (nano) particles can be used; the latter being more effective, but their formation depends highly on the process. In case of in-situ formed toughener particles, it is important that non-separated toughener polymer leads to a higher flexibilisation of the matrix.

2 TOUGH 2C EPOXY REPAIR ADHESIVES

The smaller the in situ formed toughener particles are, the better is the resulting performance. Essentially, the separating toughening polymer must stay dissolved as long as possible to yield small particles.

However, on the other hand this results in a more and more flexibilised matrix, as the content of dissolved toughener in the matrix increases. Partially, this is intended also, because a more flexible material has a higher toughness as such.

Contrariwise, structural performance requires a certain modulus, thus a too high drop in mechanics is not desired. In the automotive industry the dynamic impact peel tests (DIN ISO 11343) is an established method to judge the toughness performance on steel substrates. Figure 1 gives the E-modulus vs. the toughness performance.

Most of the structural car body repair adhesives in the market are highly stiff and as expected show a low impact peel resistance (toughness). Toughened materials are usually more flexible, but the real challenge is to show a high impact peel resistance and a high modulus.

It is shown that this is feasible with our new toughener generation, which is used to formulate a commercially available 2C epoxy repair adhesive (SikaPower®-1277) having not only an impact peel performance of app. 30 N/mm but even a stiffness in the range of standard body in white adhesives.

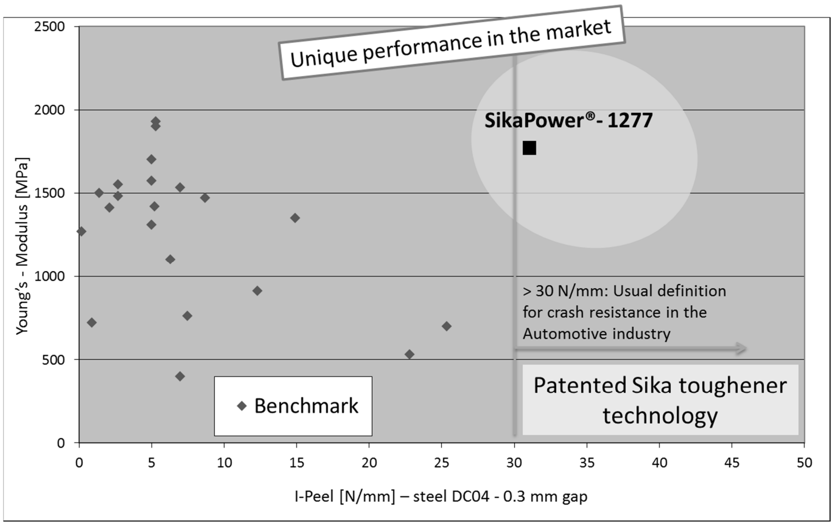

Figure 1. E-modulus vs I-Peel of different 2C epoxies adhesives. ◆commercially available products, ■ final product SikaPower®-1277.

3 TOUGH 2C EPOXY WIND TURBINE BLADE ADHESIVES

The same toughener concept can be used for wind turbine generator blades where due to the high applied volumes, low adhesives prices are essential and highly expensive, prefabricated particles are not the desired method.

Due to the yearly increasing blade length of currently over 80 m, the standard design of rotor blade bonding using relatively brittle adhesives is reaching a limit – increased resistance against fatigue cycles and a higher maximum load make toughened adhesives an important design factor towards further increased blade length.

In the Wind industry toughness is usually judged by static tests like the compact tension test ISO 13586 or double cantilever beam (DCB) resp. end-notched flexural (ENF) bending tests to determine the critical fracture energy in mode I (peel) or mode II (shear). DCB and ENF have the advantage of using normal substrates rather than testing the pure bulk adhesive but the preparation is more time consuming and the measurement requires a certain skill. To gain comparative results, the rather simple impact peel test can be used, if the adhesion is sufficient on steel.

To put the different toughness measurements into comparison with different development adhesives of the Sikadur WTG series, a big set of tests were performed (c.f. Table 1).

The last adhesive shows how potent Sika's new toughener technology is; in our internal comparison it gives more than 50% higher results than currently used standard wind turbine blade adhesives. For wind turbine blades certainly the crash performance is no issue, but the fatigue resistance is even more important for blades than it is for cars. Where the latter are designed for 10^6 loading cycles blades have to endure 10^8 cycles.

Table 1. Comparison of toughness measurements on wind blade adhesives with differing toughness. The CT measurements using optical crack tracking are based on linear elastic fracture mechanics, the resulting K1c plateau value of the respective R-curve is stated.

Measurement	Parameter [Unit]	Not toughened	Medium toughened	Highly toughened
Compact Tension with OCT(*) (DIN EN ISO 13586)	K_{Ic} [MPa $m^{1/2}$]	1.6	2.5	3.5
	G_{Ic} [N/mm]	0.6	1.8	4.2
Impact Peel	IP [N/mm]	0.5	12	21
Leichtwerk:				
DCB	G_{Ic} [N/mm]	0.5	0.9	2.1
ENF	G_{IIc} [N/mm]	1.45	5.7	10.1

(* optical crack tracking)

The fatigue performance of the highly toughened adhesive Sikadur WTG-1280 LD is highly improved in comparison to non-toughened, standard epoxy adhesive for blade bonding applications, measured in different load geometries.

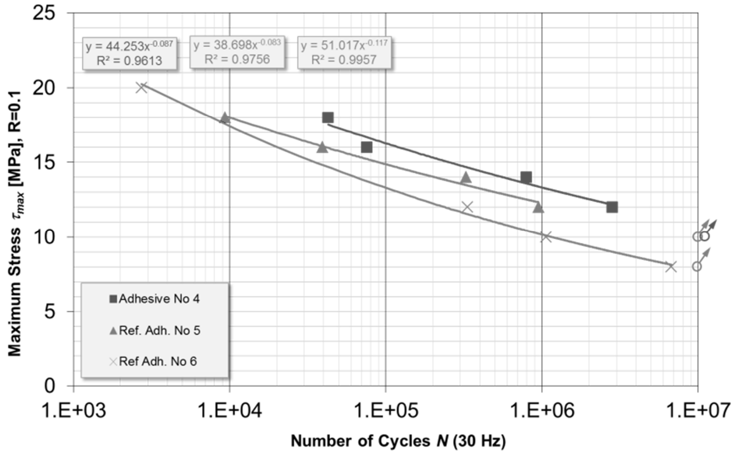

Figure 2. Dynamic lap shear strength fatigue on GRE substrates using x non-toughened adhesive, ▲medium toughened reference adhesive, ■ highly toughened adhesive.

In Figure 2, the fatigue performance of the highly toughened adhesive Sikadur WTG-1280 LD under lap shear geometry is shown in comparison with the lower toughened adhesive and the non-toughened, brittle adhesive. The improvement in fatigue properties with increasing toughening properties is clearly visible.

The crack propagation rate of adhesive is shown in Figure 3. The graph shows the crack growth per fatigue cycle at different crack Energies ΔG and was determined using DCB fatigue measurements, similar in geometry and measurement setup with the quasi-static results already shown in Tab. 2.

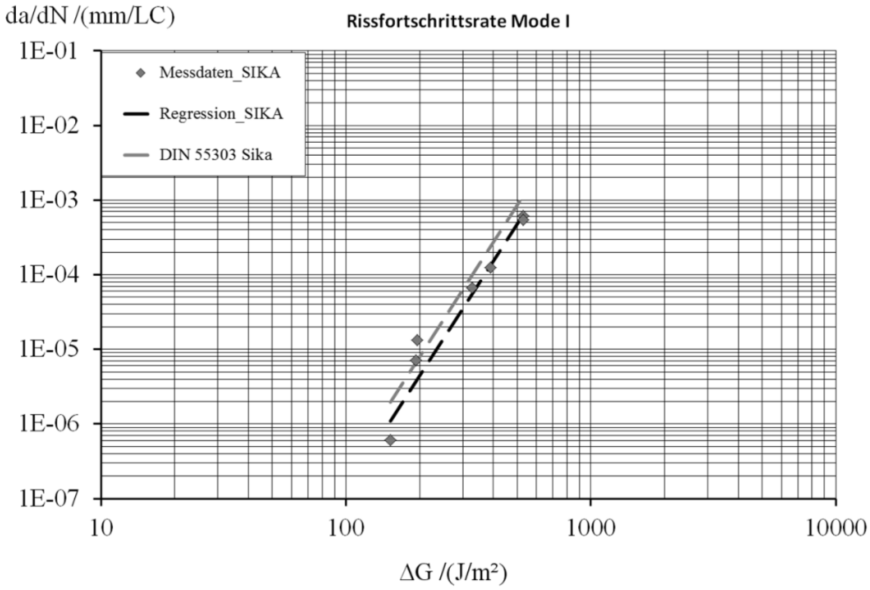

Figure 3. Crack propagation rate of the highly toughened adhesive measured under dynamic DCB loading on GRE substrates.

4 NOVEL ADHESIVES FOR REFURBISHMENT

Especially in refurbishment, a lot of 2C Epoxy adhesives are used for different applications. Even though, taking into account their highly brittle nature, they are much tougher than concrete and other cementitious systems and offer good and reliable bonding with substrate failure occurring at very high loads. However, crash resistance is not a very widespread requirement in construction and refurbishment, whereas high fatigue cycles and a long prospected lifetime are omnipresent in construction/refurbishment. This advantage of toughened adhesives, combined with less brittle substrates, such as metal structures or composite applications would open up a new field for structural bonding in construction, e.g. among others seismic guarding or construction with novel materials (composite bridges, …).

5 CONCLUSION

Where cars get lighter, blades are getting bigger and bigger – for both cases toughened adhesives are the right choice to meet future and today's demands. On the one hand a very high level of crash-resistance and toughness can be provided, on the other hand the fatigue performance and thus the life span of the bonded product can be improved. For concrete bonding, the present epoxy adhesives may perform well, but especially for structural bonding of steel and composite parts, toughened adhesives would allow a huge step forward towards fatigue resistant, structural bonding in construction/refurbishment.

6 REFERENCES

[1] B. Burchard, J.O. Schulenburg, M. Linnenbrink. 2009. New building blocks for light weight structures, *adhesion adhesive & sealants*, 10/2009:22ff.