Structural Adhesives with Customized Fast Curing

Commercial transportation industry is constantly challenged by increasing production efficiency and reducing costs, while introducing new design solutions based on lightweight materials. Two innovative adhesive technologies, 'Powerflex' and 'Curing by Design', have been developed to maximize the potential offered by modern lightweight design as well as to improve productivity by immediate curing at precisely defined time.

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The development of commercial and special vehicles (e.g., buses, caravans, trucks, trailers, etc.) is progressively more characterized by lightweight design and production efficiency. The reduction of vehicles' weight by introducing lighter materials or multi-material design concepts leads not only to the achievement of less CO_2 emissions, but also to the increment of goods capacity and passenger comfort. For instance, a lighter bus can accommodate more passenger seats; a caravan with thinner walls has more internal space that can be organized for a more livable environment for travelers. Although lightweight solutions bring various advantages in engineering and design phase, their implementation may be not successful if it disregards the needs of production departments, which often struggle with efficiency problems. While production managers aim at speeding up fabrication and assembly of vehicle components, they must reduce manufacturing costs. Moreover, they have often to cope with order backlogs, which make harder to increase output at lower costs.

Among the diverse methods available for assembling and joining vehicle components, adhesive bonding keeps up with manufacturers' challenging demands, as well as can open new possibilities for lightweight and multi-material design.

In order to achieve the full potential offered by assembly bonding, however, structural adhesives are required to show higher performance and an enhanced curing behavior, compared to standard bonding products used in commercial transportation industry. As an example, combining aluminum with steel alloys or with modern composite materials poses the issue of the accommodating differences in thermal expansion [1]. This is particularly problematic when external temperatures are low, because standard structural adhesives employed by commercial vehicle manufacturers typically undergo a significant embrittlement in cold conditions. Consequently, they are not able to compensate for thermal stresses and expose the joints to failure, even if they appear flexible and compliant at room tem-

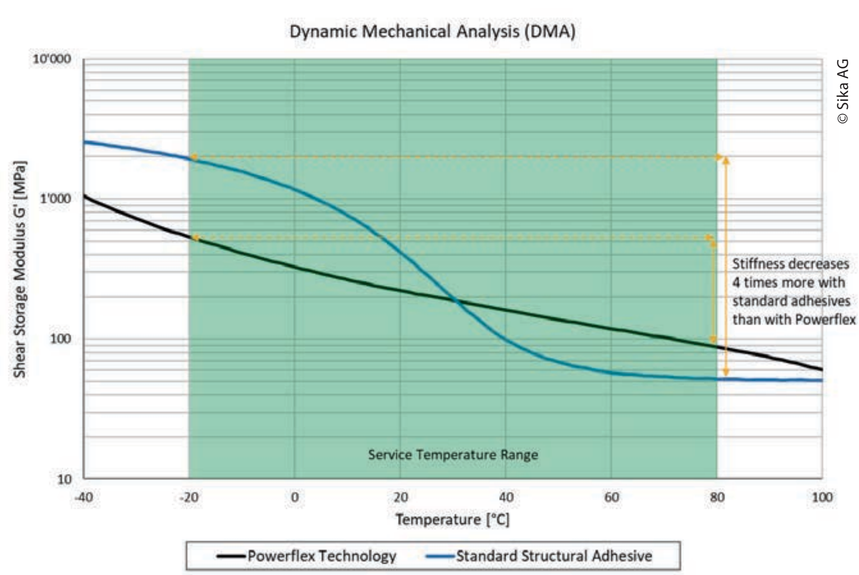

Figure 1 > Comparison of DMA between "Powerflex" technology and standard structural adhesive in commercial transportation

Material property	Typical value range
Tensile strength	10 – 20 MPa
Elongation at break	100 – 400 %
Elastic modulus	20 – 800 MPa
Lap-shear strength (1 mm thick)	10 – 20 MPa
Impact peel strength	> 50 N/mm
Shore A hardness	80 – 95

Table 1 > Typical properties achievable with 'Powerflex' technology

perature, like regular 2C polyurethanes or MMA adhesives. On the other hand, industrial adhesives that are flexible enough at low temperatures generally become very soft in warm or hot climatic conditions. Thus, they are not likely to provide adequate joint strength and stiffness, risking the structural integrity of the vehicles.

Under the names 'Powerflex' and 'Curing by Design', Sika has developed two innovative adhesive technologies that address the specific issues of commercial vehicle manufactures. These proprietary technologies can be coupled to formulate unique bonding products, which provide several benefits in terms of greater freedom of design, higher safety and durability, more time and cost-effective production. Besides the ability to bond dissimilar materials and optimize stress distribution in complex geometrical joints, the new adhesives allow for more stable properties over the whole service temperature range, keeping good flexibility at low temperatures and stiffness at high temperatures. In addition, they combine a fast strength build-up with sufficiently long open times to apply adhesives and assemble parts. In this way, waiting times during component bonding can be largely reduced, without compromising on the assembly working times. The following examples describe the features of the new technologies with reference to practical advantages for commercial transportation industry.

Features of the 'Powerflex' technology

Sika's 'Powerflex' technology [2],[3],[4] enables the formulation of 2C polyurethane-based adhesives with remarkably low glass transition temperature Tg (around -45 °C) and, at the same time, high mechanical strength and modulus in rubbery state above Tg. This feature allows enhanced toughness and impact resistance of the bonded assemblies over the whole service temperature range and life cycle. Moreover, the flexibility and the structural performance of cured adhesives result very stable between -40 °C to 100 °C. Compared to traditional structural adhe-

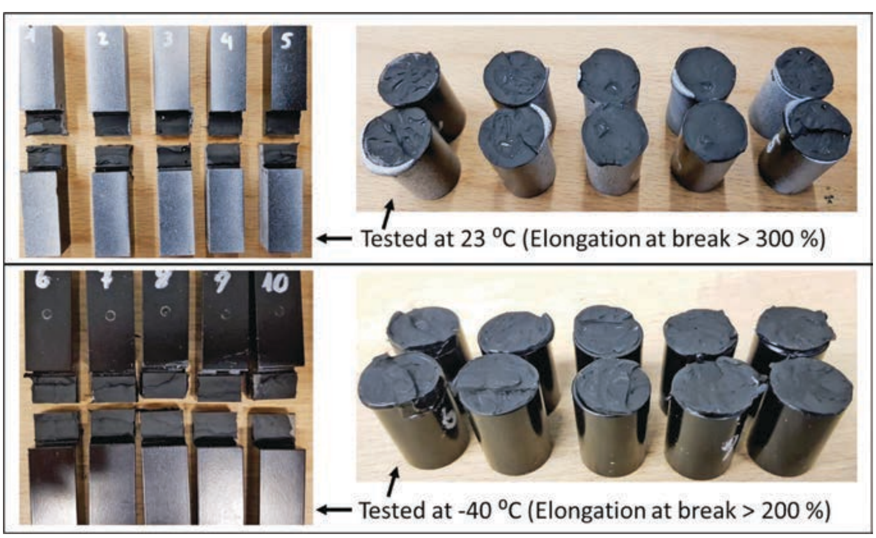

Figure 2 > Cohesive failures of 'Powerflex' adhesive on e-coated steel in 'Thick Adherent Shear Tests' (TAST) and butt joint tensile tests at 23 °C and -40 °C

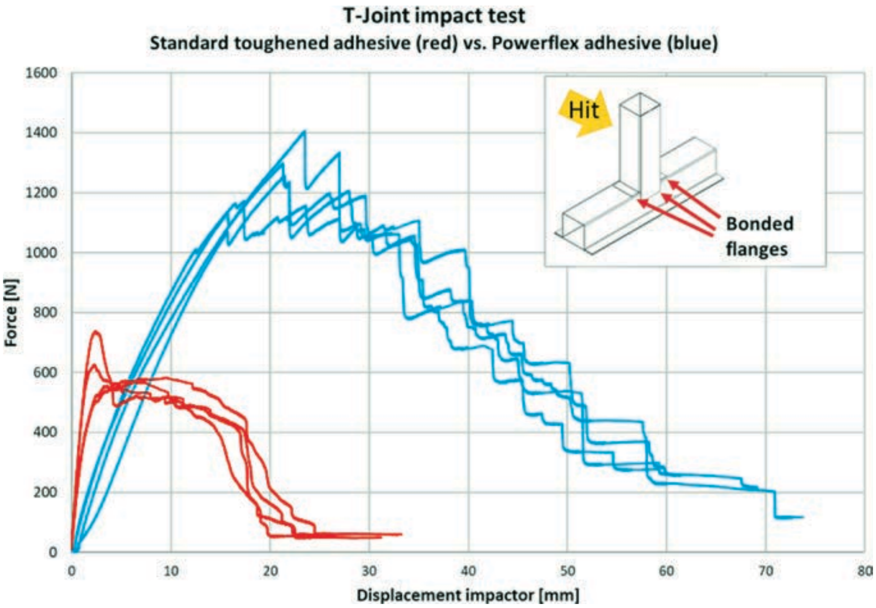

Figure 3 > Impact tests of T-joints bonded with a standard toughened adhesive (red curves) and a 'Powerflex' adhesive (blue curves): the larger area beneath the blue curves indicate a greater toughness and energy absorption.

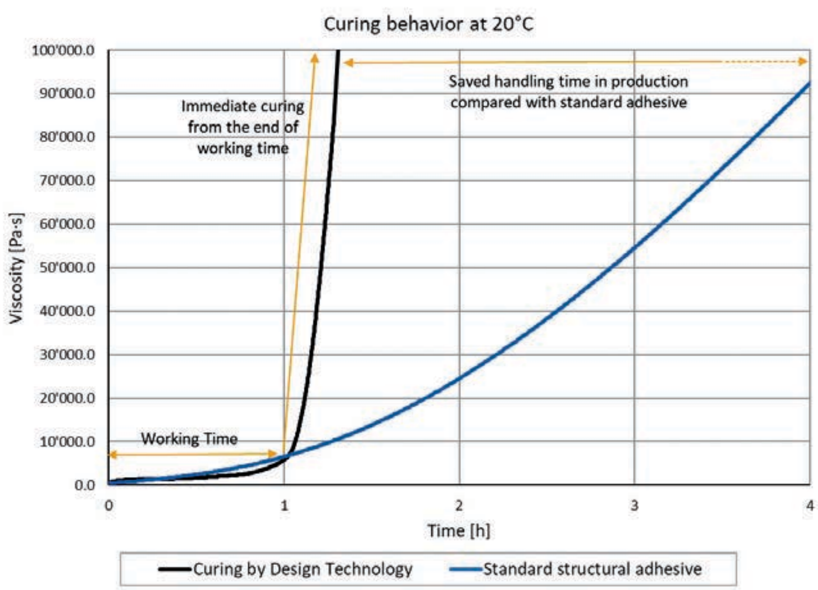

Figure 4 > Comparison of curing behavior between 'Curing by Design' technology and a standard structural adhesive with same working time

sives, the modulus does not show big variations over temperature (*Figure 1*).
Typical ranges of properties, which characterize adhesives with 'Powerflex' technology, are reported in *Table 1*. The high level of strength achievable at large elongations derives from a patented molecular chemistry that incorporates organic hard segments into an elastic matrix of long polymeric chains. Such hard segments, which are formed during the reaction of the two adhesive components at ambient temperature (neither external heating nor humidity is needed), boost the structural performance of the flexible polymer matrix. Their content is designed in the adhesive formulation to obtain a defined modulus: in this way, the adhesives are tailored to match the specific mechanical properties of the substrates and maximize the load transfer through the joint. This technology permits, for example, an excellent bonding of high-grade steels that are painted or e-coated, without damaging paints or coating layers, even at very low temperature (*Figure 2*). Furthermore, compared to common toughened structural adhesives, the inherent elasticity given by the 'Powerflex' technology allows for greater resilience and energy absorption in the case of an impact, as shown in *Figure 3*.

Combination with 'Curing by Design' technology

The advantages of 'Powerflex' can be additionally combined with 'Curing by Design' [3],[4][5], which indicates a unique proprietary technology that Sika has developed to accelerate curing reaction of 2C polyurethane adhesives while keeping long workability (*Figure 4*). In conventional 2C adhesives, the reaction starts as soon the two components are mixed, thus the

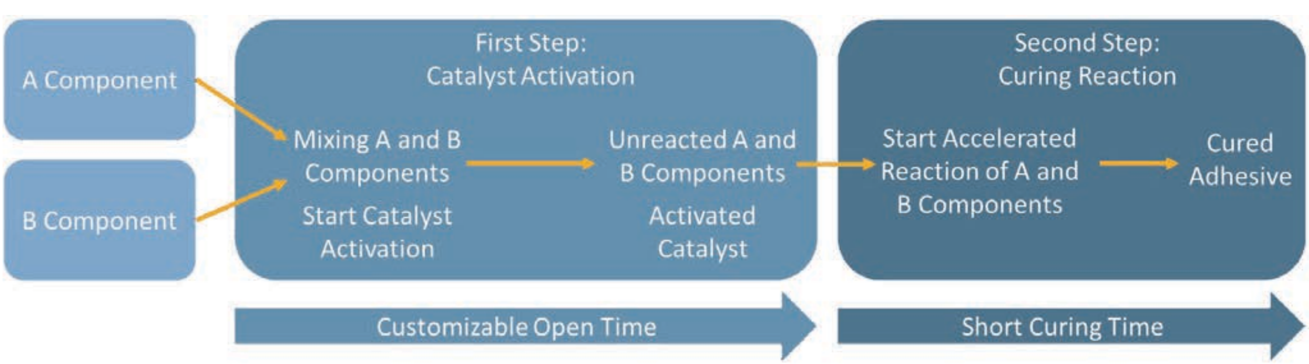

Figure 5 > 'Curing by Design' working mechanism (schematically)

working or open time is directly proportional to the curing time: The longer the open time is, the slower the curing is. In 'Curing by Design' adhesives, a catalyst is designed to obtain a tailored delay before the fast reaction starts. This permits to modulate adhesive working time and curing speed separately and, therefore, to reduce unproductive fixing or holding time until the assembly can be handled. Immediate curing performance, combined to a long enough open time, is of high interest for all bonding applications and increases throughput of industrial processes significantly.

The working mechanism of the technology is schematized in *Figure 5* and consists in a two-step reaction [6]. During the first step, the mixing of the two components (by means of a dynamic or a simple static mixer, as in cartridge application) does not initiate the curing reaction directly, but rather induces the catalyst activation. This leaves the adhesive wet and soft, as if it were fresh applied, for a sufficiently long time, matching the open time of the assembly. As a matter of fact, the duration of the first reaction step can be customized by adjusting the adhesive formulation to the specific application requirement. In the second step, the actual curing reaction of the two-component adhesive kicks off and progresses very fast, thanks to the presence of the now activated catalyst. This allows the system to rapidly reach the strength required for moving the bonded assembly to the next production stage.

Figure 6 > Application of 'Powerflex' and 'Curing by Design' adhesive for hook arm bonding on a truck chassis

It is worth highlighting that heating up the bond line can further speed up the curing reaction. But external heat is not strictly needed for fast curing, because this is already achievable at ambient temperature. Consequently, the cost of heating devices is unnecessary and potential quality issues related to cold spots in heated tools are avoided. Finally, it should be mentioned that the 'Curing by Design' technology is based on 2C polyurethanes, which release lower exothermic energy and lower smell than standard MMA adhesives.

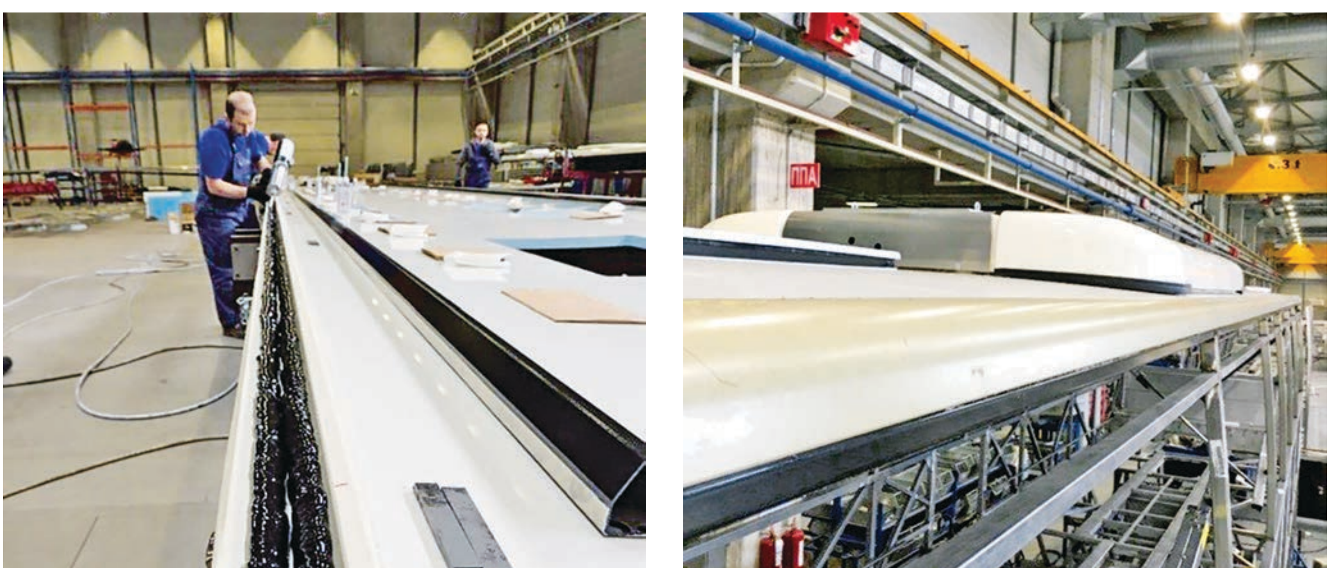

Figure 7 > Application of 'Powerflex' and 'Curing by Design' adhesive for bus roof bonding

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Figure 8 > Extended design concepts and modular bonding of lightweight bus roof

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Figure 9 > Sika's winning team of Swiss Technology Award 2019

Benefits for manufacturers

Two-component adhesives with 'Powerflex' and 'Curing by Design' technologies are optimized solutions for primerless bonding of composites (e.g., SMC, CFRP, etc.) and/or coated metals (*Figure 6*). Having low viscosity and a standard mixing ratio of 1:1, these adhesives can be applied out of cartridges or by regular dispensing equipment. As above mentioned, the curing takes place at ambient temperature, but heating devices can also be used, as in the case of heated presses for SMC bonding.

An exemplary application is given in *Figure 7*, which shows the bonding of an integral lightweight composite roof to the steel sidewalls of a bus [3]. In this case, the 'Powerflex' technology enables the construction of strong and flexible joints in both hot and cold climates, i.e., independently of the traveling conditions of the bus. Unlike traditional mechanical fixations, bonding the vehicle roof with a 'Powerflex' adhesive avoids stress concentrations and improves crashworthiness of the bus superstructure, withstanding dynamic rollover tests according to UN-ECE Regulation 66 [7] without adding extra reinforcements and weight. A weight reduction of up to 500 kg is actually achievable in comparison with conventional bus construction [3]. This opens up new opportunities for installing and upgrading the design of diverse modules on the roof, such as air conditioning units, luggage compartments and batteries or fuel cells for e-mobility vehicles (*Figure 8*).

The bus roof bonding in *Figure 7* benefits from the advantages of 'Curing by Design', in addition to the 'Powerflex' technology, provided by the same adhesive product. As a matter of fact, the practical assembly of a 12 m long bus roof needs about 30-45 minutes to be completed in production. A regular polyurethane or epoxy adhesive with such long open time typically requires a minimum of 8 hours at room temperature, in order to reach an adequate degree of curing that permits to move the assembly forward on the production line. Conversely, an accelerated adhesive system could increase production efficiency with a faster curing, but at the cost of a drastic shortening of the open time. Therefore, the bus manufacturer would be forced to invest in extra dispensing equipment and employ additional workforce on the line, so to keep up with the shortened open time. Using a structural adhesive with 'Curing by Design' technology solves the problem effectively, giving enough open time for workers to comfortably close the assembly (at least 45 minutes) and, concurrently, reducing the waiting time to reach handling strength to less than 1.5 hours after the adhesive bead application.

Conclusions

The innovative adhesive technologies 'Powerflex' and 'Curing by Design' enhance the performance of assembly bonding in commercial transportation industry. They combine in single bonding products contradictory features: high elasticity and structural strength, long open time and fast curing behavior. For the development and market introduction of adhesives with these unique characteristics, Sika has won the Swiss Technology Award 2019 [8] in the category 'Innovation Leaders' (*Figure 9*). //

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