Recyclable epoxy adhesive system for rotor blades

Amit Dixit,
Senior Vice President,
Advanced Materials-Aditya Birla Chemicals

The growth of the wind industry is supported by the development of new technologies that make it possible to harness more energy with high efficiency. Incidentally, the industry is also facing a compelling issue regarding the end-of-life management of decommissioned rotor blades.

In a wind turbine, 85% of the components are known to be eligible for recycling and reuse. This high percentage does not include the rotor blades due to their non-recyclable thermoset matrix. But with the successful implementation of the Recyclamine®, proprietary technology developed by Advanced Materials-Aditya Birla Chemicals, and the development of the world's first recyclable rotor blade, the industry has taken a leap forward in addressing sustainability concerns. The recyclable epoxy adhesive system allows 100% recycling of rotor blades, thus driving circularity.

Evolution of adhesive technologies for rotor blades

A wind turbine rotor blade generally consists of two shells bonded together with a structural adhesive – also called a bonding paste. The adhesive is subjected to significant loads, therefore higher mechanical performance is required and epoxy adhesive systems are used. Furthermore, due to the profile of rotor blades and the application process, the adhesive has to be slump resistant and exhibit a low curing shrinkage and higher resilience.

Over the years, adhesive technologies have evolved with the development of new blade designs and the growth of offshore platforms (Figure 1). Conventional epoxy adhesives were designed with resin and hardener components that were thixotropic and mechanically reinforced. These adhesives provided optimum performance properties, however the required use of a two-component dispensing machine caused increased wear on the parts and drives. This concern was addressed by the development of instant thixotropic adhesives that were comprised of low-viscosity, flowable resin and hardener components which, on mixing, provided the same level of thixotropy as conventional adhesives. The increase in blade lengths resulted in the development of slow-reacting, high-strength adhesives enabling longer open times and low-density adhesives providing a higher ductility, toughness and a lowered contribution to the blade's weight.

A recyclable low-density epoxy adhesive

With the development of the world's first recyclable rotor blade using an infusion system, the industry has taken a leap forward towards addressing sustainability concerns. However, since the majority of rotor blades are constructed in two shells, it is imperative that the epoxy adhesive is also recyclable. The recyclable low-density epoxy adhesive system leverages the Recyclamine® technology, that makes it possible to debond the two shells under specific conditions, facilitating recycling of the rotor blade. The adhesive aligns with the industry trend of longer, lighter and aerodynamically-stable blades. The processing and performance properties of the recyclable low-density epoxy adhesive are comparable to those of conventional low-density non-recyclable epoxy adhesives in terms of rheological characteristics, working time, static mechanical and adhesion properties (Table 1).

The fatigue behaviour of the recyclable low-density adhesive system, determined by plotting a S-N (stress-number of cycles to failure) curve and slope exponent (Figure 2), also confirms

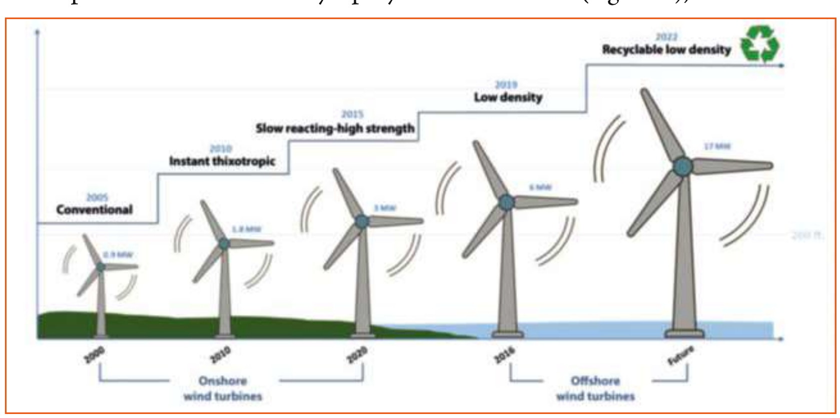


Fig.1: Evolution of adhesive technologies

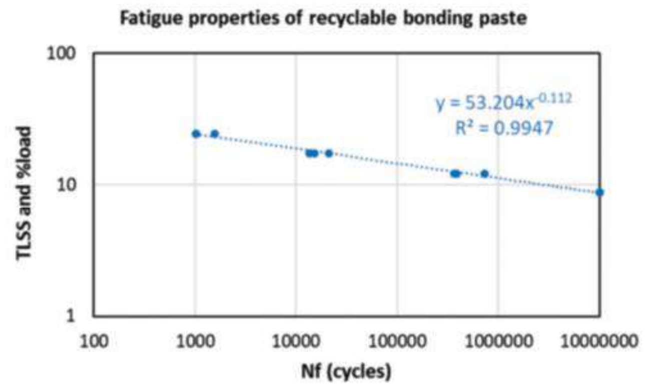
Tab. 1: Comparative properties of non-recyclable and recyclable epoxy adhesives (note: test results of typical batch)

Property	Test method	Unit	Non-recyclable epoxy adhesive	Recyclable epoxy adhesive
Mixing ratio	-	weight	100:43	100:43
Viscosity @ 25°C, 2,5s^{-1}	by rheo-meter	Pa.s		
-Resin			561	554
-Hardener			468	456
-Mix			180	263
Pot life, 100 gms. mix @ 35°C	ASTM D 2471	minutes /°C	138.8/104.2	153.5/63.0
Curing shrinkage @ 60°C/5hrs.	ABC-ADC-001	mm^2	2,465	2,127
Tensile test	ISO 527-2			
Tensile strength		MPa	53.09	52.43
Fracture strain		%	4.19	3.64
Elongation at break		%	6.06	6.06
E-modulus		MPa	2,778	2,847
Tensile lap shear strength (GRE/GRE)	ISO EN 1465	MPa	26.53	25.24
Fracture toughness	ISO 13586			
Critical stress intensity factor (K1c)		MPa. m$^{1/2}$	2.89	2.77
Critical strain energy release rate (G1C)		J/m^2	5,645	5,327
Heat distorsion temperature	ISO 75-2	°C	74.40	77.97
Glass transition temperature (Tg)	ISO 11357-2	°C	79.90	82.38
Cured density	ISO 1183-1	gm/cm^3	1.18	1.16

the equivalence to conventional structural adhesives.

Debonding the adhesive joint for recycling and recovery

The proof of concept for wind blade recycling was demonstrated using an adhesive joint simulating the joining of two rotor blade shells prepared by gluing two glass-reinforced epoxy substrates made from a recyclable epoxy infusion system. After immersion in a solvolysis solution at 75-90°C,



SN curve analysis	Results
Regression equation (y=ax-b)	y=53.204x$^{-0.112}$
Exponent of S-N curve	0.112
Coefficient of correlation	0.9947
n=1/b	8.929

Fig. 2: Fatigue behaviour of the recyclable epoxy adhesive system

the joint debonded with cleavage of the epoxy adhesive followed by cleavage of the epoxy infusion system used as a matrix for the substrates (Figure 3).
The recycling process resulted in the recovery of the glass fabric reinforcement and the epoxy thermoplastic after neutralisation and coagulation of the solvolysis solution.

Conclusion

Wind turbine rotor blades made from the recyclable epoxy resin system can be fully recycled using a low-energy solvolysis process to recover the epoxy thermoplastic matrix and the reinforcement (glass or carbon fabrics). The thermoplastic recovered from the recycling process can be re-used and re-purposed to manufacture thermoplastic objects whereas the reinforcements can be re-used to manufacture new composite parts.

The 100% recycling of wind turbine rotor blades drives circularity by contributing to the transformation from a cradle-to-grave (C2G) linear economy to a cradle-to-cradle (C2C) circular economy. Importantly, it addresses the wind industry's global concerns regarding the end-of-life management of wind turbine rotor blades. □

More information:
www.abg-am.com

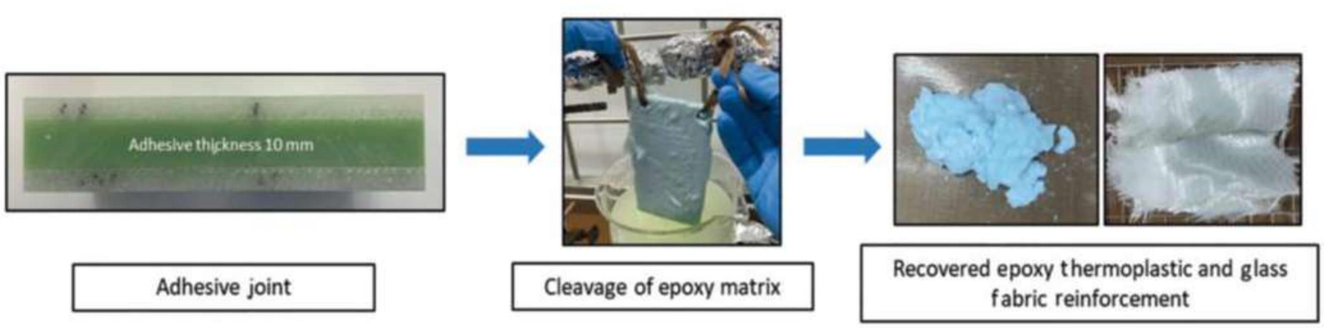


Fig. 3: Debonding of the adhesive joint, recycling and recovery