

EPOXY ADHESIVES FOR ACCELERATED STEEL BRIDGE CONSTRUCTION AND REHABILITATION

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Bridge deterioration and the need for replacement or rehabilitation continue to be an ongoing problem. Accelerated bridge construction techniques have the potential to minimize traffic disruptions during bridge renewals and help bridge owners successfully implement retrofit projects in a fast manner. As a thermoset polymer, epoxy adhesives with reliable adhesion to steel structures and a variety of construction materials have great application potentials in accelerated bridge construction. In fact, epoxy resins have been employed in the bridge construction for years, mainly in protective coatings, membrane sealing, joint bonding, injection and grouting systems. However, for many bridge engineers it is not very clear what properties should be considered in selecting an epoxy resin. Do these properties fulfill the job specifications? In this presentation, we are trying to discuss the selection criteria for epoxy adhesives through a couple of examples.

Protective coating is one of the major applications for epoxy. Specifically, epoxy asphalt chip seal can provide a fast-installation, thin and long-lasting overlay suitable for heavy traffic. A recent application of the epoxy coating in the accelerated bridge construction is on the MacDonald Bridge in 2016, Nova Scotia, Canada. The Macdonald Bridge is very important to the transportation network in Halifax and the province. To minimize impacts to transportation during the reconstruction, the new deck segments were completely prefabricated in the shop and shipped to the site, which allows for rapid replacement of the existing deck segments only at night closures for the bridge. As new deck segments were fabricated, epoxy asphalt chip seals were also installed in the shop. An ambient-temperature cured epoxy asphalt binder that develops strength quickly and allows for fast traffic opening was selected for this project. With fast curing rate, epoxy asphalt chip seal applied on can be opened to traffic 4 to 5 hours after the installation. The thin epoxy asphalt chip seal overlay provides good skid resistance, therefore enhance the driving safety on the bridge deck, at the same time, it provides an effective protective barrier for the underlying steel deck from water/moisture damage and corrosion. A full-depth wearing course was paved on top of this temporary epoxy asphalt chip seal overlay after a total of 46 deck segments had been all replaced that lasted for over 30 months. Installation and curing of the epoxy asphalt coating inside fabrication shop is shown in Figure 1.

In this project, there are a few anticipated requirements for the epoxy asphalt coating. These include relatively long work window and fast-curing ability; reliable adhesion to steel deck and aggregate chips; and proper flexibility that could accommodate the stress in orthotropic decks.

Polymer chemists modified the formulation and used high amine value and high molecular weight curing agent for extended work life, and approximately 6 hours useful time can be provided by the epoxy asphalt tack coat to receive aggregate chips. Also, as an amine-cure product, the final curing rate is relatively fast, and the layer can be trafficked on by foot or light

vehicle over the night and the binder would reach 80% of its ultimate strength in 2-3 days. The adhesion to steel deck and aggregate chip performance were evaluated in the laboratory. ASTM D4541 was used to assess the adhesive strength of the epoxy asphalt binder to metal substrates in tension. AASHTO TP114 was used for the compound shear and peel strength test between the steel deck and the skid-proofing chip seal layer; ASTM D7000 is a sweep test method to evaluate the chip loss by abrasion. Finally, MacDonald bridge is located in Nova Scotia with a cold and long winter. Polymer products would become rigid and brittle and lose flexibility in low temperatures. The encapsulated asphalt added in the polymer structure acts as an extender and contributes to the flexibility of the elastic structure even in very low temperatures.

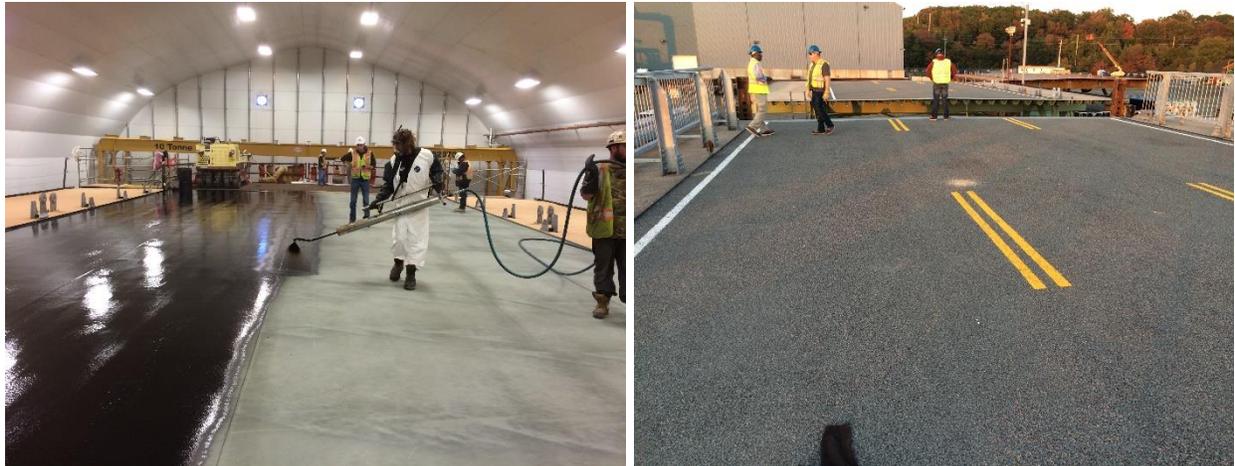


Figure 1 Fast installation and curing of epoxy asphalt coating in fabrication shop

Bridges and buildings would be inevitably exposed to hot environments, e.g. 50°C or even up to 70 °C . Compared with low temperature, moisture, UV, freeze-thaw conditions, etc., high temperatures should be given more concerns as to the safety aspect of adhesive bonding. This is because the degradation of cross-linking for polymer chains can occur due to elevated temperatures. The critical temperature can be determined by glass transition temperature (GTT) , above which the polymer transit from glassy state to rubber-like. The GTTs for most of the commonly used ambient-cured structural epoxy adhesives are between 50°C to 60°C. To ensure the successful application of structural epoxy compounds in accelerated bridge rehabilitations with carbon fiber-reinforced polymer (CFRP), the mechanical behaviors of epoxy adhesives and CFRP/steel bonded interface at elevated temperatures were investigated.

The mechanical behaviors of epoxy adhesives subjected to elevated temperatures were studied via dynamic mechanical analysis (DMA) following the ASTM D4065 and tensile strength testing by ASTM D638. DMA is a technique used to study and characterize materials under dynamic sinusoidal load. The storage modulus, loss modulus, and loss factor of epoxy adhesives tested can be depicted as a function of temperature. Also, the tensile tests were conducted to study the mechanical properties of CFRP laminate/steel double lap joints at elevated temperatures. The bond strengths of CFRP/steel lap joints at different temperatures are depicted in Figure 2, as well as the comparisons of nominal bond strengths with the nominal tensile strength (τ_a), elastic modulus (E_a) and storage modulus (E') of the adhesives. It is found that adhesives with higher tensile strength and toughness (i.e. adhesive J133) confer higher bond strengths between CFRP

and steel at under elevated temperatures. Moreover, the bond strength degradations for both types of joints are roughly correlated with those of the tensile strengths of the adhesives. The adhesive J133 has higher GTT and better mechanical properties mainly coming from rubber core-shell nanoparticles and/or other filler fibers additives, which makes them more capable of keeping the bonding integrity than other general epoxy adhesives under high temperatures. It is also found that it is improper to determine the working temperature limit of epoxy adhesives by using the loss factor-based GTTs ($T_{g,t}=68.3$ and 63.2°C for A2014 and J133, respectively) or loss modulus-based GTTs ($T_{g,t}=58.4$ and 53.9°C for A2014 and J133, respectively) as an evaluation factor. The reason is an excessive reduction in storage modulus is observed when the temperature approaches or exceeds these GTTs. Moreover, the storage modulus-based GTT ($T_{g,o}=56$ and 50°C for A2014 and J133, respectively) is more appropriate for determining the upper limit of the working temperature for EAs, which results in safer applications. A2014 is a product from Araldite structural epoxies in comparison as shown in Figure 2 and J133 is a joint research product instead.

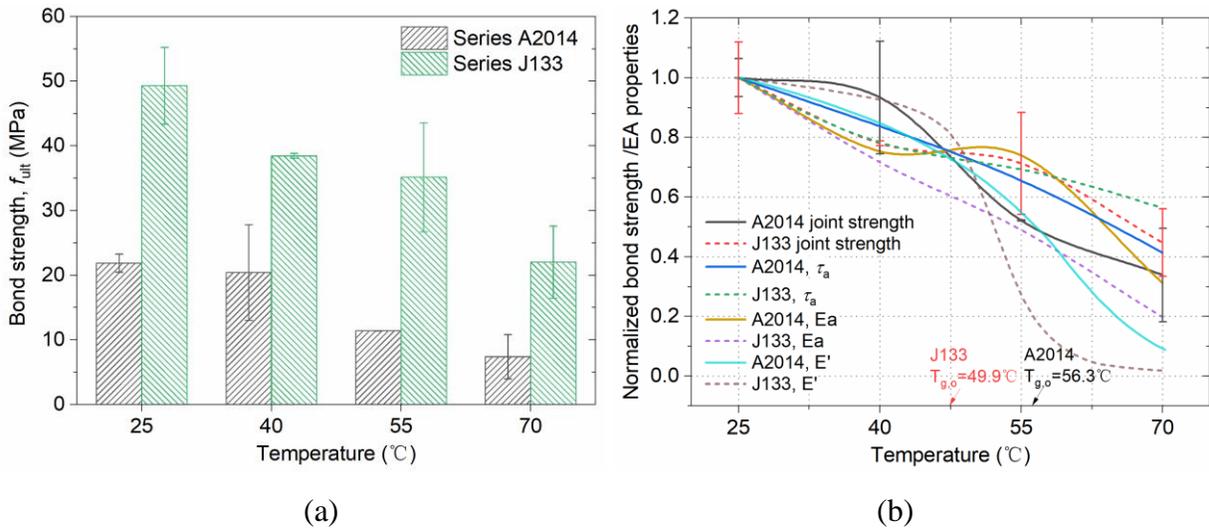


Figure 2 (a) Comparisons of bond strengths of CFRP/steel double lap joints and (b) comparisons of normalized bond strengths with tensile strength (τ_a), elastic modulus (E_a) and storage modulus (E') of adhesives at different temperatures.

In conclusion, after having reviewed three examples above about epoxy adhesive applications, The following conclusions can be drawn:

- The pot life or gel time should be long enough to allow for enough work time in mixing and surface wetting; While the epoxy adhesive's strength gain should be fast enough, with or without accelerant, to meet the suitability for accelerated construction.
- For structural adhesives, incorporation of core-shell nanoparticles into the epoxy adhesive mixture is recommended to improve the compressive strength and tensile strength of the epoxy adhesive bonding structure.
- Adhesive performance at high temperature and low temperature should be considered, such as the heat stability of epoxy as well as the bonding performance of CFRP laminates to substrates.