MASTERBOND®
CASE STUDY

EP40: Structural Epoxy Used for Steel Bonding in Marine Applications

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Overview of EP40

Master Bond EP40 is a two-part, room temperature curing epoxy for bonding, sealing, coating, and encapsulating. This low-to-moderate viscosity system has a forgiving 1-to-1 mix ratio by weight or volume and can be cured at ambient temperatures or more rapidly at higher temperatures. EP40 bonds well to a variety of substrates, including naval steel, the primary structural metal used in the shipbuilding industry.

Application

To reduce its environmental impact and pollution, the shipping industry is investigating methods to construct more lightweight ships. One potential method is using adhesive bonding techniques to replace traditional welding and riveted joints on ships to fabricate lighter ships with smaller carbon footprints. However, adhesives age and deteriorate when exposed to moisture, high temperatures, and ultraviolet light. This makes it necessary to understand how they age in maritime environments to determine whether they can truly replace traditional welding techniques.

To this end, researchers at Centro de Investigación en Tecnologías Navales e Industriales (CITENI) and Centro de Investigación TIC (CITIC) developed a new method for studying adhesive aging on naval steel substrates. Master Bond EP40 was selected as the test adhesive for this method due to its strong performance and suitability for marine conditions. By using EP40, the team ensured that the observed adhesive bonding behavior would reflect a high-quality epoxy's potential in ship structures. The goal was to evaluate how EP40 bonds to naval steel and how the bulk epoxy material would behave in seawater to provide insights into the construction of lighter ships using this approach.

Key Parameters and Requirements

The authors first characterized EP40 and the adhesive joints formed with naval steel. They then subjected both the bonded joints and bulk epoxy samples to accelerated-aging tests in seawater to analyze how EP40's properties changed. All bonding experiments were carried out using EP40, which allowed the researchers to use the same epoxy for multiple test configurations.

The tests included single-lap joint shear tests to measure the shear strength of EP40 bonding two steel pieces in an overlapping configuration, as well as tensile adhesive joint tests to measure the tensile strength of EP40 between steel substrates. The experiments also included bulk epoxy tests to measure the inherent mechanical and thermal properties of EP40 itself.

Single-Lap-Joint Shear Strength Test Specimen Preparation using EP40

For the single-lap-joint shear strength tests, the authors used an aluminum mold to prepare naval steel specimens according to ASTM D1002, which were cleaned with acetone before applying EP40, as shown in ***Figure 1***. The authors used a spacer to ensure a joint width of 0.1 mm and then cured EP40 by applying a pressure of 2 MPa for more than 72 hours at room temperature. The overlap adhesive bond dimensions were 12.7 mm in length and 25.4 mm in width, providing a total shear area of 322.6 mm^2.

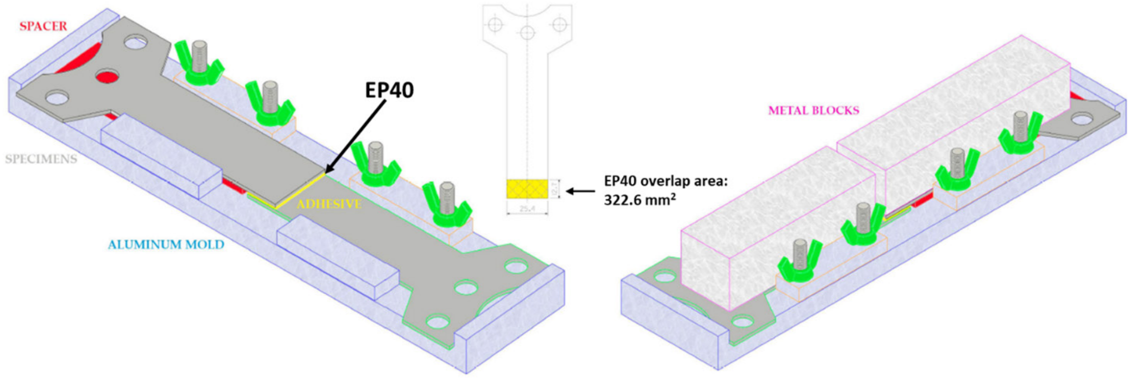

Figure 1. (left) An aluminum mold was used to ensure the correct dimensions of the adhesive single-lap joint according to ASTM D1002. Before applying EP40, the naval steel specimens (dark grey) were cleaned with acetone. (right) EP40 was cured at room temperature for more than 72 hours by applying a pressure of 2 MPa using metal blocks. (Modified from Rodríguez-Dopico et al.)

Tensile Test Specimen Preparation using EP40

For the tensile adhesion tests (ASTM D897 standard), a different specimen geometry was used. Two circular naval steel coupons were bonded in a butt-joint configuration to measure tensile pull-off strength. As with the lap joints, the steel surfaces were cleaned with acetone and prepared to ensure good bonding with EP40. A 1 mm thick spacer ring was placed between the steel disk faces to set a consistent adhesive layer thickness for the tensile specimen. EP40 was applied to the bonding area, and the assembly was clamped tightly, maintaining alignment during curing. The epoxy was again cured for 72 hours at room temperature under pressure from the clamping fixture. This produced a fully cured epoxy bond of 1 mm thickness joining the two steel disks. The use of EP40 in this configuration demonstrated its versatility in bonding different joint types, forming a strong adhesive interface across the bonded area.

Bulk Tensile Test Specimen Preparation using EP40

The authors also performed bulk adhesive tests before and after aging. To manufacture the specimens, they blended the two adhesive components in a 1:1 ratio and mixed them using a centrifuge machine. Due to the high viscosity of the blend, the authors manufactured the adhesive plates according to the French standard NF T 76-142, which involved inserting the adhesive into a mold, enclosing it in a 1-mm-thick silicone frame, and then curing EP40 at room temperature for more than 72 h in the mold under a pressure of 2 MPa.

Results

The authors used EP40 to develop a method for analyzing how the characteristics of an adhesive will change in marine environments to ensure that this type of bonding is correctly performed in different parts of ships. This included an investigation of the thermal behavior of the adhesive, as well as how the adhesive aged in seawater and how this aging affects its mechanical, thermal, and chemical properties. By starting with a known high-performance epoxy like EP40, the researchers established a reliable baseline to observe how even this material might deteriorate or maintain its properties in marine environments.

Thermal Properties of Joints Bonded using EP40

The authors first investigated the thermal properties of the joint using TGA. The cured epoxy showed excellent thermal stability, with no significant mass loss until approximately 294°C, well above any routine ship service temperatures. A reduction in shear stress

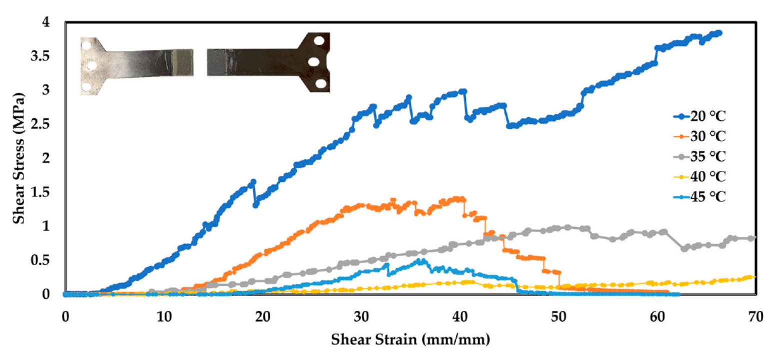

Figure 2. Comparison of the average shear stress-strain at different temperatures, including a photo of a test specimen bonded by EP40 (from Rodríguez-Dopico et al.).

was observed above the T_g of EP40 due to adhesive bond softening. Nonetheless, below the T_g, EP40 maintained its bonding performance, and it did not undergo thermal degradation until the much higher ~294°C threshold. These results demonstrate that EP40 can maintain a stable bond at typical marine temperatures, only losing its stiffness and strength when exposed to temperatures exceeding its T_g.

Mechanical Properties of Joints Bonded using EP40

To assess its mechanical properties, EP40 was tested in both joint configurations and as a bulk material. Single-lap shear tests and tensile adhesion tests at room temperature provided insight into the strength of EP40-bonded steel joints. Tensile tests on bulk EP40 specimens showed an average ultimate tensile strength of 9.71 ± 0.93 MPa for bonded steel joints, while that of the standard bulk specimens was about 14.36 MPa.

The fracture surfaces of tested joints (***Figure 3***) indicated that the epoxy remained well adhered to the steel, with cohesive failure mainly occurring within the bulk of the EP40 layer. This suggests that the surface preparation and EP40's adhesive strength were effective at bonding the steel.

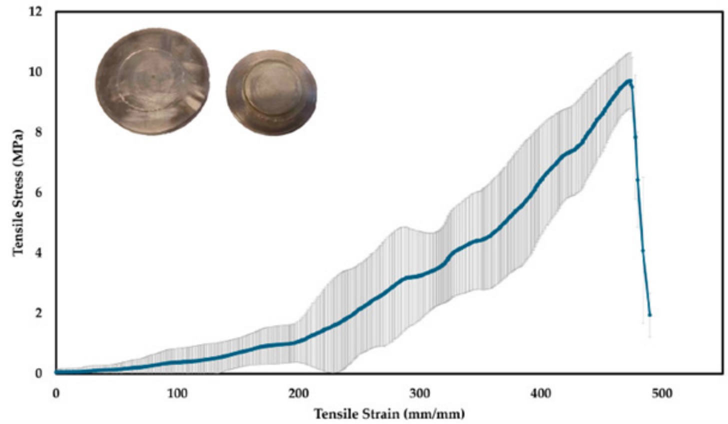

Figure 3. Average strain–stress curve under tensile deformation, with the standard deviation shown by the gray error bars, as well as a representative tensile test specimen (from Rodríguez-Dopico et al.).

Seawater uptake

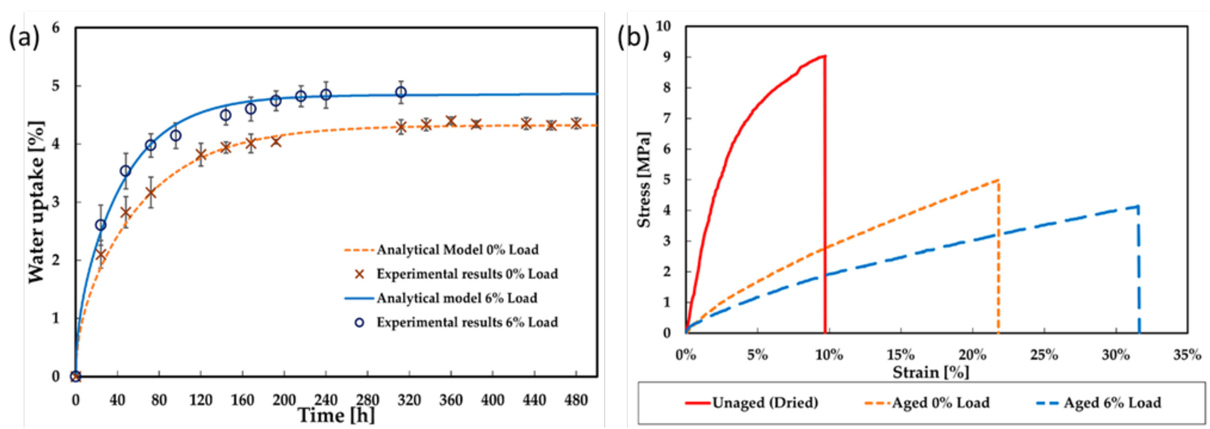

Figure 4. (a) Comparison of experimental data and analytical model for constant loads of 0% and 6% of the tensile strength of joints bonded using EP40. (b) Stress-strain curves of dried and aged bulk specimens at different loads applied. Aging was conducted until complete saturation at room temperature for 312 h for the 0% load and 522 h for the 6% load (from Rodríguez-Dopico et al.).

As shown in ***Figure 4a***, the researchers immersed EP40-bonded joints in seawater to simulate marine aging under 0% load and upon applying a constant load of 6% of EP40's measured tensile strength. The experimental water absorption data aligned with the Fickian model and plateaued below 5%, even upon applying a constant 6% load. As shown in ***Figure 4b***, EP40's mechanical properties declined after prolonged seawater immersion. The tensile strengths of the unaged sample and the samples aged with 0% and 6% applied loads during aging were approximately 9.03 MPa, 5.00 MPa, and 4.14 MPa, respectively.

This indicated a greater reduction in tensile strength for the sample aged under an applied load and water immersion. Despite this, the tensile strength remained above 4 MPa, even under the most extreme aging condition of immersion in seawater for 522 h with a 6% applied load.

Conclusions

Overall, the newly developed testing methodology using EP40 as the model adhesive was effective for evaluating the performance of marine adhesives. EP40 played a central role in establishing this method, as its reliable performance allowed the authors to confidently interpret changes due to aging rather than dealing with inconsistent material behavior. The results from EP40 suggest that structural epoxy adhesives are viable options for marine bonding applications.

As part of their study, the authors showed that EP40 maintained a tensile strength above 4 MPa, even after being immersed in seawater for more than 500 hours under an applied load. If adhesives like EP40 can replace certain welded joints, they may enable the construction of lighter, more fuel-efficient ships that produce fewer emissions. The authors of the study concluded that the methodology developed with EP40 is applicable to all types of structural adhesives intended for marine environments, allowing future researchers to use this approach to evaluate other adhesive candidates.

Reference

Rodríguez-Dopico, F. J., García, A. A.; Tarrío-Saavedra, J. *Characterization of Epoxy Adhesive for Marine Applications.* Oceans, 2024, 5(4), 906-922; https://doi.org/10.3390/oceans5040052