Bonding properties of Sikadur-30 for CFRP-strengthened steel structures

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Abstract. There is increasing demand for strengthening ageing steel structures, and bonded carbon fiber reinforced polymer (CFRP) plates strengthening is becoming more widely used. The technique can be advantageous compared to traditional welded steel plate methods, due to its ease of installation, a high strength-to-weight ratio and resistance to corrosion. This study focuses on the evaluation of a commonly used structural epoxy adhesive, Sikadur-30, for strengthening steel structures with externally bonded CFRP plates. Several key properties of the adhesive were investigated, including its thermogravimetric relationship curve, glass transition temperature, and bond strength. The thermogravimetric analysis (TGA) revealed that the adhesive retained more than 95% of its quality up to 200 °C, indicating its suitability for civil engineering applications. The dynamic mechanical analysis (DMA) showed that the glass transition temperature of the examined adhesive was 80.47 °C, which suggests that the operating temperature for CFRP-reinforced steel structures should be lower than 60.47 °C. The final lap-shear joint test demonstrated that the adhesive had a bond strength of 23.58 MPa. Overall, the adhesive exhibited appropriate thermal stability and bond strength for externally bonded CFRP strengthening application.

Keywords: Structural adhesive; thermogravimetric analysis; dynamic mechanical analysis; bond strength.

1 Introduction

Sikadur-30 is a widely utilized structural epoxy adhesive employed in the strengthening of large steel members in bridges and buildings through the application of externally bonded carbon fiber reinforced polymer (CFRP) plates. The effectiveness of this strengthening technique depends on the adhesive's capability to transfer loads between the CFRP plate and the steel structure. Various bonding models have been developed to analyze the behavior of the adhesive bonding layer at room temperature, and these models are currently utilized in design practices [1]. However, as the temperature approaches the glass transition temperature (Tg) of the structural adhesive, it undergoes a transition from a glassy state to a vitreous state, potentially leading to reduced stiffness and quality. This phenomenon raises concerns regarding the potential failure of the

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strengthened structural connections. Consequently, it becomes imperative to investigate the thermal stability and bond strength of the structural adhesive.

Previous studies have extensively investigated the performance of fiber reinforced polymer (FRP) to concrete bonded joints [2, 3, 4]. However, these studies overlooked the crucial aspect of temperature effects, despite the likelihood of strengthened steel structures possessing higher thermal conductivity and the potential exposure of bonded joints to elevated temperatures. These conditions can give rise to uncontrolled bond failure in structural adhesive joint connections.

To address this gap, the present project focused on comprehensively examining several key properties of the adhesive. Specifically, the thermogravimetric relationship curve, glass transition temperature, and bond strength were thoroughly investigated to gain insights into the adhesive's performance.

2 Thermogravimetric analysis (TGA)

In this study, the properties of Sikadur-30, a commonly used ambient-curing structural epoxy adhesive, were examined. A thermogravimetric analyzer (*TGA)*, as illustrated in Figure 1, was employed to investigate the relationship between temperature and mass change of the adhesive sample. The power adhesive sample, weighing 3 mg, was prepared at room temperature, and subsequently cured at a constant temperature of 45 °C for a duration of 7 days. The thermogravimetric analysis (*TGA*) was carried out with a ramp rate of 20 °C/min.

Fig. 1. Thermogravimetric analyzer TA TGA55

The resulting mass change data, depicted in blue in Figure 2, exhibited that the adhesive maintained over 95% of its quality up to a temperature of 200 °C. This finding highlights the adhesive's suitability for civil engineering applications.

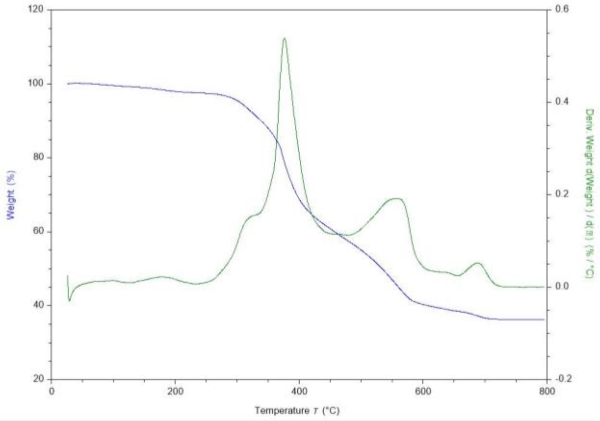

Fig. 2. Thermogravimetric curve

3 Dynamic mechanical analysis (DMA)

The storage modulus response of the adhesive was characterized using a dynamic mechanical analyzer (Figure 3) at increasing temperatures. A rectangular bar sample of the adhesive measuring 30 × 8 × 3 mm was cast at room temperature and cured for 7 days at a constant temperature of 45 °C. The DMA employed a single cantilever beam configuration, sinusoidal displacement, and a ramp rate of 2 °C/min (following a similar methodology as a previous study [5]). The resulting change in storage modulus, depicted in blue in Figure 4, indicated a decrease in stiffness as the temperature increased, signifying a transition from a glassy state to a vitreous state.

The glass transition temperature (T_g) of the adhesive was determined to be 80.47 °C. According to the relevant standard [1], this suggests that the working temperature for CFRP-strengthened steel structures should be operated below 60.47 °C. Furthermore, Figure 4 reveals that there is no significant reduction in the modulus of the adhesive when the temperature remains below 60.47 °C. These findings support the adhesive's suitability for use in CFRP- strengthened steel structures within this temperature range.

Fig. 3. Dynamic mechanical analyzer TA DMA850

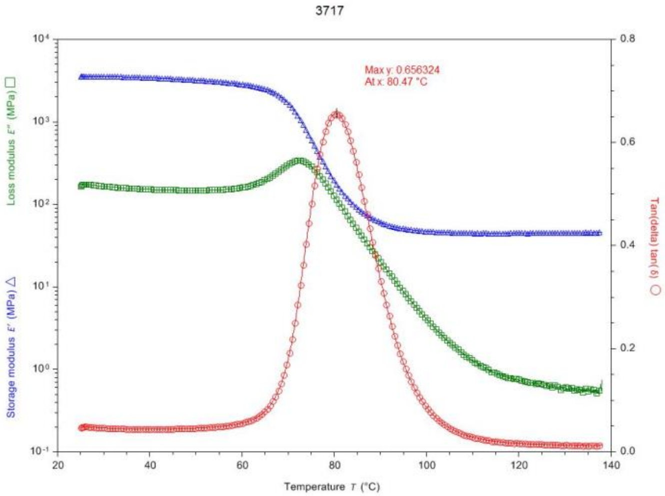

Fig. 4. Storage modulus response

4 Lap-shear joint test

The lap-shear joint was created using the structural adhesive to bond two steel plates measuring 100 × 30 × 3 mm. The bond area was 13.9 × 25 mm, and the adhesive layer had a thickness of 2 mm. The lap-shear joint was cured for 7 days at ambient temperature (21 °C). To assess the bond strength of the adhesively bonded joint, an electronic universal testing machine (CMT6103) was employed. The testing involved applying increasing tensile displacement and measuring the corresponding load. The load-displacement curve is presented in Figure 5.

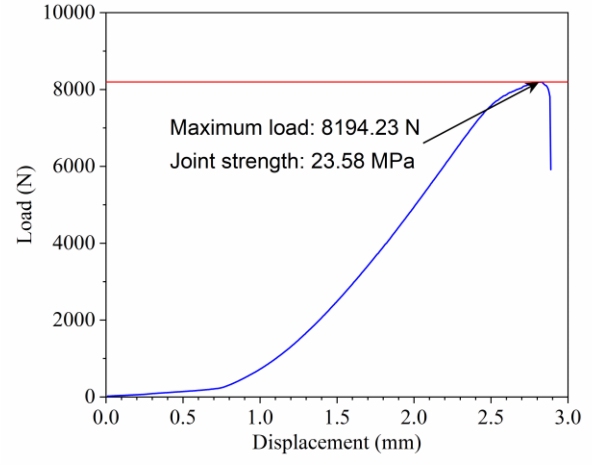

Fig. 5. Load-displacement curve of the lap-shear joint

The maximum applied load during the test was 8194.23 N, leading to a calculated joint strength of 23.58 MPa (maximum load divided by the bonded area). This strength value falls within an acceptable range for civil engineering bonded joints, indicating that even with curing at ambient temperature, the joint exhibits reasonable strength. Figure 6 further demonstrates that the failure occurred within the adhesive layer, emphasizing that the bonding properties of the structural adhesive play a vital role in determining the joint's overall performance.

Fig. 6. Failure occurred within the adhesive layer

5 Conclusion

This study conducted a comprehensive investigation on the thermomechanical properties and bond strength characteristics of Sikadur-30, a widely used structural epoxy adhesive. Thermogravimetric analysis revealed excellent thermal stability up to 200 °C. Dynamic mechanical analysis determined the glass transition temperature to be 80.47 °C, suggesting a maximum working temperature of 60.47 °C for steel structures strengthened with CFRP plates using this adhesive. Lap-shear testing indicated the adhesive provided adequate bond strength of 23.58 MPa even with ambient temperature curing.

Overall, the results provide strong evidence that Sikadur-30 possesses suitable thermomechanical properties and bonding capacity that make it well-suited for structural strengthening applications in civil engineering projects. The adhesive displays excellent thermal stability and maintains a stable modulus within typical temperature ranges experienced by steel infrastructure. Furthermore, the adhesive enables effective load transfer in bonded CFRP-steel joints.

Like any other experimental study, it is inevitable that there may be some errors in the experimental data. Nevertheless, these presented findings will be highly valuable in the design and maintenance of durable, high-performance bonded structures using this adhesive.

References

1. Wang, S., Stratford, T., & Reynolds, T. P. S. (2021). Linear creep of bonded FRP-strengthened metallic structures at warm service temperatures. *Construction and Building Materials*, 283, 122699.

2. Houhou, N., Benzarti, K., Quiertant, M. Chataigner, S., Flety, A.and Marty, C., (2014)Analysis of thenonlinear creep behavior of concrete/FRP-bonded assemblies. *Journal of adhesion science andtechnology*, 28(14-15), pp.1345-1366 .
3. Wang, S., Stratford, T., & Reynolds, T. (2023). Viscoelastic model for analysing the behaviour of adhesive-bonded FRP-to-steel joints in civil engineering applications. *International Journal of Adhesion and Adhesives*, 123, 103359.
4. Naser, M. Z., Hawileh, R. A., & Abdalla, J. (2021). Modeling strategies of finite element simulation of reinforced concrete beams strengthened with FRP: A review. *Journal of Composites Science*, *5*(1), 19.
5. Bashir, M. A. (2021). Use of dynamic mechanical analysis (DMA) for characterizing interfacial interactions in filled polymers. *Solids*, 2(1), 108-120.