What Happens When Bonded FRP Strengthened Beams Get Warm?

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INTRODUCTION

Bonded FRP strengthening has been used to extend the life of steel and cast iron structures. The performance of this strengthening at elevated temperatures, however, has received little attention. This poster presents experiments conducted on CFRP plate-bonded steel beams subjected to warm temperatures (< 100°C).

Two thermal effects act when a plated beam is heated:

- Differential expansion between the CFRP plate and the steel, causing high shear stresses across the adhesive joint.
- Glass transition of the adhesive, giving the adhesive reduced stiffness and strength, but greater deformation capacity.

Figure 1 shows the glass transition of the adhesive used in his study, a 2-part ambient cure epoxy that is widely used for FRP strengthening works.

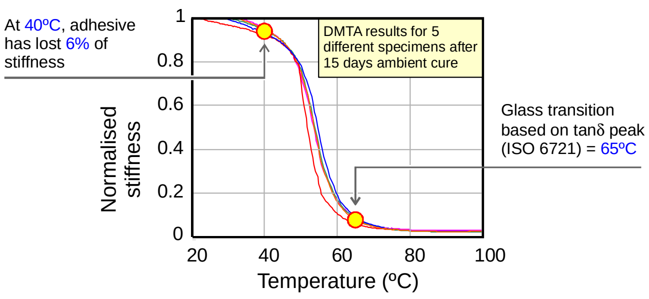

Fig. 1: Measured Loss in Stiffness of the Epoxy through the Glass Transition

RESEARCH OBJECTIVES

1. Establish how an FRP plate bonded beam is affected by warm temperatures.
2. Study the slip deformation across the adhesive joint under warm conditions.

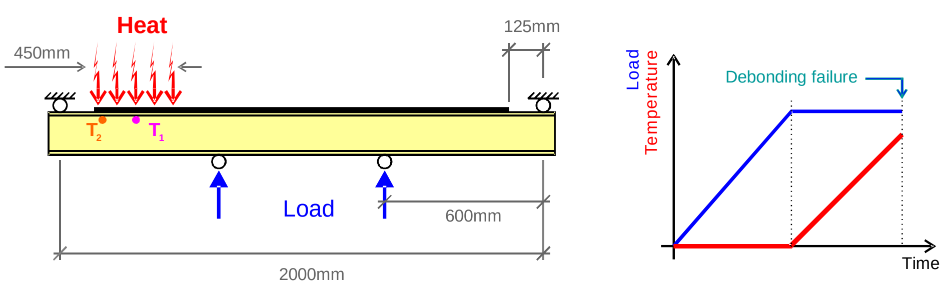

Fig. 2: (a) Test Arrangement & (b) Loading and Heating History

EXPERIMENTS

Six steel I-beams (UB 178×102×19, σ_y=355MPa) were strengthened using pultruded CFRP plates (100×1.4mm, E=170GPa) and the ambient cure epoxy adhesive characterised in Figure 1. The beams were loaded in 4-point bending, as shown in Figure 2a.

Whilst the load was held on a beam, the end of the FRP plate was heated using an electrical heating pad (Figure 2a). The temperature in the adhesive was increased until failure occurred by debonding of the strengthening plate from the steel beam (Figure 2b). The temperature of the flange of the steel beam was measured using two thermocouples, at the end of the plate (T_2) and 160mm from the end of the plate (T_1). Table 1 summarises the different tests conducted.

High resolution digital images were recorded at 10 second intervals during the tests, focusing upon the heated end of the plate (Figure 3). These images were analysed (using geoPIV software) to track the movement of patches of pixels. The relative horizontal displacement of pairs of patches across the adhesive joint gives the slip between the CFRP plate and the steel.

Table 1: Details of experimental program and headline results

Test ID	Load (kN)	Temperature T_2, (°C)	Comment
1	190.0	Ambient	Capacity of a strengthened beam (l.t. buckling).
2	Held at 150	95	Plate debonding failure.
3	Held at 160	?	Data acquisition error for this test.
4a, 4b	Held at 170	107, 97	Tests on 2 ends of 1 beam. Plate debonding failure.
5a, 5b	Held at 180	89, 97	Tests on 2 ends of 1 beam. Plate debonding failure.
6	155.6	Ambient	Premature failure due to poor bonding.
7	140.4	Ambient	Capacity of an unstrengthened beam (l.t. buckling).

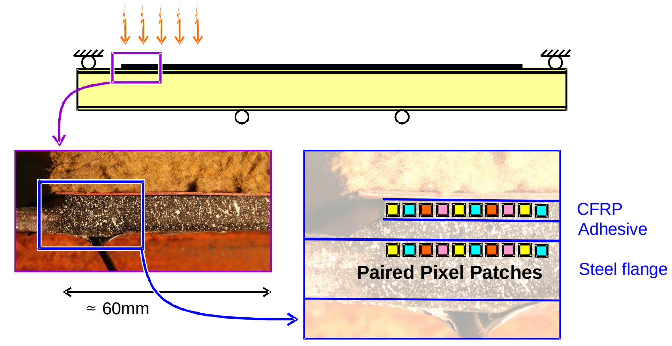

Fig. 3: Measurement of Bond Displacements by Digital Image Analysis

RESULTS

Figure 4 plots the variation in failure temperature with applied load, due to debonding of the CFRP plate from the steel flange. The temperature at the plate end (T_2) is lower than the temperature within the plate (T_1) due to conduction along the beam; however, the plate end is most critical due to the adhesive stress concentration in that region.

Significant slip deformation occurred from 40°C, substantially below the failure temperature (Figure 5). The increase in slip with temperature corresponds to the glass transition in the adhesive (Figure 1), with a sudden increase in slip deformation when plate debonding occurs.

An example of the variation in slip distribution obtained using digital image analysis is shown in Figure 6. Slip occurs along all of the observed length of the adhesive joint, in contrast to the elastic strain concentration at the end of the plate that is assumed in ambient design. The glass transition gives a weaker and less stiff adhesive, but one which has a greater deformation capacity that allows a degree of stress redistribution along the joint.

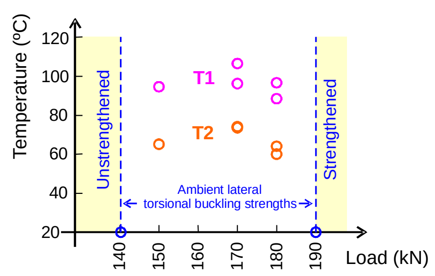

Fig. 4: Reduction in Strength due to Temperature

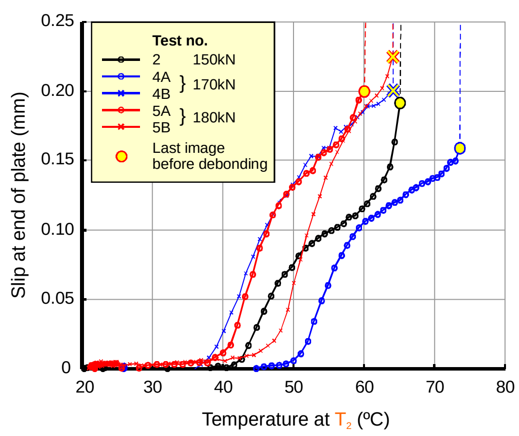

Fig. 5: Plate End Slip Variation with Temperature for all Tests

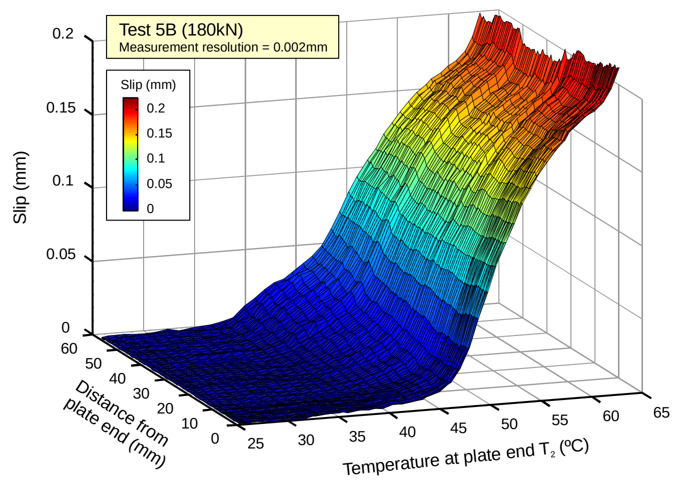

Fig. 6: Variation in Slip Distribution with Temperature for Test 5B (180kN)

CONCLUSION

The tests demonstrate that the strength of an FRP-plated steel beam can be significantly reduced by warm temperatures (<100°C). The observed slips show that this is due to the glass transition of the adhesive. The consequences of this behaviour, however, remain unknown and require further investigation.

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