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# Comparison between brittle and ductile adhesives in CFRP/steel joints

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**Abstract**

The application of bonded CFRP on metallic bridge structural elements is a repair technique with great potential. The choice of the adhesive type plays a key role in the performance of the repair. Most previous researches utilized brittle adhesives specially developed for the concrete-CFRP bonding which does not provide the best performance for steel/CFRP joints. The recent high-strength ductile adhesives developed for the automotive industry to bond metallic and composite materials are more appropriate for CFRP/Steel joints. This paper compares the performance of brittle adhesive and ductile adhesive in CFRP/steel double strap joints subjected to tensile loading. The results revealed that the ductile adhesives achieve much higher performance than brittle ones. Digital image correlation (DIC) shows that specimens with ductile adhesive have a more uniform strain distribution compared to the brittle ones.


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## 1. Introduction

In Europe, more than 30% of the railway bridge stock is over 100 years old. Many of these bridges are made of old mild steel or puddle iron assembled with riveting technology. The nature and the loading level have changed significantly compared to what they were designed for a century ago [1]. The replacement of aged metallic bridges is economically not possible. Traditional repair methods such as welding or bolting steel splices may not be feasible due to the nature of the old materials and their compatibility with current construction steel. The application of bonded CFRP on metallic bridge structural elements is a repair technique with great potential. The CFRP can increase the strength of the structural elements without altering their mechanical properties, as in the case of drilling or welding [2]. Besides, due to the lightweight of the CFRP laminates, no additional loading is added to the structure. This technology has been extensively used to repair cracked metallic structural elements in the aerospace industry for more than three decades. However, only a few field applications of CFRP to metallic bridges can be found worldwide [2]–[5]. The application of CFRP to repair metallic civil engineering structures is a niche field that is receiving a lot of research attention. Several research works reported some satisfactory results, but still not enough to convince bridge owners and engineering practitioners for the widespread of this technology. One of the potential reasons for this delay is that most previous research on steel/CFRP joints used brittle adhesives available in the construction market that might not provide the best performance, at least not enough to boost this technology in the industry. These brittle adhesives are specifically made for repairing concrete elements. As every adhesive is created from the adherends' characteristics, ductile adhesives developed for metallic-composite bonded joints for the automotive industry may be more suitable for CFRP/steel joints. In this paper, an experimental investigation is conducted to characterize the behaviour of the different adhesives and test their performance in CFRP/steel joints. Tensile tests of bulk adhesive specimens are conducted to characterize their tensile behaviour and compare their strength, stiffness, and ductility. CFRP/steel double strap joints are tested under static tensile loading. A comparison between the performance of the different joints based on the adhesives provided is provided.

## 2. Experimental program

### *2.1. Bulk Specimen test:*

Dog-bone specimens were manufactured and tested to estimate the tensile strength, young modulus of the adhesive according to ASTM D638-14 [6]. The adhesives used in this study are:

- Sikadur 30 (SK-30): Linear brittle epoxy adhesive commonly used in the construction industry.
- Araldite AW4858/HW4858 (AW): Ductile epoxy adhesive with high peeling and shear resistance.
- S&P (SP): linear brittle epoxy adhesive commonly used in the construction industry.

The dog-bone specimens have been fabricated according to the dimensions from ASTMD-638-14 category 5 that is suitable for adhesives comparison. The specimens were tested under static tensile test with a speed of 1 mm/min since the ASTM D638 recommends using a speed between 0.5-5mm/minute. Table 1 presents the results of the tensile tests that include the young modulus, Maximum strength, ultimate strength, and the ultimate strain. Figure 1 (a) illustrates the stress-strain curves, where the ductile adhesive reaches very high strength and ductility. Typical fractured dog bone specimens are presented in Figure 1 (b).

Table 1. Bulk Specimens adhesive results.

| Adhesive | E (MPa) | Maximum strength (MPa) | Peak strain | Ultimate stress (MPa) | Ultimate strain |
|---|---|---|---|---|---|
| Sikadur 30 | 14723 | 36.4 | 0.003 | 46.8 | 0.003 |
| S&P | 9637.8 | 34.8 | 0.005 | 34.8 | 0.005 |
| AW 4858 | 2225.5 | 36.17 | 0.029 | 31 | 0.110 |

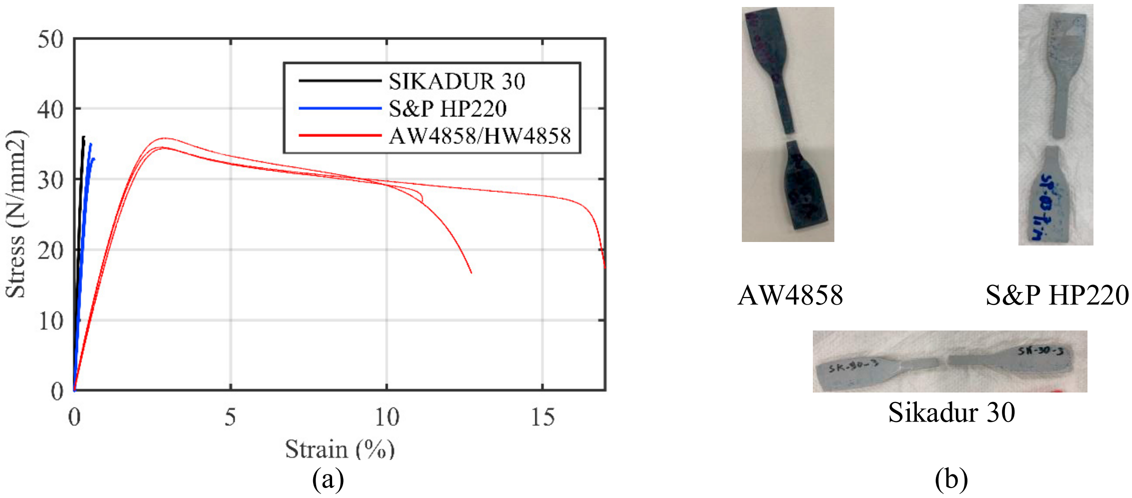


Fig. 1.(a)Tensile behavior ;(b) Bulk specimens after failure

### *2.2. CFRP/Steel joints:*

In this study, adhesively bonded CFRP/Steel double strap joint specimens were adopted to investigate the performance of the adhesive between steel and CFRP. Figure 2 shows the geometry of the double strap joint specimens which is constituted by two separate steel bars joint together with a bonded CFRP patch on both sides. The material and geometrical properties of the joints used in this study are presented in **Error! Reference source not found.** and **Error! Reference source not found.**, respectively.

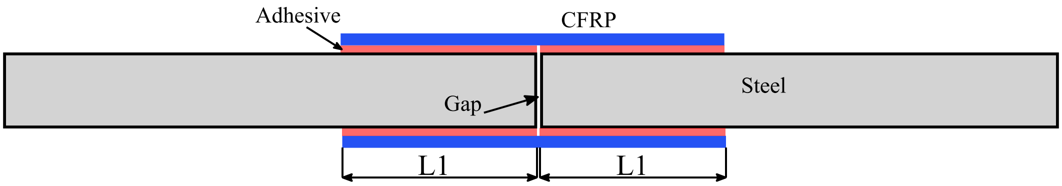


Fig. 2. Geometry of Steel/CFRP double strap joint.

Table 2. Double strap joint material properties

| Material | Young modulus (GPa) | Yield stress (MPa) | Ultimate stress (MPa) | Elongation at break (%) |
|---|---|---|---|---|
| Steel bars | 200 | 275 | 430 | 45 |
| CFRP laminates | 205 | - | 2800 | 1.6 |
| Aw adhesive | 2.23 | - | 31 | 5 |
| S&P adhesive | 9.64 | - | 34.8 | 0.5 |

Table 3. Double strap joint material dimensions

| Material | Thickness (mm) | Length (mm) | Width (mm) |
|---|---|---|---|
| Steel bars | 10 | 500 | 50 |
| CFRP laminates | 1.4 | L1=75 mm/ L2=75mm | 50 |
| Adhesives | 1 | L1=75 mm/ L2=75mm | 50 |

The double strap joint specimens were tested using a Universal testing machine 3382A-INSTRON, as shown in figure 3, with a load capacity of 200 KN. A clamp was slightly tightened in one side of the joint for safety reasons to prevent CFRP strips from blowing in the air at failure. The specimens were subjected to static tensile loading until complete failure. The loading speed was 1 mm/minute. The Digital image correlation was used to monitor the strains on the back face of the CFRP.

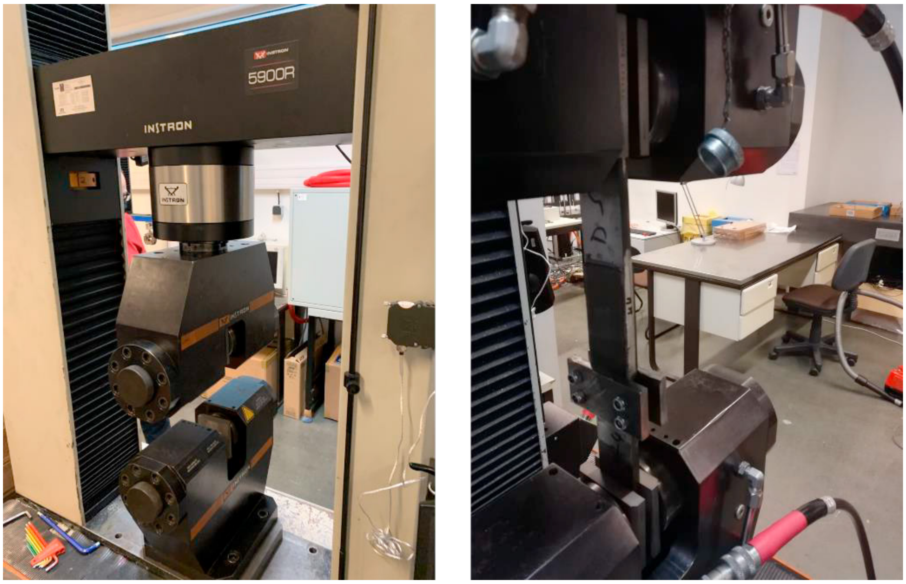


Fig. 3. Testing machine and experimental set up.

## 3. Results and discussion

Fig.4. shows the comparison between typical force-displacement curves for the DSJ specimens with the two brittle and the ductile adhesives. As can be seen, the specimens with the ductile adhesive reach very high strength compared to the brittle ones. The use of the ductile adhesive increased the strength of the joint by a factor of 2 compared to specimens with Sikadur 30 and a ratio of 1.33 compared to the specimens with SP HP220. However, the stiffness of the adhesive joint decreases when using the ductile adhesive. The specimens with the SP HP220 show higher strength than the ones with SIKADUR 30.
As shown in fig. 5. the failure mode in specimens with the ductile adhesive DSJ-AW4858 is CFRP delamination which indicates that the fracture toughness of the adhesive is higher than the CFRP matrix responsible for the delamination. For the brittle adhesive SIKADURE 30, cohesive failure combined with limited delamination in the ends of the joints governed the failure mode. Whereas for the brittle adhesive S&P HP220, a combination of CFRP delamination and cohesive failure can be observed.

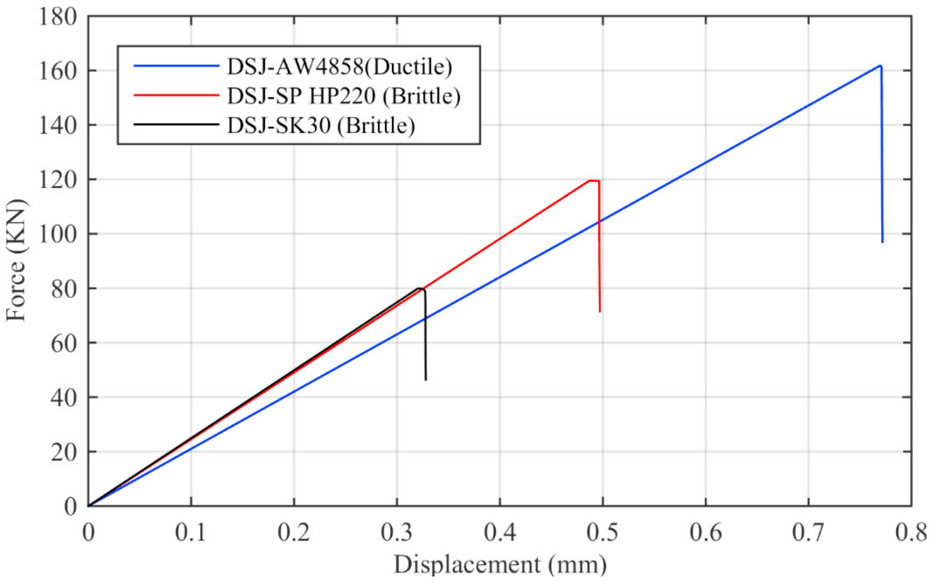


Fig. 4. Comparison between the typical force displacement curves of DSJ specimens with the ductile and the brittle adhesives.


Fig. 5. Typical failure modes for DSJ specimens with the different adhesives.

Fig. 6 shows the strain distribution on the back face of the CFRP obtained using DIC for a specimen with a brittle adhesive (SK30) and a specimen with the ductile adhesive AW4858/HW4858. The ductile adhesive promotes a more uniform distribution than the brittle one.

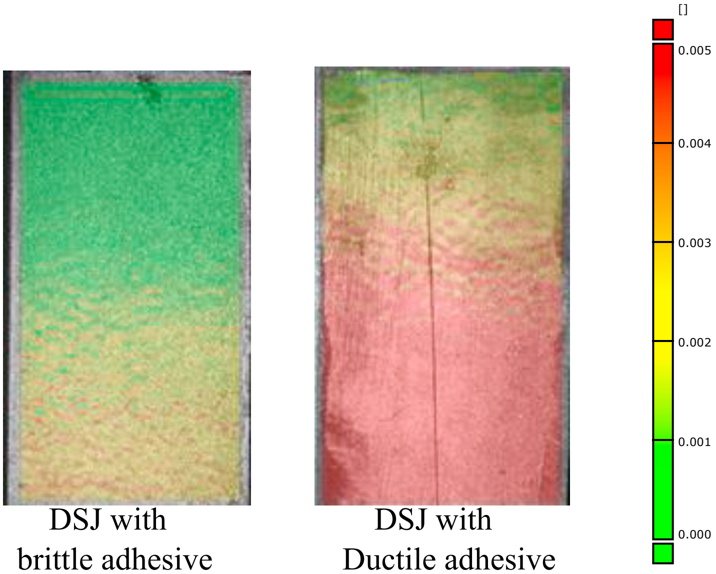


Fig. 6. Comparison between the strain distribution in the vertical direction.

## 4. Conclusion:

This study focuses on the comparison between the performance of brittle adhesives commonly used in the construction industry and ductile adhesive in CFRP/Steel double strap joints. The joints with ductile adhesive reached much significantly higher strengths than the ones with brittle adhesives. The DIC results reveal that the ductile adhesive promotes a more uniform distribution in CFRP/Steel joint than the brittle ones.

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