MECHANICAL PERFORMANCE OF LONG FIBRE REINFORCED STIFFENER PANELS MANUFACTURED USING LASER WELDING

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Abstract

In the frame of the Eurostars Project LaWocs, laser transmission welding was applied to join glass fibre fabric reinforced polyetherimide materials. In order to determine the performance of the laser welded coupons and components and the characteristics of the weld seams different mechanical test were performed as described in this paper. Furthermore, the results of the tests with the laser welded specimens were compared to tests with adhesive bonded coupons and components as a bench mark.

1. **Introduction**

Continuous carbon and glass fibre reinforced composite materials (CFRP, GFRP) are widely recognised for their uses in lightweight structures for many industrial sectors. They are particularly important in sectors where large masses are transported or where weight reduction leads to improvements in energy efficiency. Aside from the fields of transportation (e.g. aerospace, automotive, marine and the railway sectors) the use of fibre reinforced composites is particularly increasing within the field of energy (e.g. wind turbines, heavy-duty offshore pipeline elements and electronics) as well as within the field of sports and leisure. One barrier to the widespread usage of thermoplastic composite (TPC) structures is the lack of economic, quick and reliable manufacturing processes that includes joining technologies. Different joining techniques such as resistance welding, ultrasonic welding, vibration welding or induction welding are used, revealing advantages and disadvantages. [1, 2]

The aim of the Eurostars project LaWocs (Laser transmission welding of thermoplastic composite structures) was to develop a novel joining technique for TPC parts based on laser transmission

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welding (LTW) technology. Laser transmission welding is an industrially established welding technique for unreinforced and partially reinforced thermoplastics, which offers the option for a highly flexible and automated process with short cycle times and reduced manufacturing steps. Within the framework of the project this technology was adapted to the specific requirements of long fibre reinforced TPC materials.

Laser transmission welding is based on the optical transparency of thermoplastics for near infrared radiation. The laser radiation can partially pass through the upper part and is absorbed in the lower part, where the radiation is converted into heat. Due to heat conduction the transparent part becomes molten and a weld seam can develop. In order to guarantee constant heat conduction between the parts, the parts need to be pressed together, but no other surface preparation is usually needed. Depending on the kind of application of the laser radiation, it can be divided between contour and quasi-simultaneous welding. For contour welding, the laser beam is guided over the weld seam once in a continuous motion and for quasi-simultaneous the laser beam is guided several times at the same location at a high speed, often with gaps in between successive passes. [3,4,5]

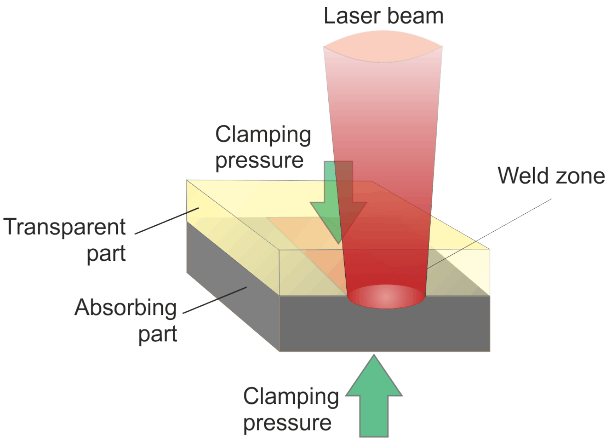

Figure 1: Principle of laser transmission welding.

One of the demonstrators of the LaWocs project was a stiffener panel made of glass fibre reinforced polyetherimide (GF PEI) with the goal of comparing laser welded samples to adhesive bonded samples. Double lap shear samples were also manufactured and tested to evaluate the temperature performance of the joints compared to adhesively bonded joints.

2. Experimental Set-up and sample preparation

The laser welding of both the double lap shear and stiffener panels was performed with a diode laser emitting at a wavelength of $\lambda = 940$ nm and having a maximum output power of $P = 300$ W. For welding of the double lap shear samples a scanner optic consisting of two Galvano mirrors was used. The scanner optic enables the laser beam to be moved rapidly over the work piece in order to apply quasi-simultaneous welding.

The double lap shear samples consisted of 1.7mm thick CETEX (GF PEI) from Tencate Advanced Composites BV. In order to be absorbing for the laser radiation, the surface of the lower part was modified with an absorbing liquid. For the adhesive bonded samples, which were used as a reverence, the adhesive Hysol EA9323 was used with the recommended surface preparation techniques. In order to be able to compare the laser welded with the bonded samples, the connection area of the adhesive bonding was reduced to the same as the area of the weld seam.

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To test the double lap shear samples, the samples were placed into a climate chamber and were loaded with 5 kg, 10 kg and 15 kg weights (Figure 2a). The temperature in the cabinet was increased at a rate of 1°C/minute. During testing the displacement across the joints was measured using LVDTs (Figure 2b). The temperature was recorded using a K type thermocouple, which was in contact with sample surface. Failure was defined as complete separation of the joints.

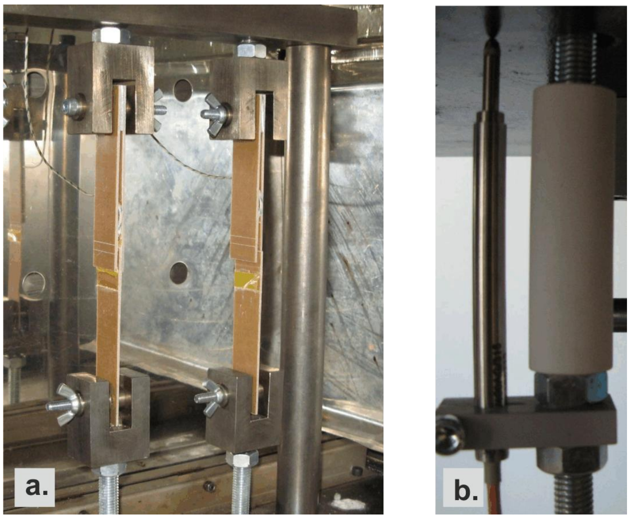

Figure 2: Test set-up for seam strength testing with increasing temperature.

For welding of the stiffener panel the laser was connected to a homogenising optic, which generates rectangular focused geometries with a homogeneous energy distribution. The stiffener panel consists of two thermoformed omega profiles made of GF PEI with carbon black additives, which were welded to two face sheets made of GF PEI. The face sheets had a thickness of 2.4 mm and a transmissivity of 17.5% for the laser wavelength. For generating long weld seams contour welding was applied.

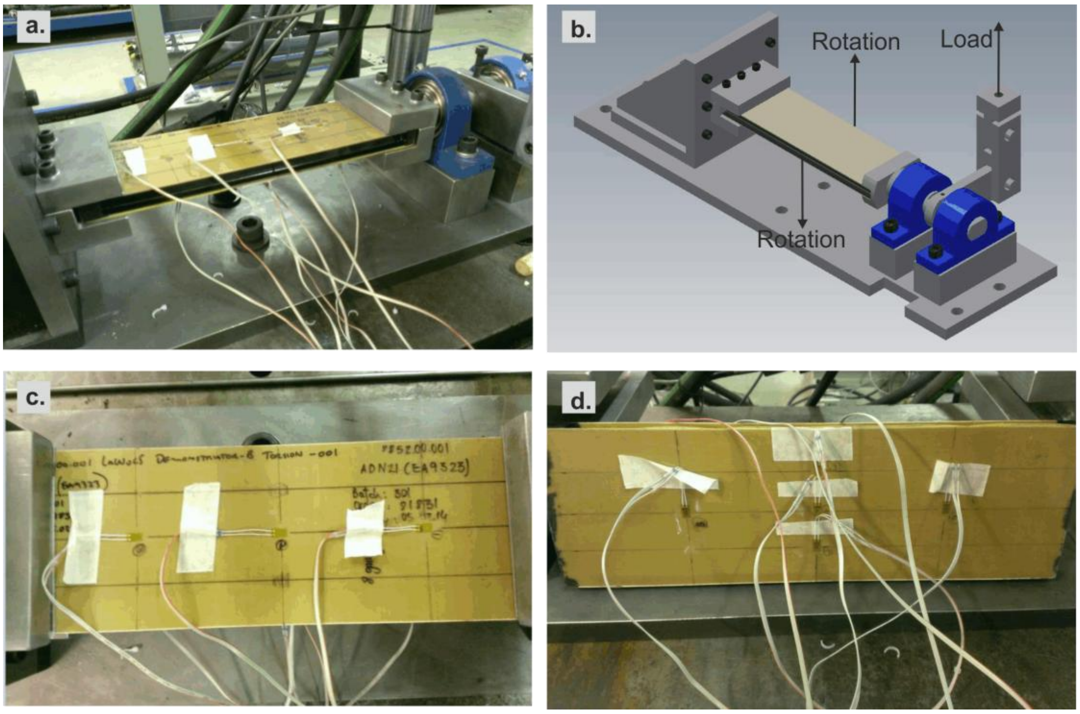

Figure 3: Torsion test set-up.

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The stiffener panel was tested in a torsional mode. A test fixture was designed to clamp the stiffener panel such that one end stays fixed and the other end can be rotated (Figure 3) using a lever arm. The sample ends were potted in epoxy resin to prevent local crushing.

The torsion was generated with a link arm, which has a length of 150 mm. This was attached to an MTS810 servo-hydraulic test machine with a 50 kN capacity. A 10 mm movement of the test machine actuator in the vertical direction resulted in approximately 4.2° rotation of the sample. The test rig enabled a maximum rotation of 30° to be applied to the test samples. Furthermore, the force to move the arm was measured. In order to detect damage of the stiffener panel during the tests, 8 strain gauges were fitted to the surface of each sample in the locations given in Figure 4.

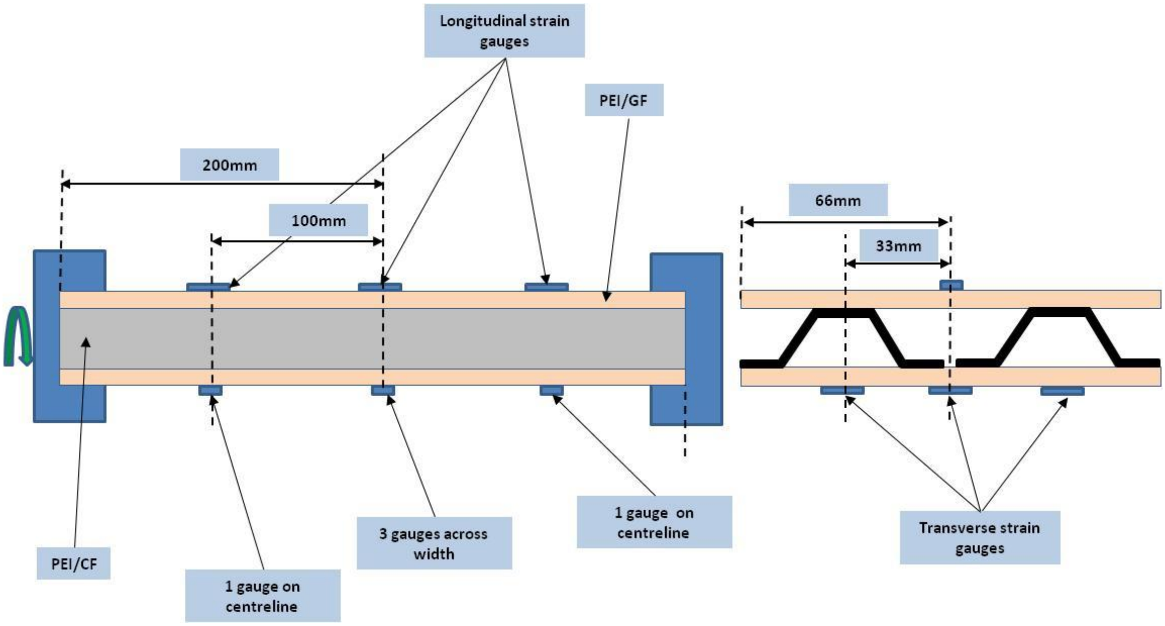

Figure 4: Location of strain gauges for torsional tests on stiffener panels

3. Results and Discussion

The reliability of the weld seams were tested at elevated temperatures to determine the temperature limit of the welded samples compared to bonded samples. Double lap shear samples were placed into a climate chamber and three different loads were applied while the temperature was slowly increased. The change of displacement with temperature is given in Figure 5. The laser welded samples exhibited a progressive failure at higher temperatures of T = 190°C to 215°C. The adhesively bonded samples failed at a temperature of T = 151°C to 156°C and the failure was more abrupt. In both the bonded and welded samples, higher static load resulted in a lower failure temperature of the joints.

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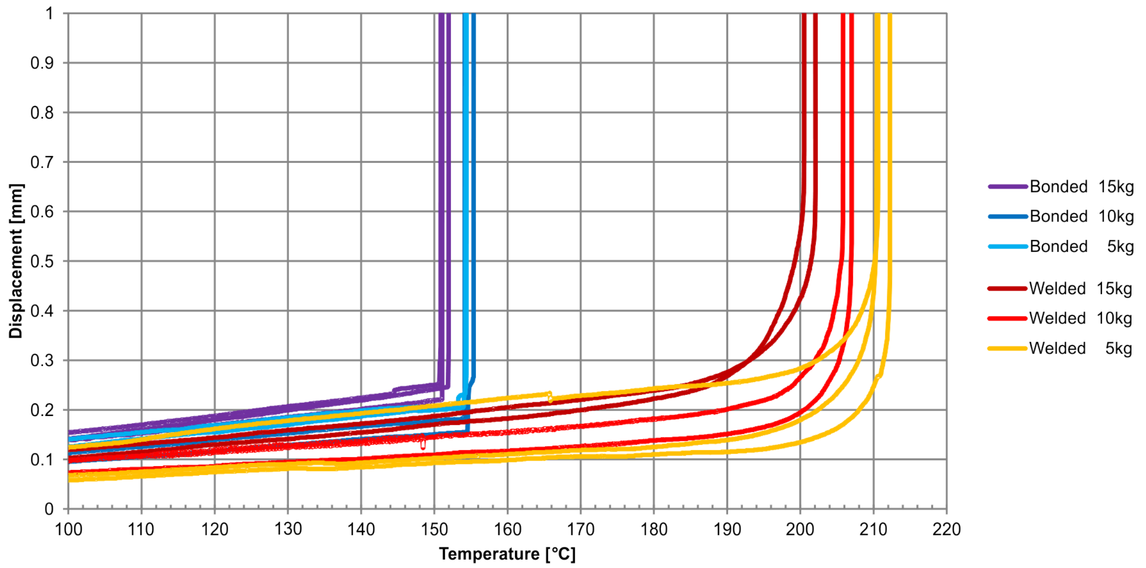

Figure 5: Displacement in the lap shear samples with increasing temperature.

The stiffener panels were tested in torsion in quasi-static and fatigue loading. For the static test a link arm vertical deflection of 10 mm was applied to one end of the test samples which resulted in a 4.2° rotation. This was then moved back to the starting position. This was repeated with increasing link arm deflections up 80 mm (34°). The link arm vertical deflection was applied at 50 mm /min. For the fatigue testing the panels were rotated by a link arm vertical deflection of +/-30 mm (+/- 12.6°) and with a test frequency of f = 0.5 Hz.

The strain gauge output vs. time for one of the adhesively bonded stiffener panels is given in Figure 6. The strains were measured on top and bottom surface of the stiffener panel. As the angle of rotation increases the maximum strain increases. For the third rotation with an angle of 12.6° some measurement curves show jumps in their course (Figure 6, right). This is an indication of failure in the stiffener panel due to the applied rotation.

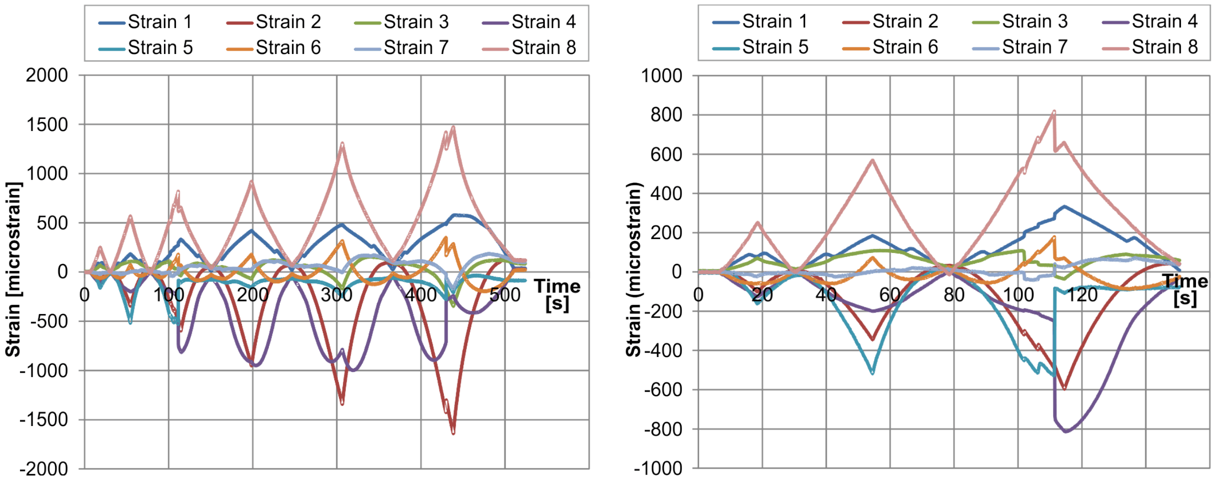

Figure 6: Example measurements of the strain progression in adhesively bonded stiffener panels during torsion testing (left – full test, right – first 3 cycles).

The strain gauge output vs. time for one of the laser welded stiffener panels is given in Figure 7. As for the adhesively bonded structures, an increase in the angle of rotation results in an increase in the maximum strain but for the welded panels there are no unexpected reductions in strain even at the

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higher rotation angles. The strains also return close to zero at the end of each loading cycle suggesting that there is negligible damage in the structures at the end of the test. The test set-up did not allow higher rotations, so the rotation until failure could not be determined for the laser welded panels.

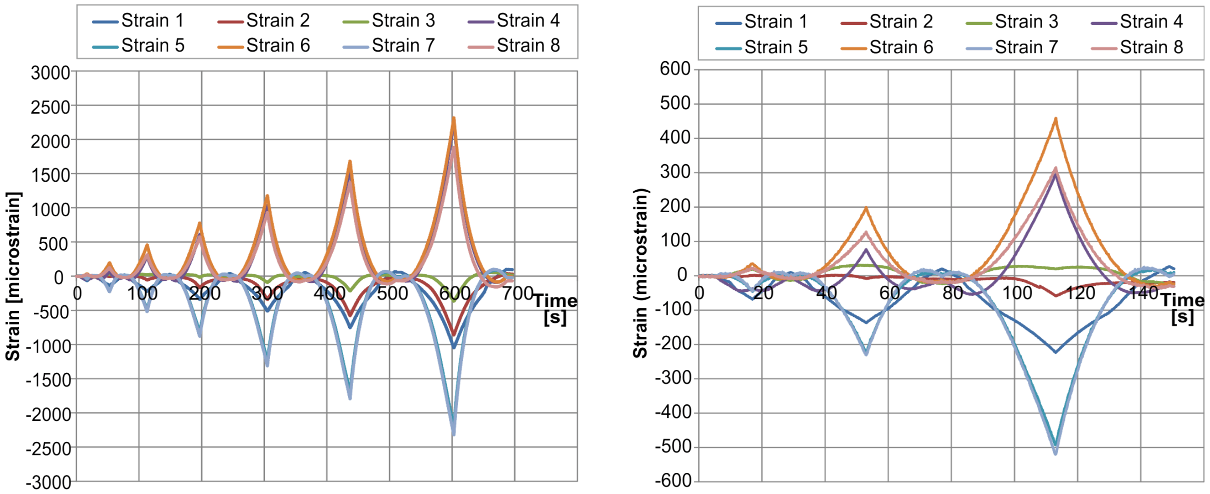

Figure 7: Example measurements of the strain progression in laser welded stiffener panels during torsion testing (left – full test, right – first 3 cycles).

As well as the strain measurements, the torque needed to rotate the stiffener panels was also measured (Figure 8). The torque to rotate the adhesively bonded stiffener panel (Figure 8, left) increases for the first four rotations and then stays then almost constant for subsequent cycles. During the testing of the welded stiffener panel the torque increased proportionally to the rotation angle (Figure 8, right). The maximum torque applied to the welded stiffener panel was 602 Nm with no failure whilst the maximum torque for the adhesively bonded stiffener panel was 309 Nm at failure. The difference in the torque is due to damage (or failure) in the adhesive bond line in stiffener panel, which reduced the stiffness of the part.

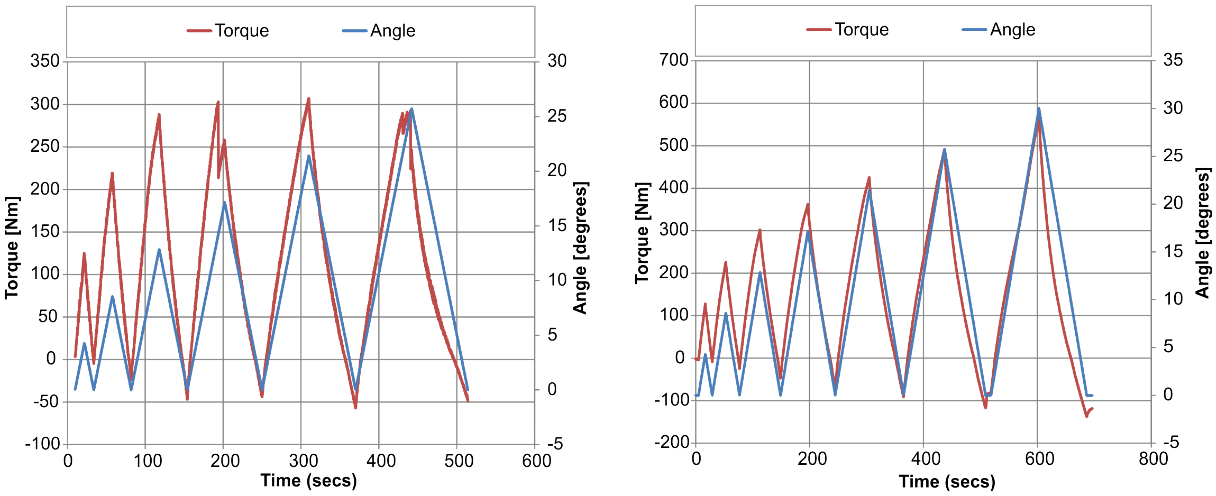

Figure 8: Examples of torque measurement during testing of adhesive bonded (left) and laser welded (right) stiffener panels during torsion testing.

For the fatigue testing the stiffener panels were rotated by +/- 12.6° with a frequency of 0.5 Hz. During the testing the peak torque was measured on each cycle and example results are given in Figure 9. The torque for the adhesively bonded stiffener panel decreased from 240-250 Nm at the start of the test to 208 Nm after 190 cycles with a sharp decrease to 135 Nm at 200 cycles. This is due to a large

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bond failure between one of the omega profiles and the outer facing. The torque stabilised after 200 cycles due and then the sample failed at 1000 cycles. The laser welded stiffener panel showed a steady decrease in torque over 100,000 cycles with no visible indication of failure in the joints.

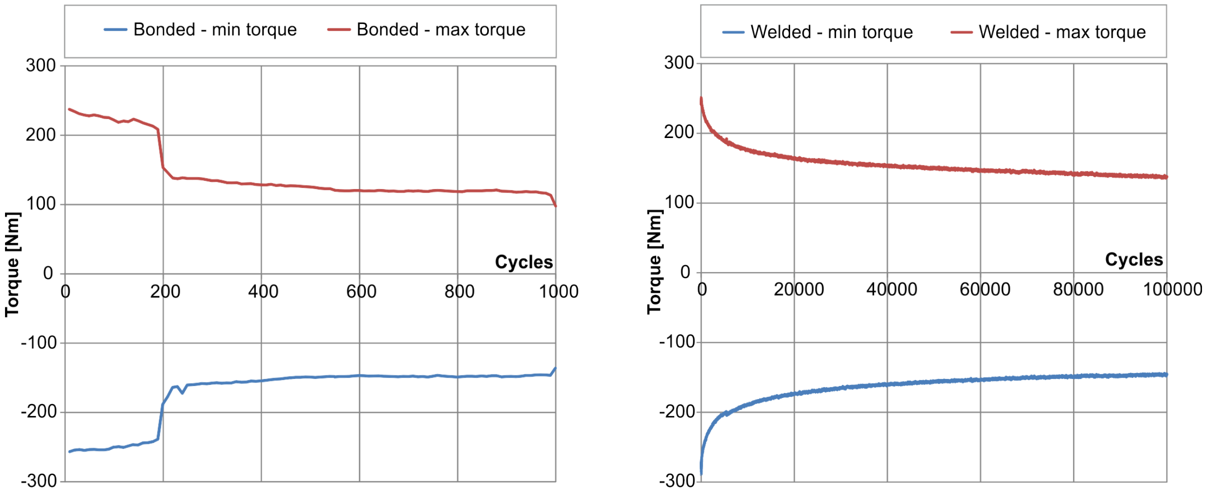

Figure 9: Examples of torque measurement during fatigue testing of adhesively boned (left) and laser welded (right) stiffener panels.

4. Conclusions

Within the Eurostars Project LaWocs, investigations were performed with laser transmission welded glass fibre (fabric) reinforced polyetherimide samples. The mechanical test results of laser welded specimens were compared to adhesive bonded specimens. The double lap shear samples were loaded with weights of 5kg, 10kg and 15kg and the deflection across the joint measured with increasing temperature. This test has shown that the adhesive bonded samples failed between T = 151°C to 156°C and the laser welded samples at T = 190°C to 215°C. The laser welded samples exhibited a progressive failure and the failure in the adhesively bonded samples was at a lower temperature and was more abrupt. In both the bonded and welded samples, higher static load results in a lower failure temperature of the joints.

Laser welded and adhesive bonded stiffener panels were also tested in torsion in static and fatigue tests. The bonded samples failed in the static tests at 20 to 30mm link arm displacement (8.5 to 13 degrees rotation) and the welded samples did not fail in static tests up 70-80mm displacement (30 to 34 degrees). In the fatigue tests, the bonded samples failed around 1000 cycles with a cohesive failure whereas the laser welded samples exhibited a progressive reduction in torque over 100,000 cycles with no visible evidence of failure. These results give a better understanding about the possibilities of applying laser transmission welding for joining long fibre reinforced thermoplastic composite structures, in particular the potential benefits to fatigue life when compared to adhesively bonded joints.

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