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Material properties

Assessment of the interlaminar behaviour of a carbon fabric reinforced thermoplastic lap shear specimen under quasi-static and tension-tension fatigue loading

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ABSTRACT

Although fusion bonded joints have already been extensively studied, they are only rarely compared to benchmark specimens with the same interlaminar behaviour as the composite material being joined, especially for lap shear geometry. Furthermore, an extensive study of these benchmarks under quasi-static and fatigue loading conditions is almost never considered.
In this manuscript, a method of producing such benchmark lap shear specimens is presented for a hot pressed carbon fabric reinforced thermoplastic. The mechanical behaviour of these specimens is then assessed using quasi-static, hysteresis and tension-tension fatigue experiments.
It could be concluded that the considered approach worked well for this material and reproducible results and values were found. With respect to the material, no crack growth was visible during the quasi-static experiments, except near the very end of life, whereas significant crack growth was present during fatigue experiments.

1. Introduction

The study presented here fits within a broader research project on the mechanical behaviour of fusion bonded joints between the material considered for this manuscript, which is a carbon fibre 5-harness satin weave reinforced polyphenylene sulphide (PPS).

A first paper was already published on the optimization of the welding parameters of this infrared welding [1], where the results of single lap shear experiments were used for the assessment of quality and reproducibility of the joints. A second study was conducted in order to determine the interlaminar behaviour under pure mode I, using the double cantilever beam test, and pure mode II, using the end notch flexure test, loading conditions [2]; values for G_I and G_{II} were also determined, both for initiation and propagation. This study was done in order to obtain a benchmark for the welded joints to be compared with.

Prior to going to fatigue lap shear experiments on the welded joints, it was decided that it would be useful to again have a benchmark for the lap shear behaviour of the base material. Therefore, the emphasis of this manuscript lies in determining the mechanical behaviour of the carbon PPS under study for a lap shear specimen, where the shear loaded overlap has exactly the same properties as the standard hot pressed plates, as for these, the production process has been optimised and should, therefore, yield the best interlaminar behaviour achievable. Although different fusion bonding processes have already been extensively studied, as illustrated in various review articles [3–5], the comparison between a benchmark and the welds is only

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rarely considered [6–8]. For these studies, benchmark or reference specimens are mentioned, but not much detail is given. Usually, only lap shear strength values are listed in a table, but detailed information and images of the production method are not given. Furthermore, only quasi-static behaviour is considered.

To obtain a lap shear geometry with the optimal properties, some possibilities are already considered in the mentioned literature.

Developing a hot pressing mould for this geometry, which was considered in [6] is not only difficult and expensive, it would also mean that a different mould is needed for other material types or other overlap lengths. In [7], an autoclaved reference is mentioned, but no further details of the process, for instance on how to obtain straight edges on the overlap. In [8], a plate of sufficient thickness is considered, after which the unnecessary material is removed by machining and grinded, but again, no further details, for instance on surface and edge quality, or the occurrence of delaminations due to the machining are given. The method presented in this paper also uses the principle of removing excess material, but with only limited machining.

Determining the interlaminar behaviour for a specific composite using lap shear specimens is in fact not new, such an approach is sometimes considered to compare adhesively bonded joints with co-cured joints [9–12]; the latter essentially having the same interlaminar properties as the base plates. Also, for Z-pin reinforced composites, the reinforcing effect of the Z-pins on the shear behaviour of the joint is sometimes assessed by comparing co-cured joints with Z-pin reinforced co-cured joints [13–18], but most authors consider Mode I or Mode II testing; the lap shear geometry is only used in [17,18]. However, the previously mentioned studies all work on fibre reinforced epoxies made with pre-pregs.

To the best of the authors' knowledge, an extensive study of the benchmark lap shear experiments both under quasi-static and tension-tension fatigue has yet not been published or assessed in open literature for continuous fibre reinforced thermoplastics.

The results in this paper, together with the Mode I and Mode II results published in [2], should provide an interesting benchmark for comparing (fatigue) data from fusion bonded joints between the carbon reinforced PPS, either by the already mentioned infrared welding, but also for other processes such as for example ultrasonic, induction welding or resistance welding [19].

The next section illustrates the used material and methods, after which the single lap shear experiments are discussed. Finally, some conclusions are drawn.

2. Materials and methods

2.1. Composite material

The material under study was a carbon fibre-reinforced polyphenylene sulphide (PPS), called CETEX. This material is supplied to us by Ten Cate. The fibre type is the carbon fibre T300J 3K and the weaving pattern is a 5-harness satin weave with a mass per surface unit of 286 g/m^2. The 5-harness satin weave is a fabric with high strength in both directions and excellent bending properties.

The carbon PPS plates were hot pressed at 10 bars and 310 °C; only one stacking sequence was used for this study, namely $[(0°,90°)_{4s}]_s$ where (0°,90°) represents one layer of fabric. The choice for this stacking sequence was driven by the fact that the experiments in this manuscript will serve as benchmark for the welded specimens, which also have this stacking sequence in their welded overlap [1].

The in-plane elastic properties of the individual carbon PPS lamina were determined by the dynamic modulus identification method as described in [20], the tensile strength properties of the lamina were determined at the Technical University of Delft. Both sets of values are listed in Table 1.

The desired geometry of the single lap shear specimen is illustrated in Fig. 1 and is chosen according to the ASTM D5868-01 '*Standard Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic Bonding*', which was also considered for [1]; the width of the specimen is 25 mm.

To obtain such a geometry using the hot pressing process, a very specific and expensive closed mould would be necessary, which would then only be suitable for one specific overlap length. As this was not available, a different way of achieving this geometry was examined, which is elaborated on in the next section.

2.2. Test specimen preparation

The idea was to produce a larger plate with the same stacking sequence of the welded overlaps in [1], and then to trim away all unwanted parts to obtain the desired lap shear geometry. By doing so, the overlap of the lap shear specimen is produced using the optimal process parameters for the standard plates. However, as it is not the purpose to induce a significant amount of damage by milling away all unnecessary material, thus corrupting the experimental data, a kapton film of 50 micron was carefully inserted in strategic places, so that four cuts with a diamond disc suffice to obtain the lap shear geometry; Teflon film was not an option, because the processing temperature of the carbon-PPS exceeds the maximum service temperature of Teflon films. Fig. 2 illustrates this process and Fig. 3 shows the placing of the kapton film in the central plane of the stacking sequence.

After hot pressing of the plate and cutting away the rough edges of the plate, the sides were examined using a microscope, and the exact position of the kapton film was marked on the plate. Then, the cuts were made, making sure that the depth did not exceed half of the plate; ideally, the cut should be just as deep as the kapton film. Finally, the excess parts are removed.

Table 1
In-plane elastic and tensile strength properties of the individual carbon/PPS lamina.

E_{11}	56.0	GPa	X_T	734.0	Mpa
E_{22}	57.0	Gpa	$\varepsilon 11^{ult}$	0.011	–
ν_{12}	0.033	–	Y_T	754.0	Mpa
G_{12}	4.175	Gpa	$\varepsilon 22^{ult}$	0.013	–
			S_T	110.0	Mpa