SHEAR TESTING OF BONDED JOINTS OF CEMENT AND REINFORCING FIBRE COMPOSITE MATERIAL

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Abstract
This publication focuses on the testing of bonded joints of cementitious and reinforcing fibre-based composite materials in shear, which is one aspect of the selection of joint properties in numerical modelling. In this study, experiments were conducted with different parameters such as adhesive type, surface preparation, and curing time to achieve optimum bond strength. The experimental results were analysed and compared. The results can be used as a basic resource for structural design. The article is related to the issue of testing interior staircases made of cement and fibre-reinforced composite material.

Keywords
Cement fibre boards, experimental testing, shear testing, surface preparation, structural integrity

1 INTRODUCTION

Cement fibre board (CFB) has recently become an important building material with good mechanical properties. These boards provide a durable alternative to conventional timber but could also replace load-bearing and non-load-bearing timber structures. The advantage of CFBs over timber structures is that they are non-flammable, although explosive deformation can occur in sudden heat [1]. As mentioned, CFBs can also be used as the load bearing structure of staircases, though the strengths of the different properties of the fasteners will need to be known in the finite element method.

The basic division of CFB joining is twofold. Joining can either be achieved mechanically using elements, or through the bonding of two materials, which are then referred to as ‘adherends’ [2]. Bonded joints are influenced by a variety of factors, which are generally divided into 3 groups. The first contains factors concerning the adhesive, which may include its viscosity, adherence by workers to prescribed application procedures, etc. The second group of factors concerns the adherends, i.e. their texture, porosity, surface moisture and internal moisture, as well as (for example) the cleanliness of the surfaces to be bonded. The third group of factors concerns the process conditions, which means the ambient humidity and temperature, and the option of applying pressure to the joint for a certain period of time, which is not much observed in practice unless it is a structural joint [3].

The most common adhesive options are polyvinyl acetate adhesives (PVAs), which are commonly available and are among the most widely used dispersion adhesives [4]. They are commonly used in the furniture industry. The adhesive is cured via the evaporation of the solvents. Polyurethane adhesives, on the other hand, were formerly often used as two-component adhesives, whereby the adhesive was cured by the reaction of the resin and the hardener [5]. Polyurethane adhesives generally have good shear and peel strength, are chemically resistant, and can form an adhesive layer even on difficult-to-bond surfaces such as CFBs.

2 METHODOLOGY

Materials

Test specimens of 150 mm × 50 mm × 30 mm were fabricated to determine the shear strength of the bonded joints. The specimens were bonded in a 50 mm × 50 mm area, which was marked for accuracy before the application of the bonding adhesive. For each type of adhesive, 3 test specimens were tested. The test specimens for determining the strength of the bonded joints were supplied and manufactured by CEMVIN. CFBs with cellulose fibre with cement matrix were chosen for experimental testing. According to the information provided by the company's expert, they were made from primary raw materials, namely: CEM I cement (84.5%), cellulose (8.0%), expanded

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perlite (7.0%) and polypropylene fibres (0.5%). All percentage values are determined as a percentage of the final product weight [6].

For the glued joints, the most commonly used adhesives for gluing wood and CFB boards were selected. SOUDAL 66A (G I.) is a polyurethane (C1) based adhesive; the clamping pressure for this adhesive is 0.098 MPa [7]. PERDIX – 124 (G II.) is a polyvinyl acetate (C2) adhesive which is suitable for spar filling with a bonding pressure of 0.5 MPa [8]. TITEBOND III. ULTIMATE (G III.) is a patented polymer (C1) with high adhesion and bonding properties. It requires a clamping pressure of 1.25 MPa - 1.75 MPa [9]. The last adhesive is DEN BRAVEN PUR ADHESIVE (G IV.), which is polyurethane (C1) based and is suitable for a variety of substrates. It can withstand a variety of chemicals and requires a clamping pressure of 1.5 MPa [10].

Methods

The shear strength test is applied to adhesive-bonded materials. It is a process that involves testing the strength of a bonded joint as two connected materials are forced to move or shift relative to each other. In this case, the method was applied to CFBs joined by adhesive. The prepared specimens were subjected to mechanical stresses that are induced parallel to the bonded joint. The method of measuring the shear in the bond between two bodies is shown in Fig. 1.

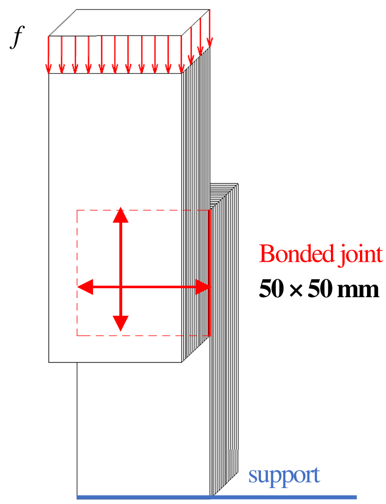

Fig. 1 Diagram of a shear strength test of bonded joints.

Before the start of the measurement of the bonded joints under loading, the calibration of the lever press was carried out, which detected the constant pressure prescribed by the manufacturer for application during the curing of bonded joints. The load force value was measured by a pressure sensor with a range of 0–25 kN, which was connected to an ALHBORN ALMENO 2590 – 2A-2 portable control panel. The pressure value was controlled by moving a number of weights along the press lever. The pressing time was determined by the technical data sheets provided by the adhesive manufacturers, and these values are shown in Tab. 1. Testing was carried out over 24 hours.

Tab. 1 Values for applied pressures and times according to the regulations of adhesive manufacturers.

	Producer	Applied pressure in MPa	Technical data sheet	Pressing time in s	Material consumption in $ml \cdot m^{-2}$
G I.	**SOUDAL 66A (C1)**	0.18	1 $kg \cdot cm^{-2}$ = 0.098 MPa	180	150
G II.	**TITEBOND III (C2)**	1.5	1.2 to 1.75	25	150
G III.	**PERDIX DČ (C1)**	0.5	0.5	20	200
G IV.	**DEN BRAVEN D4 (C1)**	1.5	max. 1.5	480	200

The adhesive was applied to the individual test specimens in the prescribed amount, and they were placed immediately after application in a lever press for the time prescribed by the individual manufacturers. To determine

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the shear strength of the bonded joints, the test fixture in Fig. 2 would first be fitted and secured to the base of the press by means of screws. The test specimen was then placed in the jig and secured to the measuring position using wedges and screws, which can be seen in Fig. 3. Loading was carried out until the bonded joint was broken or the material of the test specimen was damaged. During loading, the failure mode of the test specimen was monitored.

Fig. 2 3D model of the fixture used to hold the specimen for the shear test.

In order to orient the test specimen during the shear strength testing of bonded joints, it was necessary to create a fixture that would allow the test specimen to be properly seated during loading. From the material point of view, it is theoretically possible to make a jig from steel. The fixture was fabricated using additive 3D printing technology, specifically the Fused Deposition Modelling (FDM) method. The test fixture was supplemented with nuts and bolts that were used to lock the test specimen and fixture to the base. The locking assembly was secured by wedges that were moved in the groove by tightening the screws, thus defining the space for the test fixture (Fig. 2). The load on the test specimen was then induced using a FPZ 100/1 mechanical press with a maximum possible load of up to 100 kN and a constant travel increment. The sensors for recording the measurements were connected to an 8-channel SPIDER 8 control panel and from there to a PC.

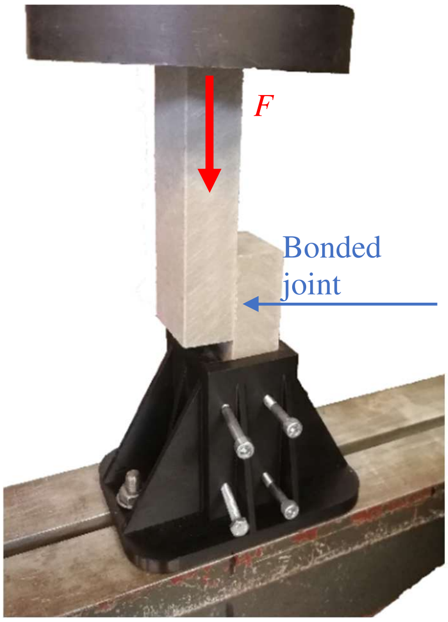

Fig. 3 Assembly setup when testing bonded joints in shear.

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The strength of bonded joints is calculated according to the following relation (1):

$$f_g = \frac{F_{\max,i}}{A_{\mathrm{eff},i}} \tag{1}$$

where f_g is the strength of bonded joints in MPa, $F_{\max,\,i}$ is the maximal force at bond failure in N and $A_{\mathrm{eff},\,i}$ is the area of the bonded joint in mm^2.

3 RESULTS

The values from the experimental measurements of the bonded shear strength were recorded on a PC and exported from the CatManEasy software into a spreadsheet format. During the experimental strength testing of the bonded joint, the maximum achieved failure forces Fmax, i and also the failure mode were recorded and monitored. The failure modes were expressed as percentage of the bonded area failure and by defining the shear. The measured average experimentally determined values are shown in Tab. 2.

Tab. 2 Overview of experimentally determined shear strength values of bonded joints.

	Producer	**$F_{\max;\,ave}$ in kN**	**$f_{s,g}$ in MPa**
G I.	**SOUDAL 66A (C1)**	14.61	5.85
G II.	**TITEBOND III (C2)**	7.63	3.05
G III.	**PERDIX DČ (C1)**	12.65	5.06
G IV.	**DEN BRAVEN D4 (C1)**	17.57	7.03

From the measured results it is possible to observe the different behaviour of the individual variants of bonded joints. The strongest bonded joint, in terms of shear strength, is the specimen with a polyurethane-based bonded joint utilising DEN BRAVEN adhesive. This joint is almost 1.2 MPa stronger than the joint bonded with SOUDAL 66 A, which is also polyurethane-based. The different behaviour of these bonded joints was caused by the internal integrity of the board, i.e. at the transition between the adhesion zone and the adherend, i.e. the CFB of the sample. Both adhesives penetrated the CFB specimen to a certain depth. Subsequently, during loading, the DEN BRAVEN adhesive bonded specimen failed in the bonded joint, i.e. in the adhesion zone, across up to 80% of the area. This trend was also evident in the bonded joint with SOUDAL 66 A, but only across 10% of the area. The remaining adhesive formulations, despite one being of higher strength, were always broken in the transition adhesion layer, i.e. on the CFB surface of the test specimen. Fig. 4 shows representative test specimens displaying the individual failures that occurred during the shear strength testing of the bonded joints.

Fig. 4 Overview of test specimen failures during the shear strength testing of bonded joints.

4 DISCUSSION

Several key findings can be identified in the presented experimental results on the shear strength of bonded joints. The first important aspect is the choice of adhesives for the bonded joints, where four different adhesives from

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different manufacturers were used. These adhesives exhibit different properties and technical parameters, which are reflected in the measured results.

The results show that the DEN BRAVEN D4 polyurethane-based adhesive achieves the highest shear strength of all the adhesives in the bonded joints (17.573 kN converted to a shear strength of 7.029 MPa). It was also found that SOUDAL 66A and TITEBOND III adhesives achieved lower shear strengths (5.845 MPa and 3.054 MPa, respectively). This may be due to the lower ability of the adhesives to penetrate the material structure or to their different chemical properties. The experimental results also show the bonded joints experienced different failure modes depending on the adhesive used. The adhesives DEN BRAVEN D4 and SOUDAL 66A show failure in the adhesion zone with a larger or smaller area range (80% and 10%), while the adhesives TITEBOND III and PERDIX show failure in the transition adhesion zone.

Thus, it can be concluded that the choice of adhesive has a significant effect on the strength of bonded joints, especially for specimens made from CFB. Therefore, when CFBs are used in staircase construction, adhesive choice will play a major role in assuring structural durability.

5 CONCLUSION

In this manuscript, a systematic analysis of the shear strength of bonded joints was performed, with an emphasis on the influence of the adhesives and materials used. The experimental results clearly show that the choice of adhesive has a significant impact on the resulting joint strength. The polyurethane based DEN BRAVEN DC adhesive achieved a higher shear strength, which may be related to its ability to penetrate the CFB structure with the cementitious matrix.

Different bonded joint behaviour was observed for two of the other adhesives used, SOUDAL 66A and TITEBOND III: SOUDAL 66A showed higher strength than TITEBOND III. This variation in results highlights the importance of careful adhesive selection depending on the specific application and joint strength requirements.

Experimental methods, including the use of a lever press and 3D printing to create the formulation, proved effective for investigating the strength of bonded joints. This manuscript provides relevant information for use with regard to structural and non-structural joints where the quality and strength of bonded joints is a critical factor, especially when using specific materials such as CFB. For further research, extension of the study to include additional parameters or mechanical bonding options may be recommended to better understand the strength dynamics of bonded joints under realistic conditions. Such an expanded view would further provide additional opportunities for the development of either bonded or mechanical joints between CFBs, which will be subsequently implemented in staircase development.

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