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SHEAR TESTS ON PERFOBOND CONNECTIONS IN TIMBER CONCRETE COMPOSITES

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ABSTRACT: With an increase in trend to integrate more wood into the construction industry, timber concrete composite (TCC) solutions are an efficient manner to overcome the limitations of timber. In the current literature, there are various connections that have been investigated for TCC systems. One with sufficient performance to target massive constructions is still limited. In this paper the use of the Perfobond connector, originally developed for steel concrete composite (SCC), is explored in TCC. The connection consists of a discrete steel plate with dowel action in the concrete side. For TCC an adjustment of gluing a part of the Perfobond to the timber member is made. Experimental investigation with the variable of a few parameters such as, different types of concrete and surface roughness of the Perfobond (bonded in the timber part) is performed. As a result of this experimental work, it is possible to observe that the Perfobond connector is performant in terms of both strength and stiffness. The results of this work indicate that, by using the most optimal design of a Perfobond connector, a performant connection can be introduced to TCC which makes it possible to target longer spans.

KEYWORDS: Perfobond connector, adhesively bonded connection, timber concrete composite, shear test

1 INTRODUCTION

The use of TCC systems in construction is in an increasing trend as more environmentally friendly solutions are targeted. Therefore, performant shear connections between timber and concrete are needed. The goal is to target a high composite action, by using a stiff shear connection, which minimizes the slip between the members and ideally leading to compression stresses in the concrete and tension stresses in the timber.

In TCC literature, dowel connections, notch connections and recently bonded-in dowel are extensively studied [1]. Bonded-in dowel connections are proven to minimize the strength and the stiffness limitations, of the traditional dowel connections, and to avoid the brittle failure common in notch connections [2]. The major problem with the bonded-in dowels was to come to common design rules for researchers and designers. The use of an adhesive makes a significant difference in the behaviour of the connection [3]. In the recently consolidated version of the prEN 1995-1-1 under preparation for the 2nd generation of Eurocodes, a subsection is devoted to the bonded-in rods [4]. Even though the guidelines are limited, it will support designers. Since the early 21st century, bonded-in steel plates are an ongoing application in TCC. The first patented system is HBV developed in Germany by Bathon [5-7]. This is a continuous steel mesh adhesively bonded to timber and the remainder of the connector is embedded into the concrete. With the mesh on the steel, a bonding is formed with the adhesive in the timber part and with the concrete. The continuous steel mesh is designed to be controlled by the yielding of the steel mesh, which leads to a ductile behaviour of the connection.

Since the success of HBV, multiple researchers worked on continuous or discrete steel plate connections [3, 8-12]. In this paper, a connector commonly used in SCC, the Perfobond connector was used, which was developed to be used in long span bridge constructions [13]. This connector is welded to the steel beam, and inserted into the concrete layer of the SCC member. The part in the concrete has holes, which mobilizes dowel action between the connector and the concrete in addition to the bearing component at the tip of the connector. The application of the connector is slightly modified to be used in TCC. The part welded to the steel profile is now extended to be embedded into the timber element. An adhesive is used to bond the connector to the timber. The plate in the concrete part is designed and used as done in SCC [14].

In this work, an experimental investigation of the Perfobond connector is performed. The impact of concrete type and surface roughness of Perfobond on strength and stiffness is investigated. The results show that a Perfobond is a promising performant connector with high strength and stiffness, however, with limited ductility, which can be further improved to be used in industrial application.

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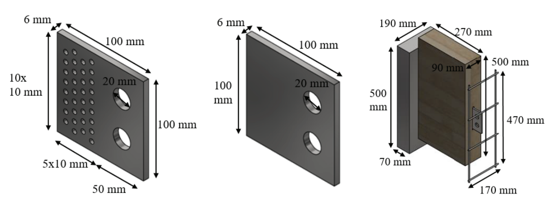
2 DESIGN OF TEST SPECIMENS

The use of Perfobond connections are a common application in SCC. They have been developed to replace studs in long span construction and with the optimized design requirements in the literature, strong and stiff connections are obtained in which one Perfobond replaces a significant number of studs [13].
In this work, the connections that are embedded in the concrete part are designed using the experimental work conducted by Oguejiofor and Hosain [14]. The steel plate is designed using EN 1993-1-8 [15]. The part adhesively bonded to timber was slightly more challenging to design as there are no guidelines. Potential failure modes are identified that can occur in the timber part by using examples from the bonded-in literature [2] and application of bonded-in steel plates [3, 8-10]. The final dimensions of the Perfobond can be found in Figure 1 (a) and (b). In both of the plates, the surface of the steel plate is smooth without any treatment. To assess the bond between the steel plate and the adhesive, two different configurations are tested; i) a smooth Perfobond in which the bond with adhesive is directly through the surface of the plate (Figure 1 (a)) and ii) perforations formed in the part embedded in the timber to increase the surface area of the adhesive and with the adhesive filled through the perforations, a mechanical interlock is targeted (Figure 1 (b)).
In this experimental work, two different parameters are investigated; i) the effect of perforations on the connector and ii) the type of the concrete.



a) b) c)

Figure 1 *Test specimens (a) Perfobond without perforations, (b) Perfobond with perforations, (c) 3D view of the specimens*

3 MATERIALS AND METHODS

3.1 TEST SPECIMENS

Symmetrical shear push-out type tests were conducted with a central timber and concrete layer on both sides. The timber is predrilled with groove dimensions of 110x10x55 mm, and the sides that were in contact with concrete are taped to avoid moisture entering the timber and to avoid the friction between the two materials. The 2/3 of the groove is filled with an epoxy acrylate-based anchoring adhesive, Sika Anchorfix-3030 [16], and the Perfobond is inseerted as soon as the adhesive is applied. The specimens are prepared in an indoor lab environment and were left a minimum of 24h for the adhesive to dry as recommended by the manufacturer [16]. The concrete is casted approximately after 7-days the adhesive was applied. Minimum reinforcement is used to avoid concrete tension failure [17]. Detailed dimensions of the specimens are given in Figure 1 (c) [18].

3.2 MATERIALS

The timber used in this work is GL 24h with a moisture content of 12.34% (Hydromete or oven dry method) and average density of 483 kg/m^3.
The Perfobond connector is steel grade S355 without any surface treatment.
For the concrete, two different concrete types are used: normal weight and lightweight concrete. Physical and mechanical properties of the concrete, determined according to the EN 12390-3 [19], can be found in Table 1 along with the other testing variable, the use or not of perforation in the perforbond connector (Figure 1 a) and b)).

Each specimen is named by the connection name initial (P) – presence of perforations in the bonded part (Y if available, N if not) and by the concrete type used (NWC for normal weight concrete and LWC for lightweight concrete).

Table 1 *Test specimen properties*

Experimental ID	Concrete type & Density (kg/m^3)	Concrete mean cube strength (MPa)	Perforation
P-Y-NWC	NWC 2400	78	Yes
P-N-NWC			No
P-Y-LWC	LWC 1600	25	Yes
P-N-LWC			No

3.3 TEST SET-UP, MONITORING AND TEST PROCEDURE

The experimental set-up (Figure 2), including monitoring system, consists of a test frame, a hydraulic jack, a load cell and LVDTs (Linear Variable Differential Transformer). The specimens are equipped with seven LVDTs, two horizontal and five vertical ones. The horizontal ones are placed at the top and bottom of the specimens to record timber-concrete separation. Four of the vertical ones are placed at the connection level, on both sides of the specimens as recommended by EN 26891 [20], to measure relative slip between materials. The remaining vertical LVDT is placed at the level of the load cell.
The loading procedure from EN 26891 is followed [20].

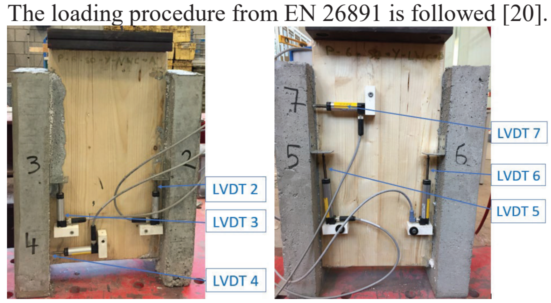


Figure 2 *LVDTs 2-4 (b) LVDTs 5-7*

4 RESULTS AND DISCUSSION

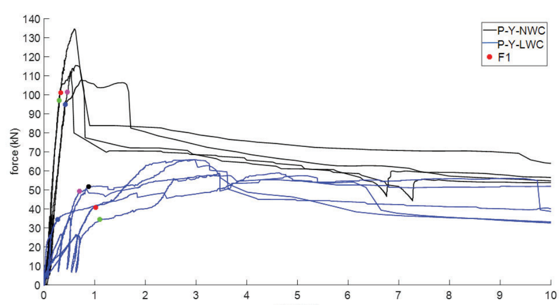
4.1 TEST RESULTS

In Table 2, mean value and coefficient of variation (COV) of the initial damage load (F_1), maximum load capacity (F_{max}) and stiffness (K_{ser}) are given for all four series. Initial damage load is determined by the reduction on the slope of the force-slip curve. The maximum load capacity is determined by the maximum capacity a connection could bear and the stiffness of the connection is determined as recommended in EN 26891 [20] and corresponding to the load-slip curve slope at 10% and 40% of F_{max}. In Figure 3, the load-slip curve for the series with and without perforations are presented. In both figures, F_1 is marked to clearly illustrate the initial damage load.

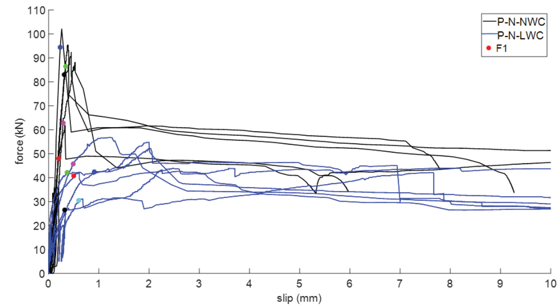
In series P-Y-NWC and P-Y-LWC, given in Figure 3 (a), the initial reduction in stiffness is caused by the damage between the bondline to the timber at 94.4 kN and 44.4 kN, respectively. With the loss of adhesion, load is transferred through bearing to the timber. Because the concrete was strong enough, crushing of timber started in the specimens with the use of normal weight concrete and governed the load capacity. When the bonding was totally lost, the connection reached its maximum capacity of 117.4 kN. For the specimens with lightweight concrete, with bondline failure, the load is transferred to the concrete through bearing between timber and perfobond connector and due to the lower strength of the concrete, concrete dowel failure is observed at 60.8 kN.

For the series P-N-NWC and P-N-LWC, given in Figure 3 (b), initial damage is due to the bondline failure of the bond to Perfobond connector at 76.7 kN and 38 kN, respectively. After the initial damage, the failure patterns are very similar to cases with the presence of surface roughness.

In all series, a very high stiffness is recorded, ranging between 297 to 442 kN/mm. It should also be noted that the COV is high for this parameter as a small deviations or inaccuracies in measurments as low as 0.1 mm have a significant impact.



a)



b)

Figure 3 *Force-slip curves (a) for the specimens with perforated connections (P-Y-NWC and P-Y-LWC) and (b) for the specimens without perforated connections (P-N-NWC and P-N-LWC)*

Table 2 *Test results*

Specimen ID		F_1 (kN)	F_{max} (kN)	K_{ser} (kN/mm)
P-Y-NWC	Overall mean	94.4	117.4	441.9
	COV (%)	9.7	18.1	24.0
P-N-NWC	Overall mean	76.7	87.5	419.7
	COV (%)	27.0	17.5	41.3
P-Y-LWC	Overall mean	44.4	60.8	403.4
	COV (%)	16.6	6.5	39.3
P-N-LWC	Overall mean	38.0	48.3	296.9
	COV (%)	20.1	14.7	44.3

4.2 DISCUSSION OF TESTING PARAMETERS

In this experimental work, the effect of concrete type and the connector perforations in the timber part are investigated. In Figure 3, the effect of the concrete type can be clearly observed. In both figures, the series with the use of normal weight concrete have a very stiff behaviour until (almost) the maximum load carrying capacity, after this point, with brittle failure at the bondline, a sudden decrease in the load capacity (30 – 50%) is observed. In the series with the use of lightweight concrete, the behaviour is linear until F_1, with much flexible behaviour due to participation of the concrete. After this load level, the force-slip behaviour shows a nonlinear response until the maximum load capacity is reached. Unlike the series with normal weight concrete, the drop in load capacity is smaller, as the use of lightweight concrete lead to a more ductile behaviour since the participation of the concrete was higher. In terms of maximum load capacity, the use of normal concrete

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lead to double capacity in comparison to the lightweight concrete (Table 2).

The use of perforated connections leads to a difference in the mechanics of the connector as the bond between the connector and the timber is efficient. The use of perforations leads to an increased load capacity and stiffness behaviour.

5 COMPARISON WITH THE LITERATURE

In order to contextualize the mechanical performance of the Perfobond connector for TCC, the different types of connections available for use in composite beam floor solutions, and covering different target applications, are here discussed. In Table 3, various connections used in TCC and Perfobond connections used in steel-concrete composites (SCC) are summarized in terms of strength (F_{max}), stiffness (K_{ser}) and ultimate slip (v_u). The ultimate slip is determined by EN 12512 [21], which is the slip value corresponding to the 80% of the force after the maximum load capacity is reached.

Four groups of connections are identified: i) dowel type connections; ii) notch connections; iii) steel plate connections in TCC; iv) Perfobond connections in SCC. The results of the referred mechanical properties are given per connection per shear plane. Details of the experiments can be found in the given references. In Figure 4 the chart provides a comparative overview of the different types of shear connections collected. For each mechanical property (F_{max}, K_{ser} and v_u), values are normalized to the respective maximum reported value, namely: strength and stiffness connection 11 [22] and ultimate slip connection 12 [23]. Then, the mean values of test specimens (normalized) P-Y-NWC and P-Y-LWC are also included (represented by the dots). Only these two type of specimens have been used because, as discussed previously, the use of perforations can delay the failure of the bondline zone and consequently, the connection can perform better.

Though, a quantitative comparison may not be entirely realistic, given the geometrical and material differences between the collected test specimens, however, Figure 4 provides a good perception on their relative mechanical performance. The chart shows that Perfobond in SCC is the strongest, the stiffest and the most ductile [22, 23]. Then, on the other side, screw connections present a lower load capacity and stiffness. Consequently, their application in TCC solutions targets lower load-bearing demands and is mainly due to the easiness and cost of application. Notches are as performant as the connections with steel plates, being the limited ultimate slip the main drawback. However, except for case 7, limited ultimate slip is also a problem in shear connections using plates in TCC due to the brittle behaviour of glue connections. Regarding this mechanical property, connections using Perfobond in SCC and SNP toothed metal plate (case 7) can provide the highest values, even higher than screws [22-24]. The extensive research on Perfobond connections for SCC also demonstrates that, if optimally designed, this type of connections can provide a balanced response, combining high stiffness and load bearing capacity with interesting plastic deformation on the Perfobond connector.

The comparison of the tested connection with the collected connections shows that it is as performant as the connections with bonded-in plates (cases 7 – 10). Case 9 is the case most similar to the configuration investigated in this paper, with a steel plate glued to the timber using an epoxy based adhesive [24]. In the reference (case 9), normal weight concrete is used. The strength of the series P-Y-NWC is in perfect agreement. In terms of stiffness, P-Y-NWC behaves slightly better (due to surface roughness). In terms of slip capacity however, a small reduction is observed. However, given the fact that the connection was design to avoid plastic deformations in the Perfobond connector, there is potential to increase plastic deformations, as it is the case of the Perfobond in SCC.

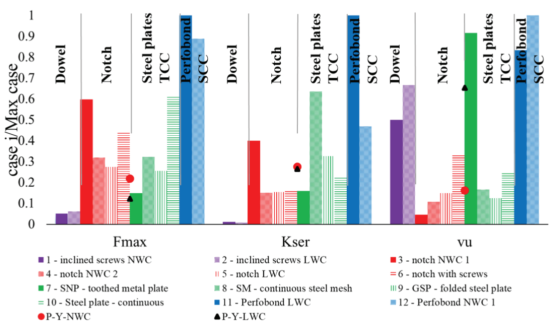

Figure 4 *Comparison of the mechanical performance of the tested Perfobond with the different type of connections available for TCC (including Perfobond in SCC)*

Table 3 Collection of different type of shear connections for TCC (including Perfobond in SCC)

Type	ID	Fmax (kN/m)	Kser ((kN/mm)/m)	vu (mm)
Dowel	1 - inclined screws NWC [25]	13	9	6
	2 - inclined screws LWC [25]	15	7	8
Notch	3 - notch NWC 1 [26]	150	305	1
	4 - notch NWC 2 [27]	80	115	1
	5 - notch LWC [27]	69	117	2
	6 - notch with screws [27]	110	125	4
Steel plate (S-TCC)	7 - SNP - toothed metal plate [12]	37	121	11
	8 - SM - continuous steel mesh [12]	81	484	2
	9 - GSP - folded steel plate [12]	64	249	2
	10 - Steel plate – continuous [11]	153	170	3
Perfobond (P-SCC)	11 - Perfobond LWC [22]	**251**	**760**	10
	12 - Perfobond NWC 1 [23]	223	357	**12**

6 CONCLUSIONS

As a result of this experimental work, it can be concluded that Perfobond connection are strong and very stiff therefore a high composite action can be achieved. The concrete type and strength had a significant effect on the load capacity of the connections. Adding surface roughness through the inclusion of perforations had a positive impact on the performance of the connection as the bond between the connector and the timber improved. Moreover, a comparison with commonly used TCC connections has been made and showed that the solution is as performant as notch connections and as similar connections using steel plates. The tested Perfobond connections present high strength and stiffness with relatively low ultimate slip, however, the latter was somehow expected, as the focus was on the performance of the connection depending mainly on the adhesive part. Ductility should be sought with the plastic deformations of the connector and / or by adding a rebar through the holes on the concrete side of the connection, which was not covered in the present study.

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