INFLUENCE OF BOLT DIAMETER ON THE BEARING FAILURE LOAD OF GFRP BOLTED LAMINATES

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Abstract

An experimental investigation on the influence of the bolt diameter on the bearing failure load of glass fibre/epoxy (GFRP) bolted laminates has been carried out in this paper. Two different types of laminates have been tested: unidirectional and bidirectional. Significant reductions in bearing ultimate load when bolt diameter decreases are highlighted. A bearing design formula is also proposed based on experimental results.

INTRODUCTION

The noteworthy mechanical properties of Fibre Reinforced Polymer (FRP) materials, as for instance high values of rigidity/weight, resistance/weight ratios and high corrosion resistance, have made very interesting their use [1-2] in the area of civil engineering, substituting or being integrated with traditional materials. One of the most complex and important themes, for these applications, that has not been yet adequately understood, is related to the design and verification of structural joints (both adhesive and bolted).
With reference to the bolted joints the typical failure modes are summarized below:

1) net-section failure;
2) shear-out failure;
3) bearing failure;
4) fastener shear failure.

In particular, the third one has attracted the attention of the international scientific community, as confirmed by the great number of researches carried out in these last years. It is worth taking into account the results obtained by Kelly and Hallström [3], Counts and Johnson [4], Xiao and Ishikawa [5, 6], Vangrimde and Boukhili [7-9], Li, Kelly and Crosky [10], Ascione, Feo and Maceri [11].
The results of these studies have highlighted that the bearing failure mode of FRP bolted joints depends on the following main factors:

- joint geometry: bolt diameter (d), plate width (w), end distance (e) and thickness of the composite laminates (t);
- matrix type and fibre nature;
- fibre inclination angle;
- stacking sequence of the laminates.

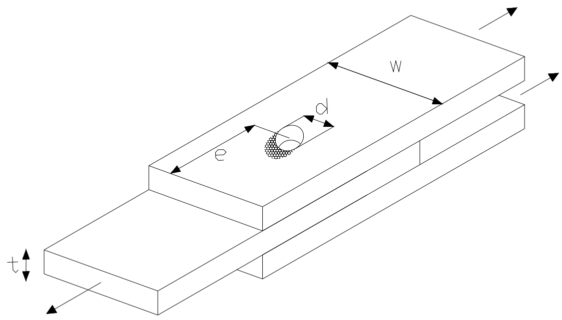

Fig. 1. Bearing failure.

In [11] the influence of the fibre inclination angle and stacking sequence on the bearing failure load of GFRP plates connected with a single bolt has been investigated by the authors. To perform the experimental investigation, a bearing test set-up was developed. Starting from the experimental results, a design formula for the calculation of the aforementioned bearing failure load referring to the variables introduced before (stacking sequence and fibre inclination angle) was proposed.
The objective of this paper is to extend the experimental study in order to investigate the influence of bolt diameter on the bearing failure load of glass fibre reinforced composite laminates.

EXPRIMENTAL PROCEDURES

Materials

In order to perform the experimental study, the three different types of symmetrical laminates already studied in [11] have been tested. All of them were fabricated by vacuum laminating 8 or 24 sheets of unidirectional glass fibre and two plies of chopped strand mat (CSM), impregnated with epoxy resin. Their thickness, stacking sequence and volume fractions of fiber and matrix are briefly described below.
Type 1 Laminate. This laminate was constructed from eight equally oriented plies of GFRP $[CSM/0_4]_S$. The volume fractions of fibres and matrix of type 1 laminate were approximatively equal to 60% and 40%, respectively, and its thickness was equal to 10mm.
Type 2 Laminate. This laminate was constructed according to the stacking sequence $[CSM/0_6/90_6]_S$. In detail, it was fabricated using four ply groups, two made of six plies in the 0-degree direction, and the other two made of six plies in the 90-degree direction. The volume fractions of fibres and matrix of type 2 laminate were approximatively equal to 65% and 35%, respectively, and its thickness was equal to 12mm.
Type 3 Laminate. This laminate was fabricated according to the laminating sequence $[(CSM/0_3/90_3)_2]_S$. In detail, it was fabricated using eight ply groups, four made of three plies in the 0-degree direction, and the other four made of three plies in the 90-degree direction. The volume fractions of fibres and matrix of type 3 laminate were approximatively equal to 65% and 35%, respectively, and its thickness was equal to 12mm.
The mechanical properties of all laminates were determined by the authors through compression and traction tests, and the results are reported in Table 1 and 2. For a more detailed description see [11].

Table 1 – Mechanical Properties of the GFRP type 1 laminate (experimental values).

Property	**Value [MPa]**
Traction Limit Strength, 0°	222
Traction Limit Strength, 90°	71
Compressive Limit Strength, 0°	201
Compressive Limit Strength, 90°	81
Modulus of Elasticity, 0°	28431
Modulus of Elasticity, 90°	11210

Table 2 – Mechanical Properties of the GFRP type 2 and 3 laminates (experimental values).

Property	**Value [MPa]**
Traction Limit Strength, 0°	310
Traction Limit Strength, 90°	310
Compressive Limit Strength, 0°	381
Compressive Limit Strength, 90°	381
Modulus of Elasticity, 0°	25000
Modulus of Elasticity, 90°	23000

Test analysis

GFRP square samples, 500mm wide, were made up for this study (Fig. 2). Each specimen was characterized by the presence of two holes: the first one (*hole 0*) was located at the centre, while the second (*hole i*) near the edge of the specimen in order to obtain a pre-established value of the fibre inclination angle, α, between the direction of the external applied force, coincident with the straight line passing through the centre of the two above mentioned holes, r_{0i}, and the 0° direction [11].

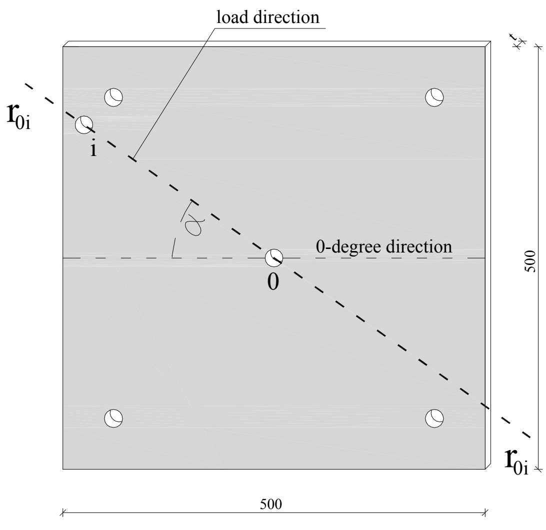

Fig. 2. GFRP specimen: geometry *(dimensions in mm).*

The following sixteen values of α were considered for type 1 laminate: 0°, 1°, 3°, 5°, 7°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 60°, 75° and 90°. Instead, for type 2 and 3 laminates seven values were considered for α: 0°, 1°, 5°, 20°, 25°, 45° and 90°.

The central hole is 21mm in diameter and, in order to investigate the effects of the bolt diameter on the bearing capacity of the laminates, three different values of the bolt diameter were considered: 18, 19 and 20 mm.
The bearing experimental set-up is shown in Fig. 3. It was composed of two couples of square steel plates measuring 500mm wide and 50mm thick, with a centre hole of 300mm in diameter. Each steel plate had four corner holes corresponding to the holes made on the edges of the GFRP laminates (Fig. 2). More details are reported in [11].

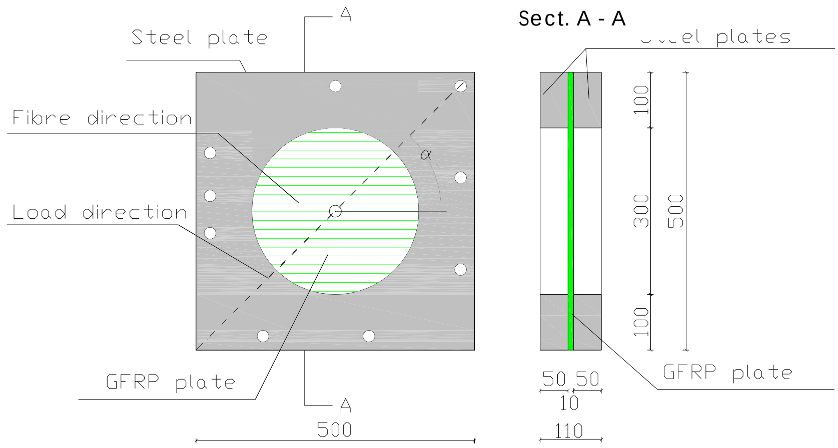

Fig. 3. Glass composite plate (GFRP) and steel plates (*dimensions in mm*).

This fixture was attached to a 630 KN load cell of a Shenck Hydropuls servo-hydraulic testing machine (Fig. 4) and the load was applied at a constant grip displacement speed of 9.9×10^{-3} mm/sec.

Fig. 4. Fixture attached to Shenck Hydropuls servo-hydraulic testing machine.

The centre hole bolt (hole 0 of Fig.2) was fixed to the lower clamp, while the edge hole bolt was attached to the upper clamp in order to obtain a preset direction of the applied force.
To measure the bearing strain, all the laminates were equipped on both sides with ten rectangular temperature self compensated strain gages (Vishay MM C2A-06-062LR-120), placed as shown in Fig 5.

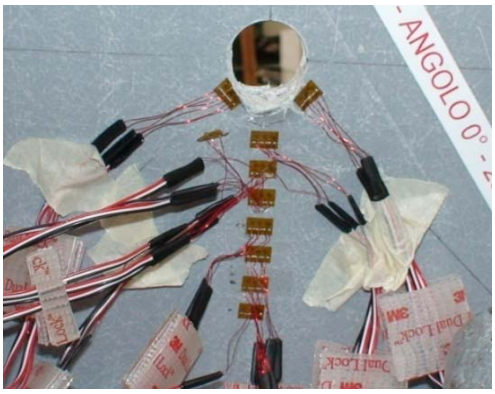

Fig. 5. Scheme of the strain gages around the central hole of the GFRP laminate (post failure photo illustrating the debonding of one of the strain gages).

During the tests, load, displacements and strain were recorded by an automatic data acquisition system consisting of three “System 5100 Vishay MM” switchboards, with 60 extensometric channels set out in parallel. Data obtained during the tests were subsequently elaborated using the *StrainSmart* software.
The bearing failure load has been evaluated by means of the load-displacement curve. In particular, it corresponds to the first peak value of the aforementioned curve, as shown in Fig. 6.

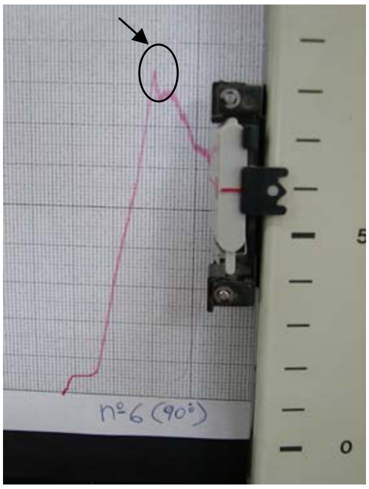

Fig. 6. Evaluation of the bearing failure load.

RESULTS AND DISCUSSION

In this section the bearing failure load values, $F_u^{(\alpha)}$, for all the GFRP laminates are presented and discussed.
Type 1 Laminate: Figure 7 shows the curves of $F_u^{(\alpha)}$ varying the angle α and the bolt diameter (*d*) for type 1 laminate. It is worth noting that the curves have been obtained using average values. In particular, for each value of α and for d equal to 20mm three samples have been tested, while for the other two values of the bolt diameter only two specimens have been analysed.

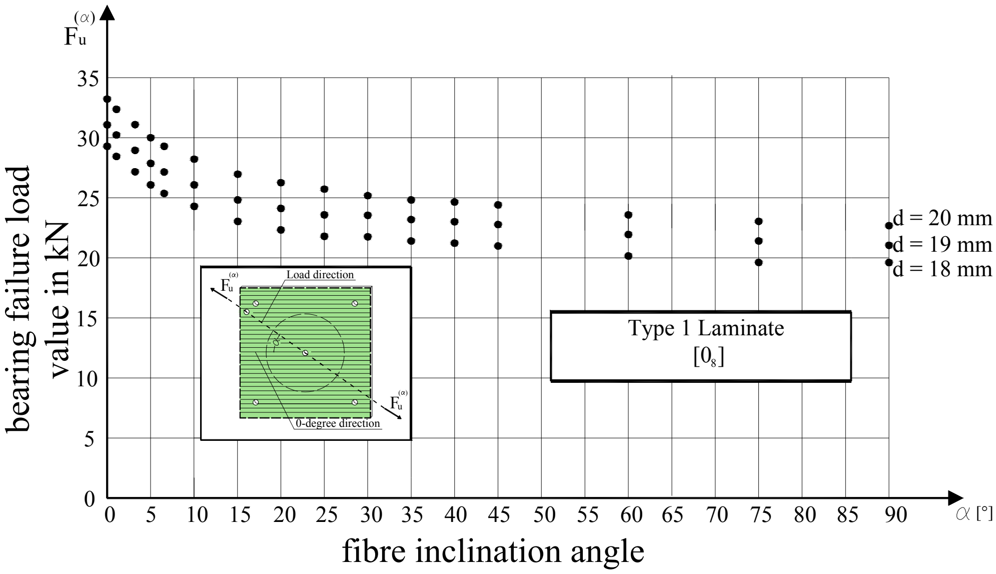

Fig. 7. Type 1 laminate: Curve of $F_u^{(\alpha)}$ in function of the angle α for each bolt diameter *d*.

As observed from the plots, for all the examined values of bolt diameter the bearing load failure notably decreases in the interval of the angle α between 0° and 10° (reduction of 16%).

In the interval 10°<α<90° the bearing failure load curve is characterised by a less accentuated inclination in relation to the initial part (0°<α<10°) and, as expected, it gives the lowest value in correspondence to angle α equal to 90° (sample P15 – Tab. 3).

For what concern the bolt diameter effect, fig. 7 shows that the bearing failure load decreases as the bolt diameter decreases.

Tables 3 and 4 summarize the obtained experimental results. In particular table 3 is relative to all ultimate bearing loads for all specimens tested, while table 4 concerns mean values and standard deviations of the aforementioned loads.

Table 3 – Values of the bearing failure load for all samples tested : type 1 laminate.

Bolt diameter d [mm]		20			19		18	
Sample	α±0.2	$F_{u,1}^{(\alpha)}$	$F_{u,2}^{(\alpha)}$	$F_{u,3}^{(\alpha)}$	$F_{u,1}^{(\alpha)}$	$F_{u,2}^{(\alpha)}$	$F_{u,1}^{(\alpha)}$	$F_{u,2}^{(\alpha)}$
	[°]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
0 (P0)	0	33.22	32.92	33.52	30.80	31.20	29.05	28.86
1 (P1)	1	32.60	32.44	32.94	30.25	30.15	28.25	28.65
2 (P2)	3	32.76	30.24	31.74	29.40	29.20	27.65	27.37
3 (P3)	5	31.13	30.07	30.12	28.00	28.20	26.50	26.81
4 (P4)	7	29.90	29.90	27.71	27.00	27.20	26.05	25.73
5 (P5)	10	28.22	29.13	25.90	26.55	26.05	24.75	25.05
6 (P6)	15	25.72	28.01	26.73	25.05	25.19	23.50	23.74
7 (P7)	20	25.92	27.52	25.22	23.85	24.15	22.90	22.57
8 (P8)	25	26.46	26.46	24.00	23.90	23.50	22.00	22.32
9 (P9)	30	25.20	26.42	25.33	23.20	23.58	22.00	21.60
10 (P10)	35	24.67	25.96	23.92	23.10	22.90	21.40	21.75
11 (P11)	40	24.01	25.40	24.51	23.00	22.60	21.55	21.27
12 (P12)	45	24.57	23.82	24.93	22.30	22.70	21.35	21.16
13 (P13)	60	23.62	23.63	23.55	22.00	22.40	20.50	20.73
14 (P14)	75	22.99	23.00	23.19	21.75	21.45	19.70	20.07
15 (P15)	90	22.68	22.42	22.76	21.50	21.10	19.80	19.52

Table 4 – Mean values of the bearing failure load for type 1 laminate.

Bolt diameter d [mm]		20		19		18	
Sample	α±0.2	$F^{(\alpha)}_{u,\,mean}$	St. Dev.	$F^{(\alpha)}_{u,\,mean}$	St. Dev.	$F^{(\alpha)}_{u,\,mean}$	St. Dev.
	[°]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
0 (P0)	0	33.28	0.0468	31.00	0.0186	29.28	0.0800
1 (P1)	1	32.58	0.0172	30.20	0.0791	28.50	0.0050
2 (P2)	3	31.38	0.0972	29.30	0.0405	27.38	0.0200
3 (P3)	5	30.03	0.0133	28.10	0.0486	26.50	0.0200
4 (P4)	7	29.17	0.0433	27.10	0.0505	25.40	0.0200
5 (P5)	10	28.15	0.0948	26.30	0.0441	24.45	0.1250
6 (P6)	15	27.01	0.0813	25.12	0.0286	23.55	0.0096
7 (P7)	20	26.22	0.0841	24.00	0.0529	22.90	0.0450
8 (P8)	25	25.64	0.0075	23.70	0.0521	22.30	0.0800
9 (P9)	30	25.15	0.0616	23.39	0.0791	21.85	0.0718
10 (P10)	35	24.82	0.0886	23.00	0.0604	21.50	0.0200
11 (P11)	40	24.62	0.0220	22.80	0.0394	21.30	0.0800
12 (P12)	45	24.43	0.0283	22.50	0.0177	21.00	0.0800
13 (P13)	60	23.60	0.0019	22.20	0.0268	20.50	0.0800
14 (P14)	75	23.03	0.0127	21.60	0.0697	20.00	0.0450
15 (P15)	90	22.60	0.0316	21.30	0.0381	19.60	0.0800

Moreover, in table 5 the values of the expressions $1-F_u^{(\alpha)}(19)/F_u^{(\alpha)}(20)$ and $1-F_u^{(\alpha)}(18)/F_u^{(\alpha)}(20)$ are reported and give the reduction, in terms of percentage, of the bearing failure load varying the bolt diameter d.

Table 5 –Reduction of the bearing failure load varying the bolt diameter d.

Sample	α±0.2	$1-F_u^{(\alpha)}(19)/F_u^{(\alpha)}(20)$	$1-F_u^{(\alpha)}(18)/F_u^{(\alpha)}(20)$
	[°]	[%]	[%]
0 (P0)	0	6.9	12.0
1 (P1)	1	7.3	12.5
2 (P2)	3	6.6	12.7
3 (P3)	5	6.4	11.8
4 (P4)	7	7.1	12.9
5 (P5)	10	6.6	13.1
6 (P6)	15	7.0	12.8
7 (P7)	20	8.5	12.7
8 (P8)	25	7.6	13.0
9 (P9)	30	7.0	13.1
10 (P10)	35	7.3	13.4
11 (P11)	40	7.4	13.5
12 (P12)	45	7.9	14.0
13 (P13)	60	5.9	13.1
14 (P14)	75	6.2	13.2
15 (P15)	90	5.8	13.3
mean value		**7.0**	**13.0**
standard deviation		**0.55**	**0.71**

Roughly, is possible to assume that the bearing failure load depends linearly on the diameter d. In fact, the average percentage reductions of the aforementioned load for the diameters 18 and 19mm, as reported in table 5, with respect to the value obtained for bolt diameter 20mm, are equal to 13% and 7% less, respectively.

Type 2 and 3 Laminates:

Figure 8 shows the curves of $F_u^{(\alpha)}$ varying the angle α and the bolt diameter (*d*) for type 2 and 3 laminates. It is worth noting that the curves have been obtained using the average values. In particular, for each value of angle α and bolt diameter two samples have been tested. It is possible to observe that the three curves present a symmetrical trend with respect to the minimum value obtained for α=45°.
As already obtained in [11], in terms of bearing failure load between the two cross-ply laminates there is a difference less than 5%. Then, it can be assumed that bearing capacity is not affected by the stacking sequence and therefore, for the sake of brevity, the complete set of the experimental values for type 3 laminates is not reported here. Confirming the trade shown for type 1 laminate, bearing failure load notably decreases (14%) in the interval of the angle α between 0° and 15°.
In the interval (15°<α<45°) the reduction attains the value of 20% less. For a detailed discussion about the influence of angle α see [11].
Tables 6-8 summarize the results of the experimental investigation for type 2 (and 3) laminates.

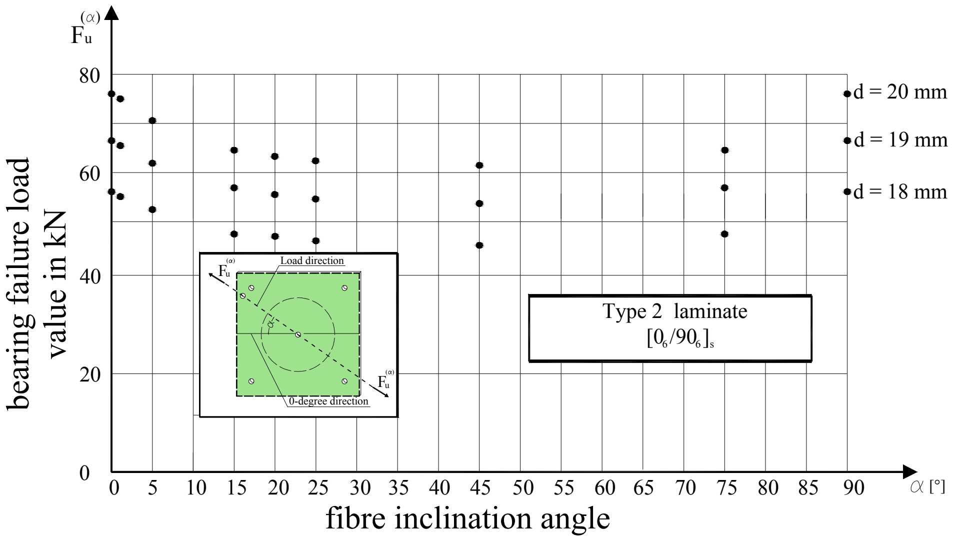

Fig. 8. Type 2 (and 3) laminates: Curve of $F_u^{(\alpha)}$ in function of the angle α and bolt diameter d.

Table 6 – Values of the bearing failure load for all samples tested: type 2 and 3 laminates.

Bolt diameter d [mm]		20		19		18	
Sample	α±0.2	$F_{u,1}^{(\alpha)}$	$F_{u,2}^{(\alpha)}$	$F_{u,1}^{(\alpha)}$	$F_{u,2}^{(\alpha)}$	$F_{u,1}^{(\alpha)}$	$F_{u,2}^{(\alpha)}$
	[°]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
0 (P0)	0	76.10	75.78	66.15	65.85	57.10	56.90
1 (P1)	1	74.20	74.60	64.80	65.20	55.90	56.10
2 (P2)	5	70.10	69.90	61.05	60.95	53.15	52.85
3 (P3)	15	64.91	65.09	56.90	56.10	49.50	48.70
4 (P4)	20	63.32	62.68	54.80	55.20	47.80	48.20
5 (P5)	25	61.85	62.15	54.10	53.90	46.95	47.05
6 (P6)	45	60.87	61.13	53.15	52.85	45.55	45.45
7 (P7)	75	65.21	64.79	57.00	57.04	49.30	48.70
8 (P8)	90	76.00	75.88	65.90	66.10	57.20	56.80

Table 7 – Mean values of the bearing failure load for type 2 and 3 laminates.

Bolt diameter d [mm]		20		19		18	
Sample	α±0.2	$F_{u,\,mean}^{(\alpha)}$	St. Dev.	$F_{u,\,mean}^{(\alpha)}$	St. Dev.	$F_{u,\,mean}^{(\alpha)}$	St. Dev.
	[°]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
0 (P0)	0	75.94	0.0630	66.00	0.0450	57.00	0.0200
1 (P1)	1	74.40	0.2310	65.00	0.0800	56.00	0.0200
2 (P2)	5	70.00	0.0280	61.00	0.0050	53.00	0.0450
3 (P3)	15	65.00	0.0160	56.50	0.0200	49.10	0.0020
4 (P4)	20	63.00	0.0160	55.00	0.0800	48.00	0.0800
5 (P5)	25	62.00	0.0240	54.00	0.0200	47.00	0.0050
6 (P6)	45	61.00	0.0600	53.00	0.0450	45.50	0.0050
7 (P7)	75	65.00	0.0880	56.60	0.0200	49.00	0.0100
8 (P8)	90	75.94	0.0078	66.00	0.0200	57.00	0.0800

Table 8 –Reduction of the bearing failure load varying the diameter d.

Sample	α±0.2	$1-F_u^{(\alpha)}(19)/F_u^{(\alpha)}(20)$	$1-F_u^{(\alpha)}(18)/F_u^{(\alpha)}(20)$
	[°]	[%]	[%]
0 (P0)	0	13.1	24.9
1 (P1)	1	12.6	24.7
2 (P2)	5	12.9	24.3
3 (P3)	15	12.3	23.7
4 (P4)	20	12.7	23.8
5 (P5)	25	12.9	24.2
6 (P6)	45	13.1	25.4
7 (P7)	75	12.3	23.7
8 (P8)	90	13.1	24.9
mean value		**12.8**	**24.4**
standard deviation		**0.31**	**0.62**

It is confirmed that bearing failure load depends linearly on the bolt diameter d. In particular, when d assumes the value 19mm the average reduction of bearing failure load is about 13% while for d=18mm such reduction attains the value 25%.

BEARING FAILURE LOAD: DESIGN FORMULA

Starting from the results of the present experimental investigations, a new design formula for the evaluation of the bearing ultimate load of symmetrical GFRP laminates is presented, generalizing the previous one reported in [11].

It takes into account the following main features:

1) the stacking sequence has a negligible influence on the bearing failure load for symmetrical GFRP laminates;
2) the $F_u^{(\alpha)}$-α curves obtained for different values of the diameter d are nearly affine, that is their ratio is independent on α;
3) the maximum value of the $F_u^{(\alpha)}$-α curve is a nearly linear function of d;
4) for bidirectional laminates, the maximum value of each $F_u^{(\alpha)}$-α curve is proportional to the fibre volume fraction in the 0° direction.

As a result, the bearing failure load $F_u^{(\alpha)}$ can be expressed as follows:

$$F_u^{\alpha} = \xi \cdot F_u^{0}\left[\left(1-\frac{F_u^{(\pi/2m)}}{F_u^{0}}\right)\cdot\left(A_\alpha\right)^5+\frac{F_u^{(\pi/2m)}}{F_u^{0}}+C\cdot\left(m\,\alpha\right)^3\cdot\left(A_\alpha\right)^3\right] \quad (\alpha \text{ in rad}). \qquad (1)$$

In eqn. (1), parameters have the following meaning:

$$A_\alpha = \frac{\pi/2 - (m\,\alpha)}{\pi/2}, \quad (2)$$

$$C = \left(\frac{\pi}{8}\right)^{-3}\left[\frac{F_u^{(\pi/4m)}}{F_u^0} - \left(1 - \frac{F_u^{(\pi/2m)}}{F_u^0}\right)\left(\frac{1}{2}\right)^5 - \frac{F_u^{(\pi/2m)}}{F_u^0}\right], \quad (3)$$

$$\xi = 1 + 1.3\left(\frac{n_{tot.plies}}{n_{plies}^{0^\circ}}\right)\left(\frac{d_b - (d_h - 1)}{(d_h - 1)}\right) \; (d_b,\, d_h \text{ in mm}), \quad (4)$$

$n_{tot.plies}$ = total number of plies, (5)

n^0_{plies} = number of plies in 0-degree direction, (6)

F^0_u = experimental bearing failure load for α equal to 0°, (7)

$F_u^{\pi/2m}$ = experimental bearing failure load for α equal to $\pi/2m$, (8)

$F_u^{\pi/4m}$ = experimental bearing failure load for α equal to $\pi/4m$. (9)

The above mentioned formula needs three experimental determination of the bearing failure load in correspondence of three values of α: 0, $\pi/2m$ and $\pi/4m$. The coefficient m, called "*replicability module*", assumes the value 1 for unidirectional plates (type 1 laminate) and value 2 for bi-directional (cross-ply) plates (type 2 and 3 laminates). It can be interpreted as the number of equal rotations of the laminate around its orthogonal axis in order to return to the original configurations (the influence of the stacking sequence is neglected). The "*reduction factor*" ξ is a function of the hole diameter (d_h), bolt diameter (d_b) and volume fractions of plies parallel to 0° direction.

In tables 9 and 10 comparisons are presented, in terms of bearing failure load, between the experimental values and those obtained by using the eqn. (1). As it is possible to see, the difference are no more than 3% for both type of laminates tested (type 1 laminate and type 2 laminate).

Table 9 – Differences between experimental and analytical mean values: type 1 laminate.

Bolt diameter d [mm]		20			19			18		
Sample	α±0.2	$F^{(\alpha)}_{u,exp.}$	$F^{(\alpha)}_{u,anal.}$	Diff.	$F^{(\alpha)}_{u,exp.}$	$F^{(\alpha)}_{u,anal.}$	Diff.	$F^{(\alpha)}_{u,exp.}$	$F^{(\alpha)}_{u,anal.}$	Diff.
	[°]	[kN]	[kN]	[%]	[kN]	[kN]	[%]	[kN]	[kN]	[%]
0 (P0)	0	33.28	33.28	0.0	31.00	31.12	0.4	29.28	28.95	1.1
1 (P1)	1	32.58	32.70	0.4	30.20	30.57	1.2	28.50	28.45	0.2
2 (P2)	3	31.38	31.62	0.8	29.30	29.56	0.9	27.38	27.51	0.5
3 (P3)	5	30.03	30.64	2.0	28.10	28.65	1.9	26.50	26.66	0.6
4 (P4)	7	29.17	29.76	2.0	27.10	27.83	2.7	25.40	25.89	1.9
5 (P5)	10	28.15	28.62	1.6	26.30	26.76	1.7	24.45	24.90	1.8
6 (P6)	15	27.01	27.15	0.5	25.12	25.38	1.1	23.55	23.62	0.3
7 (P7)	20	26.22	26.13	0.3	24.00	24.44	1.8	22.90	22.74	0.7
8 (P8)	25	25.64	25.47	0.7	23.70	23.82	0.5	22.30	22.16	0.6
9 (P9)	30	25.15	25.06	0.4	23.39	23.43	0.2	21.85	21.80	0.2
10 (P10)	35	24.82	24.79	0.1	23.00	23.19	0.8	21.50	21.57	0.3
11 (P11)	40	24.62	24.61	0.0	22.80	23.01	0.9	21.30	21.41	0.5
12 (P12)	45	24.43	24.43	0.0	22.50	22.84	1.5	21.00	21.26	1.2
13 (P13)	60	23.60	23.69	0.4	22.20	22.16	0.2	20.50	20.62	0.6
14 (P14)	75	23.03	22.86	0.8	21.60	21.37	1.1	20.00	19.89	0.6
15 (P15)	90	22.60	22.60	0.0	21.30	21.13	0.8	19.60	19.66	0.3

Table 10 – Differences between experimental and analytical mean values: type 2 (and 3) laminates.

Bolt diameter d [mm]		20			19			18		
Sample	α±0.2	$F^{(\alpha)}_{u,exp.}$	$F^{(\alpha)}_{u,anal.}$	Diff.	$F^{(\alpha)}_{u,exp.}$	$F^{(\alpha)}_{u,anal.}$	Diff.	$F^{(\alpha)}_{u,exp.}$	$F^{(\alpha)}_{u,anal.}$	Diff.
	[°]	[kN]	[kN]	[%]	[kN]	[kN]	[%]	[kN]	[kN]	[%]
0 (P0)	0	75.94	75.94	0.0	66.00	66.07	0.1	57.00	56.20	1.4
1 (P1)	1	74.40	74.35	0.1	65.00	64.69	0.5	56.00	55.00	1.8
2 (P2)	5	70.00	69.29	1.0	61.00	60.28	1.2	53.00	51.30	3.4
3 (P3)	20	63.00	61.73	2.0	55.00	53.71	2.4	48.00	45.70	5.1
4 (P4)	25	62.00	61.20	1.3	54.00	53.25	1.4	47.00	45.30	3.8
5 (P5)	45	61.00	61.00	0.0	53.00	53.07	0.1	45.50	45.10	0.8
6 (P6)	90	75.94	75.94	0.0	66.00	66.06	0.0	57.00	56.20	1.5

CONCLUSIONS

The effects of bolt diameter on the bearing failure load of composite bolted joints have been investigated in this experimental study. Three different types of laminates have been tested: one of them is mono-directional while the other two are bi-directional. The results presented have shown a linear reduction of the above failure load varying the bolt diameter for the three types of symmetrical laminates. Finally the authors have proposed a design formulas for the prediction of the bearing failure load in function of fibre inclination angle and bolt diameter.

Further developments of this study will include:

- the study of the influence on the bearing load failure of the surface of the rigid washers placed under the bolt-head on both one-layered and multi-layered FRP elements;
- the analysis of different types of bolted joints characterised by the presence of more rows of bolts in order to evaluate the shear attribution coefficients of each row.

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