EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 9, NO. 3, JULY 2012, pp. 13 - 23 **ISSN 2090 - 5882**

ON THE STRENGTH AND FAILURE MODE OF CRACKED BOLTED JOINT OF POLYMERIC COMPOSITE

Aboelenen M. S.[1], Ghanem M. A.[2], El-batanony I. G.[3], Moshref S. B.[4]

[1]Ministry of military production E-mail (mohmed.aboelenen@yahoo.com)
[2]Mech, Dept, Faculty of Industrial Education, Suez Canal University
E-mail (ghanim64@yahoo.com).
[3]Mech. Eng, Dept, Faculty of engineering, Al-Azhar University.
E-mail (ibatanony@yahoo.com)
[4]Professor, Mech. Eng, Dept, Faculty of engineering, Al-Azhar University.
E-mail (sherifbahi43@yahoo.com)

ABSTRACT
This paper investigates the effect of crack angle and crack length on the mechanical behavior and mode of failure of bolted composites joints $[0/90]_{4S}$. The experimental program consists of twenty one groups with constant W/D, E/D, different angles of crack (0°, 15°, 30°, and 45°) and length of crack (2, 3, 4, 5, and 6 mm).

The experimental results showed that, for uncracked bolted joint (Group 1) the mode is a combination between bearings and shearing out failures. Although the presence of crack (crack length up to 5 mm) did not change the mode of failure, it decreased the ultimate load and the stiffness of the joint. This may be attributed to the reduction in the net section area resisting the load of the pin. In the case of crack length of 6 mm, the mode changed to a combination between bearing and tensile failures.

KEYWORDS
Polymeric composite, bolted joints, bearing failures, crack, fasteners.

INTRODUCTION
Joining by mechanical fasteners is a common practice in the assembly of structural components. Since the failure of the joints can lead to the catastrophic failure of the structures, an accurate design methodology is essential for the optimal design of the joints. As a result of the complicated stress field near the hole area and the complex failure modes of composite materials, the mechanical joining of structures made of composite materials demands much more rigorous design knowledge and techniques than those currently available to the traditional metallic joints, [l]. The susceptibility of composite materials to effects of stress concentration such as those caused by notches, holes, cracks, etc., is much less than for metals. Failure in long fiber-reinforced laminate composite structure containing stress concentration areas, such as a circular holes or bolt-loaded holes, has been one of the technological issues by many researchers during the last decades [2-5]. The mechanism of such failures is significantly affected by fiber orientation, relative strength of the matrix and fibers, and the bond strength between them.

Open holes, notches, scratches, inclusions, and so on, all produce concentration of strain and stress. The principle failure modes of bolted joints are: (a) bearing failure of the material, (b) net-tension failure of the material in the reduced cross-section through the bolt-hole, (c) wedge type splitting, (d) shear-out failure of the materials, and (e) bolt failure. Combination of these failure modes do occur [6 - 7]. Some numerical researches studied the analysis of the stress field in a fiber reinforced composite with a transverse crack. [8, 9]. Results show the effects of crack lengths, fiber volume fractions, and ratios of fiber to matrix Young's module and matrix Poisson's ratio on the resulting elastic field at various locations of interest. Comparisons with the predictions obtained from the shear lag theory are presented.

The main objective of the present work is to study the effect of crack angle and crack length on the mechanical behavior and mode of failure of bolted GFRE (Glass Fiber Reinforced Epoxy) composites joints $[0/90]_{4S}$ with constant W/D and, E/D,

EXPERIMENTAL WORK

The angle-ply $[0/90]_{4s}$ GFRE composite laminate with 4 mm thickness were fabricated using hand lay-up technique. The types of matrix are PY1092, HY5160 and the types of reinforcement materials are E-Roving glass fiber. Fiber volume fraction was determined experimentally by physical removing the matrix using the burning technique according to ASTM D 3171-99. The average value of V_f was 39 %.

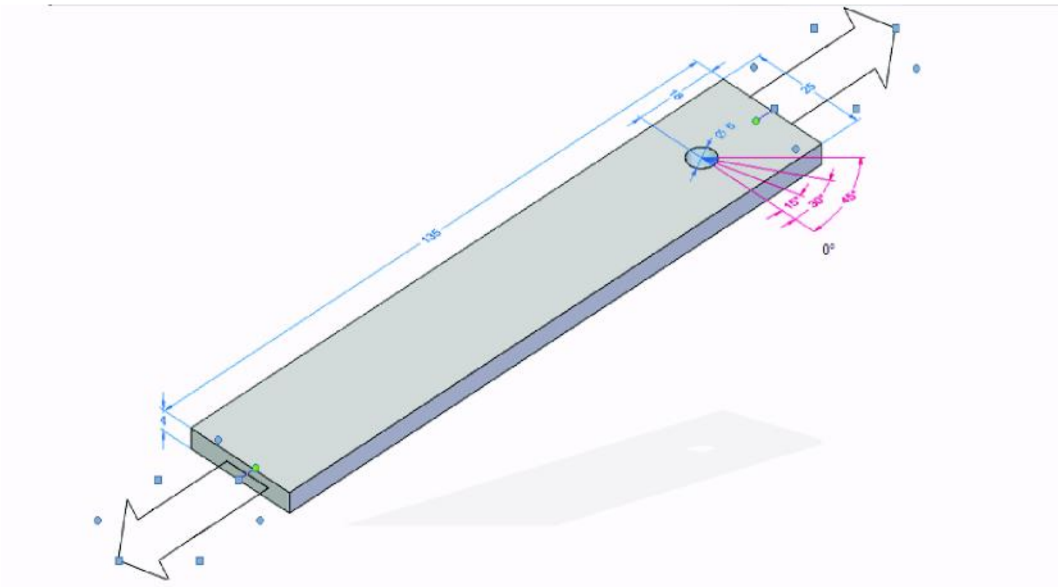


Fig.1. A schematic drawing of bolted joint specimens

The mechanical properties, i.e. tensile, compressive, in-plan shear and flexural, of angle ply $[0/90]_{4S}$ GFRE composite are determined experimentally according to ASTM D3039/D3039M-00, the compression test was carried out according to Boeing modified ASTM D695, the in-plane shear test was carried out according to ASTM D5379. Bolted and crack tests of angle ply $[0/90]_{4S}$ GFRE composite were carried out according to ASTM D5961.

Table. 1: The geometry of bolted test specimens

Group No.	Dimension, mm				Width Distance W/D	Edge Distance E/D	Crack Angle	Crack length, mm
1	135		18.6	6.2	4	3	Without	Without
2	135		18.6	6.2	4	3	0°	2
3	135		18.6	6.2	4	3	0°	3
4	135		18.6	6.2	4	3	0°	4
5	135		18.6	6.2	4	3	0°	5
6	135		18.6	6.2	4	3	0°	6
7	135		18.6	6.2	4	3	15°	2
8	135		18.6	6.2	4	3	15°	3
9	135		18.6	6.2	4	3	15°	4
10	135		18.6	6.2	4	3	15°	5
11	135		18.6	6.2	4	3	15°	6
12	135		18.6	6.2	4	3	30°	2
13	135		18.6	6.2	4	3	30°	3
14	135		18.6	6.2	4	3	30°	4
15	135		18.6	6.2	4	3	30°	5
16	135		18.6	6.2	4	3	30°	6
17	135		18.6	6.2	4	3	45°	2
18	135		18.6	6.2	4	3	45°	3
19	135		18.6	6.2	4	3	45°	4
20	135		18.6	6.2	4	3	45°	5
21	135		18.6	6.2	4	3	45°	6

The dimensions of specimens were 135 mm long, 4 mm thickness, 24 mm width, with various crack angles (0°, 15°, 30°' and 45°), and various crack lengths (2, 3, 4, 5, and 6 mm). The diameter of bolted hole was 6.2 mm. The hole-bolt clearance was 0.1 mm, as being typical of air craft joints, [10]. The geometry of specimens is summarized in Table 1 and schematic drawing of the specimen is shown in Fig. l. The machine crosshead speed was 2 mm/min. Five specimens were tested for each test condition and the average values were used for plotting the different relationships.

RESULTS AND DISCUSION

Effect of crack angle 0° on the strength and failure mode of bolted joints

Load versus pin-displacement curves for groups 1 to 6 [without crack, crack angle 0° and crack length (2, 3, 4, 5, and 6 mm) are illustrated in Figs. 2 and 3. In group one the relationship between the applied load and pin displacement can be divided into four stages. In the first stage of this curve (before damage), the relation between the applied load and pin-displacement is approximately linear up to applied load of 4.3 kN and the pin-displacement is 7 mm. The stiffness, *PI S*, of the joint in this group is 0.61 kN/mm.

In the second stage of the curve (unstable stage) the load decreased to 3.5 kN and pin-displacement to 13 mm. In the third stage of the curve, the curve became stable again and the load increased with increasing pin-displacement up to 3.6 kN at pin-displacement of 22 mm. In the fourth stage of the curve, the strength of the joint decreased with increasing pin-displacement. The mode of failure is a combination between bearings and shearing out. In groups 2 to 5, load versus pin-displacement curves and failure mode are similar to that of group 1

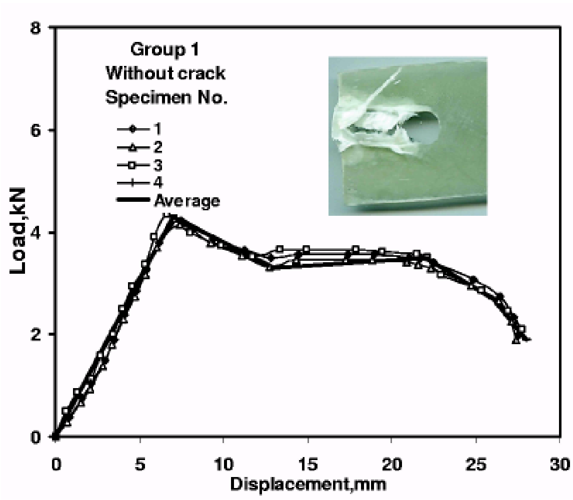
except that the strength and the stiffness is lower than group 1. In the case of group 6 [crack length of 6 mm] the mode of failure changed to a combination between bearing and tensile failures.

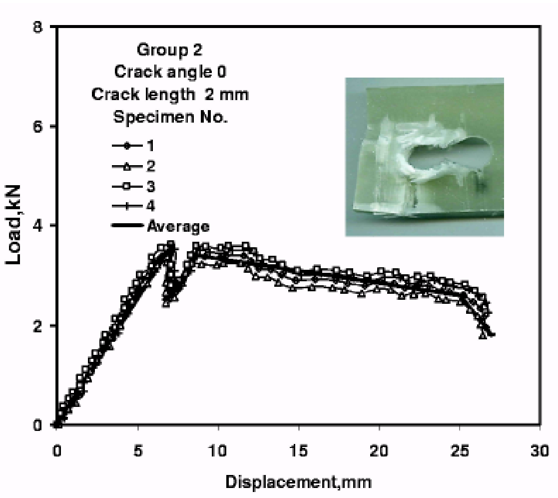
Effect of crack angle 15° on the strength and failure mode of bolted joints

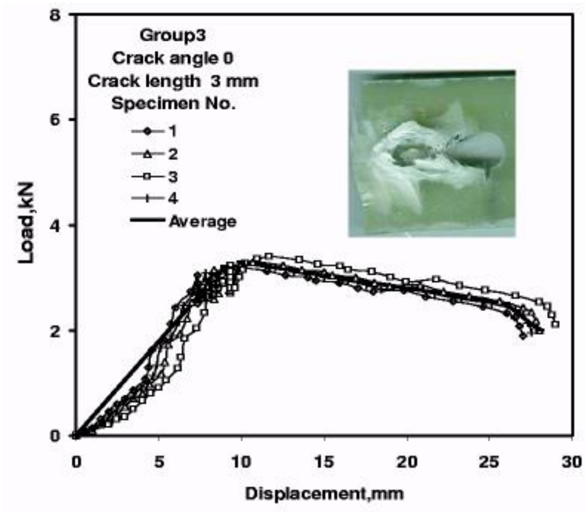
In groups 7 to 11, crack angle 15° and crack length [2, 3, 4, 5, and 6 mm] are illustrated in Fig.4 and 5. Load versus pin-displacement curves of groups 7 to 10 and failure mode are similar to that of group 5 except for the strength and the stiffness which are lower than group 6. The mode of failure is a combination between bearings and shearing out. In the case of group 11 [crack length of 6 mm] the mode changed to a combination between bearing and tensile failures.

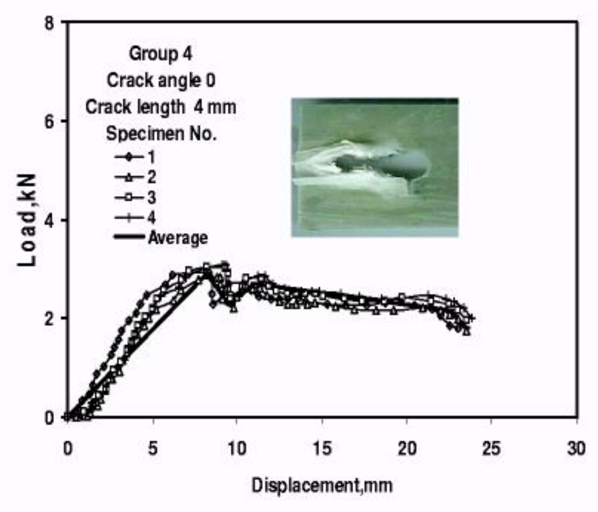
Effect of crack angle 30° on the strength and failure mode of bolted joints

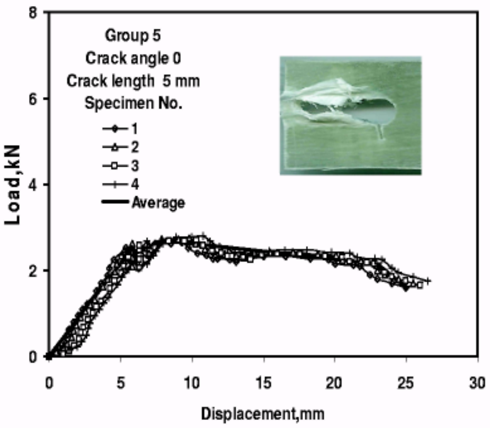
In groups 12 to 16, crack angle 30° and crack length [2, 3, 4, 5, and 6 mm] are illustrated in Fig. 6 and 7. Load versus pin-displacement curves of groups 12 to 15 and failure mode are similar to that of group 10 except for the strength and the stiffness which are lower than that of group 10. The mode of failure is a combination between bearings and shearing out. In the case of group 16 [crack length 6 mm] the mode changed to a combination between bearing and net tensile failures.











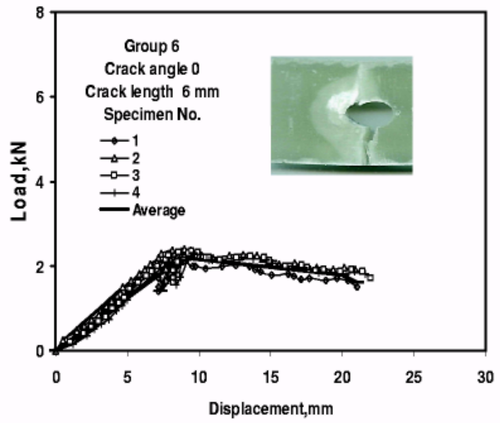
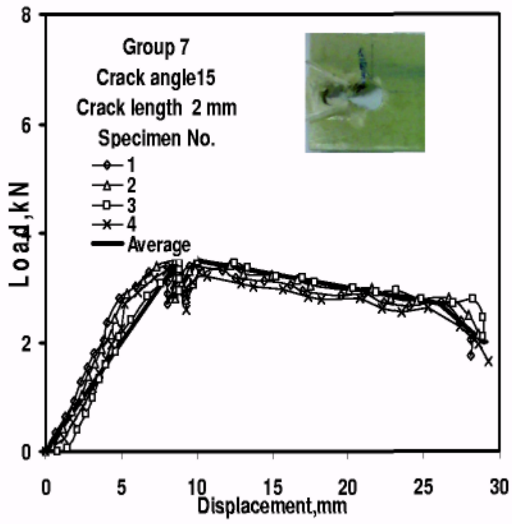
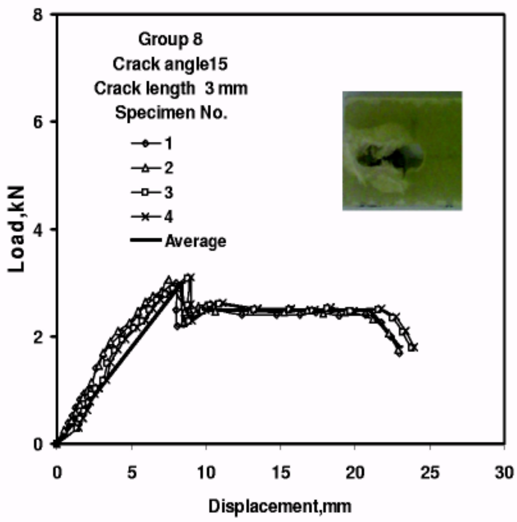
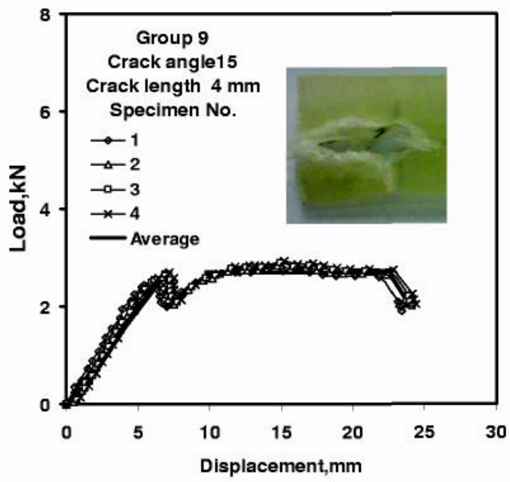
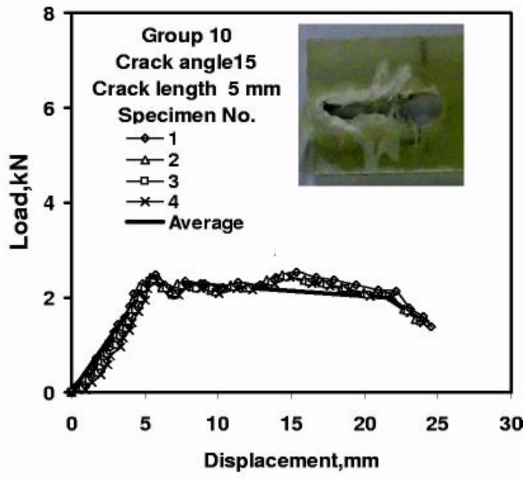


Fig.2 Load versus pin-displacement curves and failure modes of group 1 to 6.









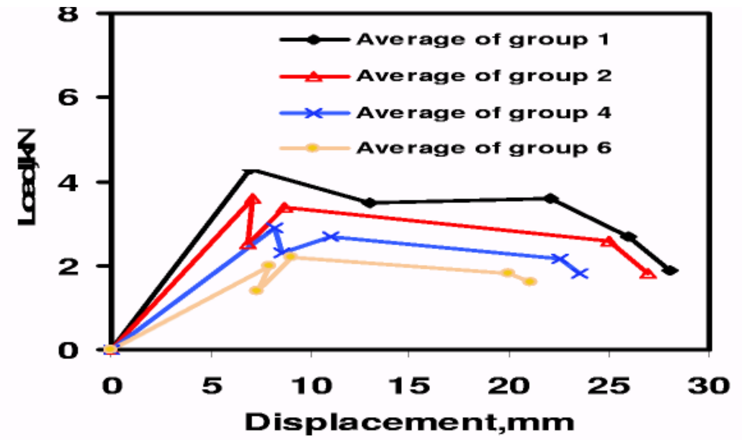


Fig.3 Comparison between loads vs. pin-displacement curves of groups 1 to 6.

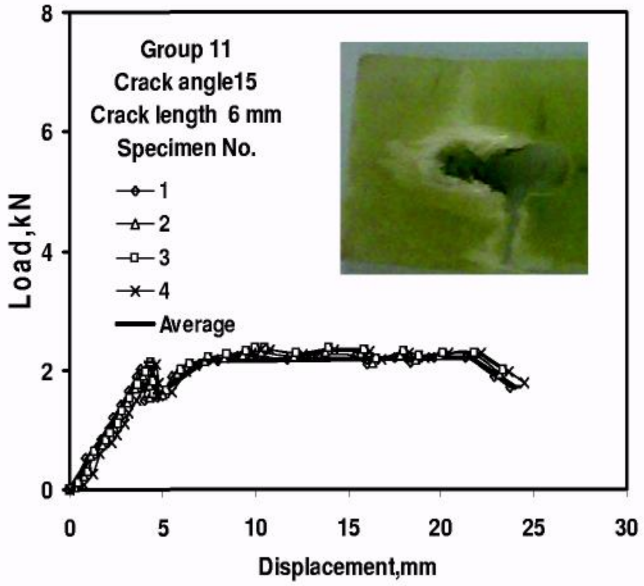


Fig.4 Load versus pin-displacement curves and failure modes of group 7 to 11

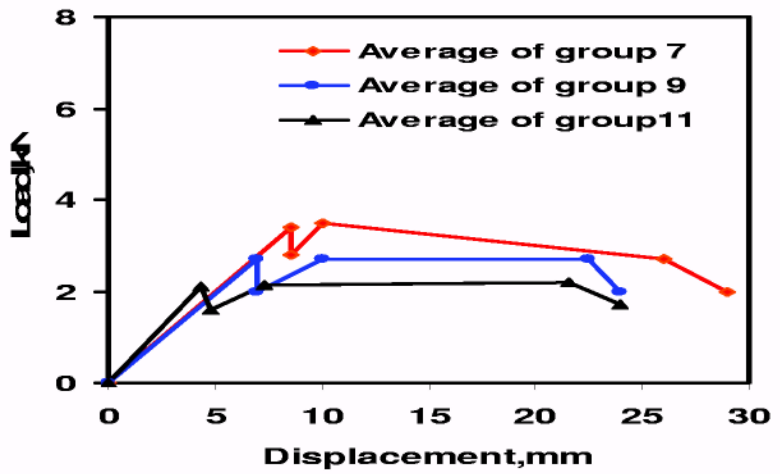
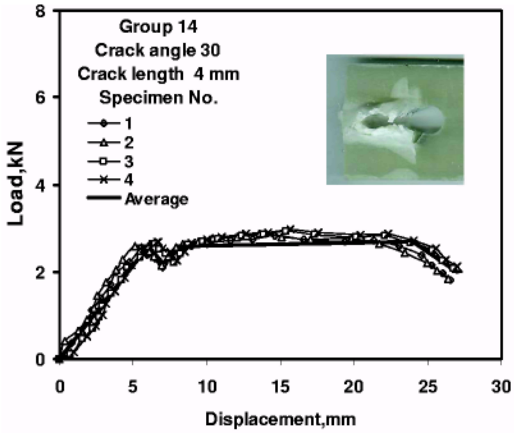
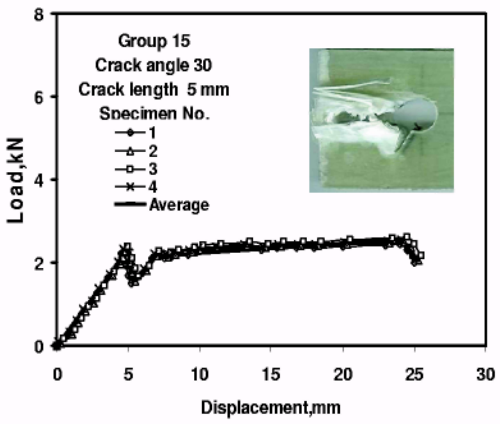


Fig.5 Comparison between loads vs. pin-displacement curves of groups 7 to 11.





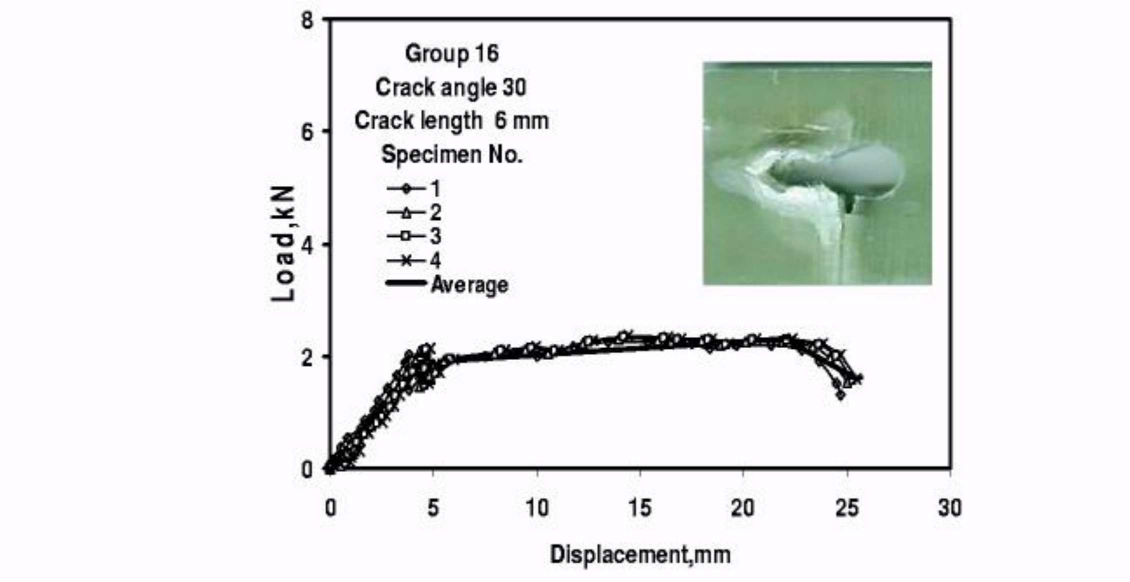
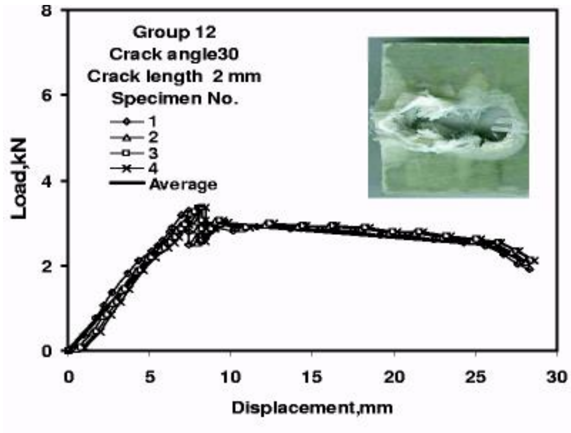
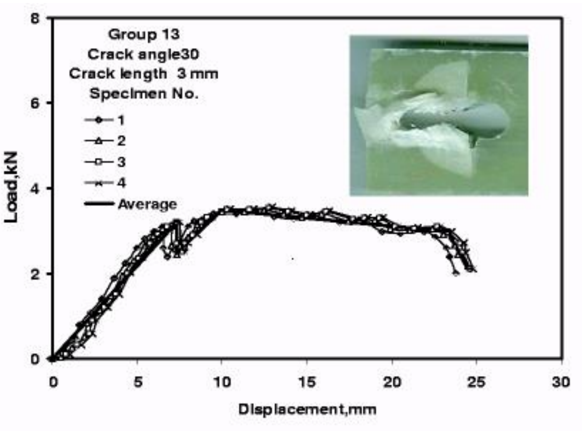


Fig. 6 Load versus pin- displacement curves and failure modes of group 12.





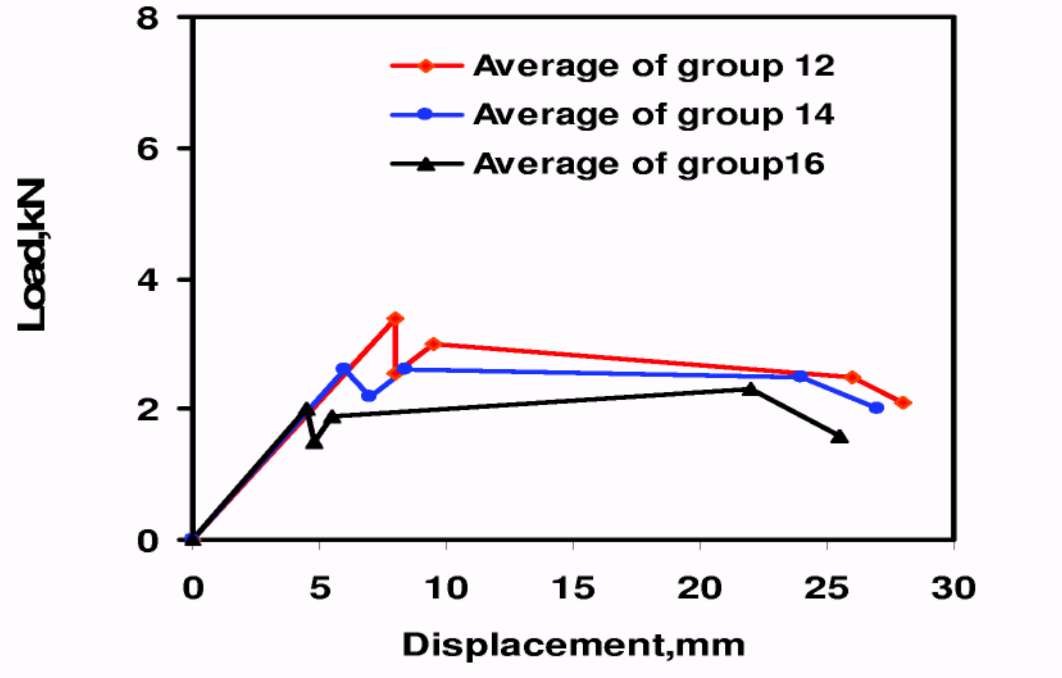
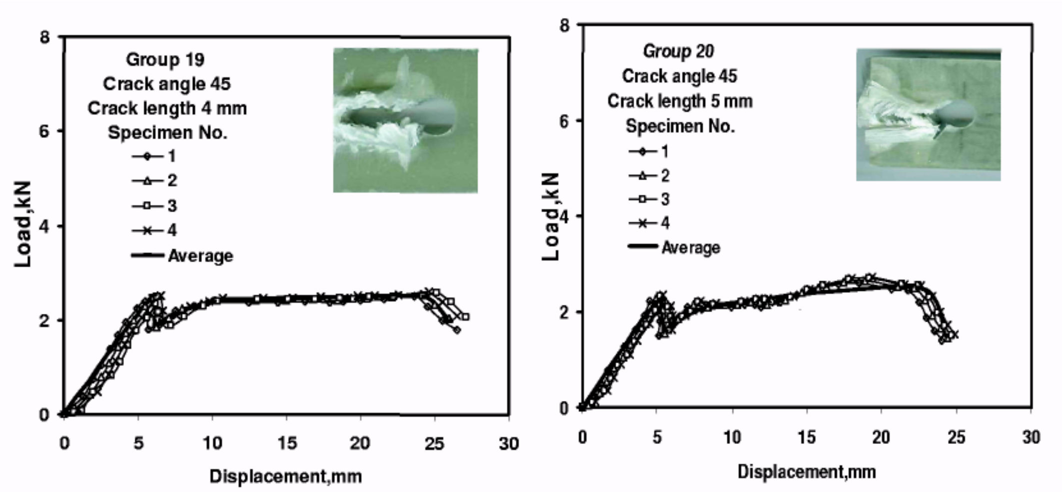


Fig.7 Comparison between loads vs. pin-displacement curves of groups 12, 14 and 16.

Effect of crack angle 45° on the strength and failure mode of bolted joints

In groups 17 to 21, crack angle 45° and crack length [2, 3, 4, 5, and 6 mm] are illustrated in Fig. 8 and 9. Load versus pin-displacement curves of groups 17 to 20 and failure mode are similar to that of group 15 except for the strength and the stiffness which are lower than groups 15. The mode of failure is a combination between bearings and shearing out. In the case of group 21 [crack length of 6 mm] the mode changed to a combination between bearing and tensile failures.



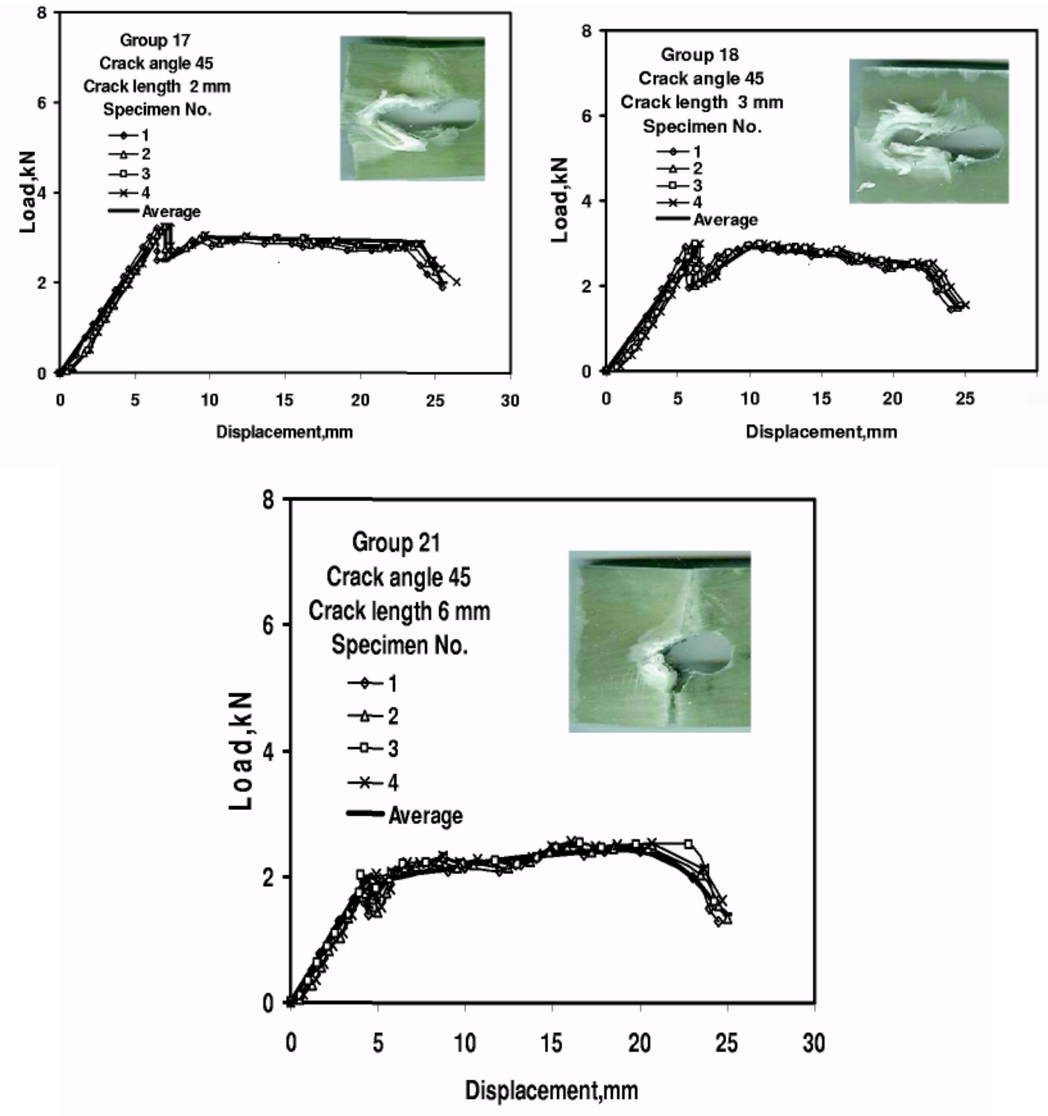


Fig.8 Load versus pin-displacement curves and failure modes of group 17 to21

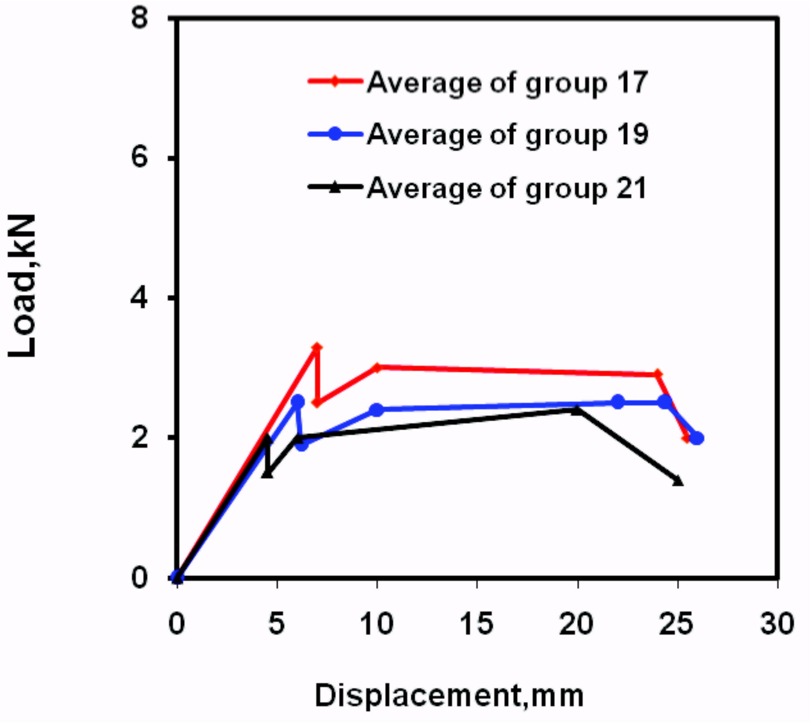


Fig.9 Comparison between loads vs. pin-displacement curves of groups 17 to 21.

CONCLUSIONS

The results of the present study support the following conclusions:

1. For uncracked bolted joint the mode of failure is a combination between bearings and shearing out.

2. The presence of crack (up to crack length of 5 mm) did not change the mode of failure. It decreased the ultimate load and the stiffness of the joint.

3. For crack length of 6 mm, the mode changed to combination of bearing and tensile failures.

REFERENCES

1. Icten B.M. and Sayman O., "Failure analysis of pin-loaded aluminum-glass-epoxy sandwich composite plates", Composite Science and Technology, Vol. 63, pp. 727 - 37, (2003).

2. Sallam H. E. M., Nayeb-Hashemi H., "Effect of specimen geometry on fatigue crack growth behavior of metal matrix composite", Recent Advanced in Solid/Structures and Application of Metallic Materials, PVP, Vol. 342/MD, Vol. 72, pp. 17 - 26, ASME, (1996).

3. Pinckney R. L., "Helicopter rotor blades", ASTM STP, pp. 108 - 133, (1973).

4. Hassan N. K., Mohamedien, M., and Rizkalla, S. H., "Rational model for multi bolted connections for GFRP members", Journal of Composite, Construct ASCE, Vol. 1, No. 2, pp. 71 - 78, (1997).

5. Tsangapakis N., Slepetz J. M., and Nunes J., "Static and fatigue notch strength in alumina fiber reinforced aluminum plates with a circular hole", Journal of Composite Materials., Vol. 22, pp. 396 - 393, (1988).

6. Camanho, P. P. and Matthews F. L., "Stress analysis and strength prediction of mechanically fastened joints in FRP: Review", Composites Part A, Vol. 28, pp. 529 - 547, (1997).

7. Icten B. M. and Karakuzu R., "Progressive failure analysis of pin-loaded carbon-epoxy woven composite plate", Composite Science and Technology, Vol. 62, pp. 1259 - 1271, (2002).

8. Bernasconia A., Carbonia M. and Comollia. L.," Monitoring of fatigue crack growth in composite adhesively bonded joints using Fiber Bragg Gratings", Procedia Engineering.

Vol. 10, pp. 207 - 212, (2011).
9. Bojing Z. and Taiyan Q., "Application of hypersingular integral equation method to three-dimensional crack in electromagnetothermoelastic multiphase composites" International Journal of Solids and Structures.Vol. 44, pp. 5994 - 6000, (2007).
10. Herrington P. D. and Sabbaghian, M., "Effect of radial clearance between bolt and washer on the bearing strength of composite bolted joints", J. Composite Materials, Vol. 2, pp. 1826 - 1843, (1992).