

Effect of Hygrothermal Aging and Circular Notch on Tensile Strenght of Woven Composite Materials Repaired by a Bonded Composite Patch

Djilali Beida Maamar¹, R. Zenasni^{1,*}, Jaime Vina Olay², Antonio Arguelles Amado³

¹University of Mostaganem, Department of Mechanics, Mostaganem, Algeria

²University of Oviedo, Department of Material Sciences, Gijon, Spain

³University of Oviedo, Department of Construction, Gijon, Spain

Abstract The process of repair of structures by using the bonding of composites is an effective and economic method to increase the durability of the damaged components. This article addresses the experimental characterization of the effect of bonded composite patch on the tensile strength behavior of two woven glass fiber and carbon composite materials. After cutting the tensile specimens with a numerical controlled machine, two series of samples were mechanized with different types of notches. Of each composite material, two series of specimens were drilled with a different central hole of diameter 2, 4, 6 mm. The second series were exposed to hygrothermal aging during 180 days. The hygrothermal conditions were of temperature 70°C and relative humidity of 95%. Of each composite material, one group was repaired with a composite patch which the material was the same of the specimen material. The tensile test was performed to all the specimens. The displacement and the maximum load were tailored. The tensile load of glass fiber composite decrease quickly than carbon fiber. The double patch had more efficiency than a single patch. The SEM reveals a fracture of fiber bundles and a rich-resin zones.

Keywords 8H satin woven fabric, Glass fiber, Carbon fiber, Bonded Patch repair, Tensile strength, Circular notch, SEM

1. Introduction

Recently, the use of the adhesives is accepted in a process of repair of the structures in order to increase the lifespan of the damaged components. The metal or composite parts are bonded to one side or the two sides of the cracked part in order to extend its lifespan of service [1-6]. The repair of the cracks by bonding of composite material patch has proved its efficiency to reduce the stress intensity in a crack tips, in other words to reduce the propagation velocity of the cracks. This method is employed to repair the damaged plane components. Considerable research was carried out to develop the technology of bonding the patches in composites in the aeronautical structures.

Alan Baker had conducted many research [7-9] based on simple analyses, or experimental testing. The development of the super computers had conducted the use of the finite element method to model the effectiveness of repair. The bonded patches offer several advantages among which, the improvement of the fatigue life of the material, the reduction

of corrosion and the easy suitable to the complex aerodynamic shape. The finite element method gives with a higher degree of accuracy the stress intensity factor at the crack tip. The authors have used the method of calculation of the factor in the case of stiffened cracks, Bachir B. et al. [10]. Heung Soo K. et al [11] investigated the three dimensional stress analysis of a composite patch using stress functions. The analysis shown, that the interlaminar stresses reach the maximum at the free edge and decrease at the inner part of the patch. The proposed method accurately predicts the tridimensional stresses in a composite patch bonded on the metal, it can be used for designing structural components. Adhesively bonded joints have found important application areas in the marine and offshore industry during the last years. One particular application is the use of bonded patches to repair steel structures such as floating production storage and offloading units. Harald O. et al [12] used the finite element analysis for the adhesive bondline. It is a powerful tool in strength predictions of adhesively bonded joints. S.P et al [13], have studied the micromechanical behavior by finite element of the 2/2 twill weave T300 carbon/epoxy woven fabric composite laminates. Circular holes of different sizes were drilled in a composite. Based on the uniaxial, shear and Von Mises stress distributions in the yarn and matrix, the influence of hole-size on the stress

* Corresponding author:

zramdane@netcourrier.com (R. Zenasni)

Published online at <http://journal.sapub.org/cmaterials>

Copyright © 2015 Scientific & Academic Publishing. All Rights Reserved

distributions and stress concentration is discussed.

The investigation conducted by Khashaba U.A. *et al* [14], was to study the bending behavior of notched and unnotched diameter angle-ply, $[0/\pm 30/\pm 60/90]_s$, glass fiber reinforced epoxy (GFRE). The material was tested at static and fatigue loads. For this purpose different circular notch sizes (2, 4.5, 7, 9 mm) were drilled at the specimen center. The results show that the ultimate bending strength of notched GFRE specimens decreased linearly with increasing. Other experimental investigations were realized by Lee W. K. *et al* [15]. A 2D triaxial braided composites notched coupon was evaluated to tensile. The observations concluded that the shear failure edge initiated has been observed in transverse tension tests. The aim of this investigation was the analysis of the effect of the hygrothermal aging on the ultimate tensile load of two woven composite materials repaired by adhesively bonded composite patch.

2. Experimental Procedure

2.1. Materials

Two woven fabric composite materials manufactured by TEN Cate advanced Composite were investigated. They were manufactured two series of panels of 350 by 350 mm, with a nominal thickness of 3.5 mm. The commercial denominations for the materials were SS303 and CD342. The first series of panels were made of 8H satin Glass fiber, while the second were made of 8H Satin carbon fiber, see figure. The matrix was a Polyetherimide a thermoplastic with high mechanical prestations. The laminated was manufactured of 32 layers. The weight fraction fiber was 58% for SS303 and 33% for C342.

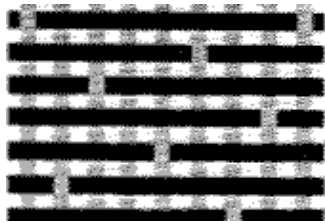


Figure 1. Woven fabric composite 8H satin

2.2. Preparation of Specimens

The moulding conditions were at a temperature of 315°C and a pressure of 2 Bar for 20 min, and finally 10 min to 20 Bar at 140°C. The specimens were cut according to ASTM D3039 [16]. The Aluminium tabs were bonded to both sides of the specimens using an adhesive. The dimensions of the specimens were of: 120 mm length, 20 mm width and 3.5 mm thickness. Circular central holes of 2, 4 and 6 mm in diameter were drilled at the centre of the specimens. Of the same material, they were manufactured a square composite patches of dimensions 20 by 20mm. The patches were being glued at the centre at one or two sides of the specimens using an adhesive 3M. The table 1, depicts the mechanical properties of the adhesive 3M. Figure 2, present a specimen

repaired by a double patch.

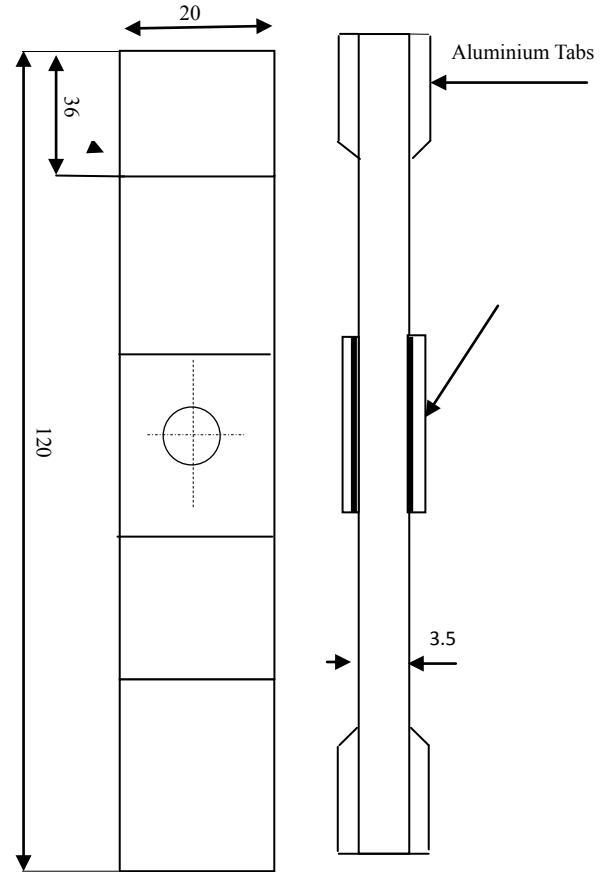


Figure 2. Composite material repaired by patch

Table 1. Mechanical properties of adhesive 3M

Glass transition temperature (Tg)	120 - 130 °C
Tensile strength	85 N/mm ²
Tensile Modulus	10,500 N/mm ²
Elongation at break	0.8%
Flexural strength	112 N/mm ²
Flexural Modulus	10,000 N/mm ²
Compressive Strength	190 N/mm ²
Coefficient of linear thermal expansion	34 10 ⁻⁶

2.3. Specimens Conditioning

First, the two series of samples were subjected into room temperature to hygrothermal effect of temperature of 70°C and 95% of relative humidity during 6 months. The fig.3, present, gained weight of composite materials. We note that the material CD342 present a gained weight about 0.2%, while the SS303 present a gained weight of 0.3%.

3.4. Tensile Test

The tensile test was performed using an Instron machine with a rate speed of 0.2mm/S according to ASTM protocol [16]. They were tested five specimens, and the load versus displacement was represented graphically.

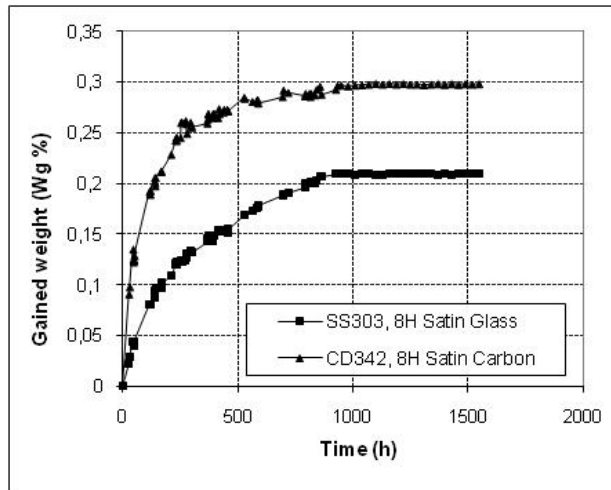


Figure 3. Gained weight

3.5. Tensile Results

The fig. 4, shown the medium values of the tensile loads as function of a hole diameter. From, the fig.4, we note that the tensile load decrease no linearly in function of the diameter. After aging, the glass fiber composite material presents a lower tensile load. For the diameter 6 mm, the lost in tensile load was about 70% in respect to dry state. At the same diameter, the Carbon fiber had shown a decrease about 51%. After the hygrothermal aging, the glass fiber composite present a decrease in tensile load about 44%, however, the carbon fiber show a loss of tensile load about 24% in respect to the original value. By increasing the notch diameter, the tensile load decrease more specially in the case of aged composites.

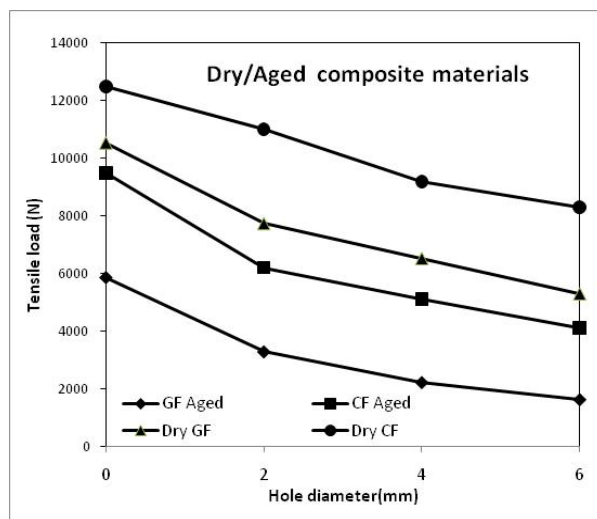


Figure 4. Tensile load versus hole diameter for glass and carbon fiber

The fig.5, present the variation of the tensile load of repaired glass fiber at the dry state in respect of hole diameter for a single and double composite patch. Also, we note that the double patch increase the load about 29% for a diameter 6mm in respect a single patch (25%). For a diameter 4mm, the increase in load was 21% (double patch) and 18% for a

single patch.

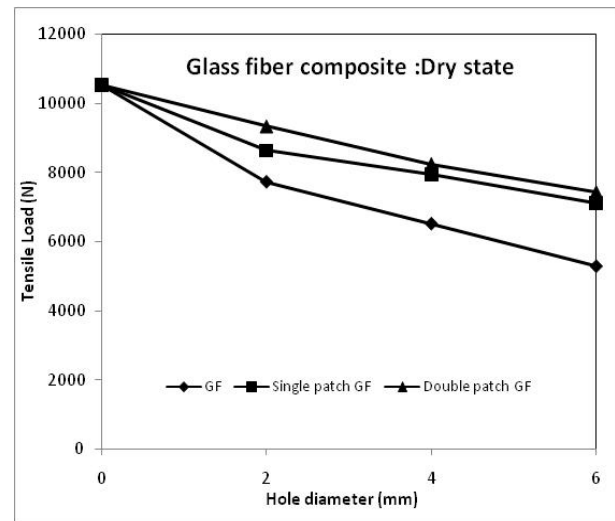


Figure 5. Tensile load versus hole diameter for glass fiber (dry state)

The fig.6, shown the no linearly variation of the tensile load for a different diameters in the case of the aged repaired glass fiber composite. We note that the double patch had a more efficiency in increasing the tensile load in respect to a simple patch. For a diameter 6 mm, the double patch increases the load about 31%, while the simple patch 23%. The same behaviour was shown for diameters 2 and 4 mm.

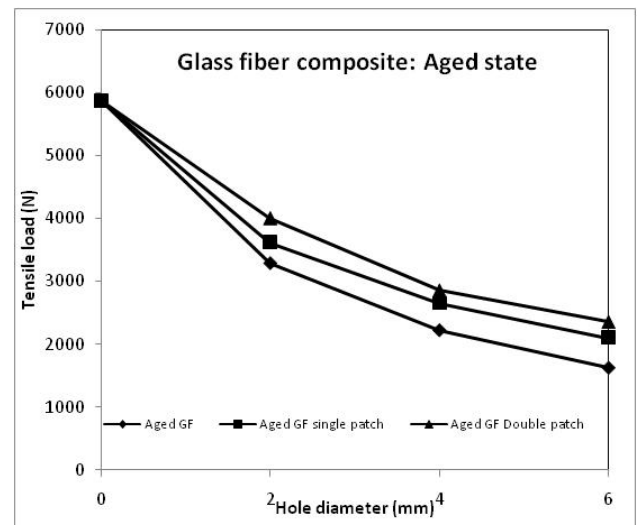


Figure 6. Tensile load versus hole diameter for glass fiber (aged state)

Fig.7 depicts the decreases of the tensile load versus the hole diameter for material carbon fiber at the dry state repaired by a single and a double carbon composite patch. The double patch increases the tensile strength about 13% in respect to a single patch (7%) at the diameter 6 mm. Also for a diameter 4 mm, the double patch increase the load about 12% and a single patch 6%.

In the case of the aged carbon fiber composite, see fig.8, we note the same tendency. The double patch increase the load about 39% and 29% for a single patch at the diameter 6mm (in respect to the aged value).

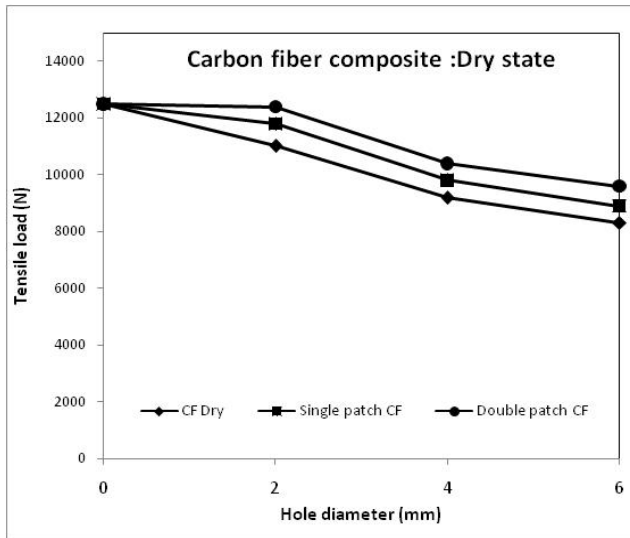


Figure 7. Tensile load versus hole diameter for carbon fiber (dry state)

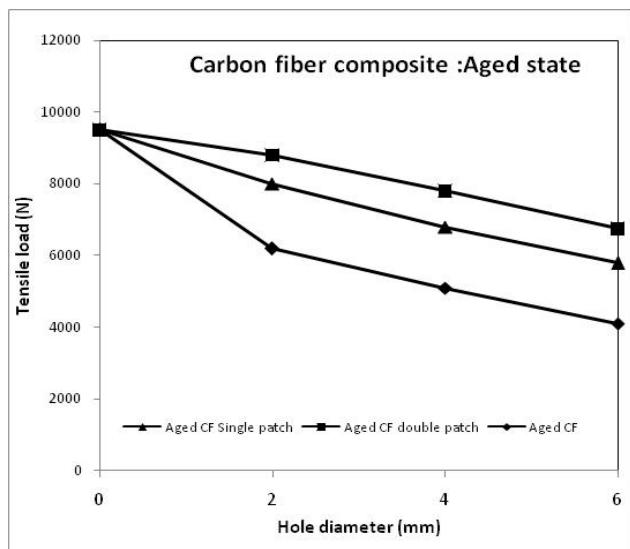


Figure 8. Tensile load versus hole diameter for carbon fiber (aged state)

4. Fractography

Figure 9(a) and (b) presents the fracture zones of a specimen tested in tensile strength of material SS303. In fig.9 (a), we note an important large zone resin – rich. In fig.9 (b), we appreciate a zone of fracture of fiber bundles. The failure was more catastrophic in this material.

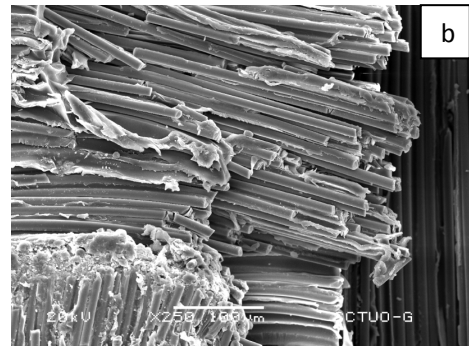
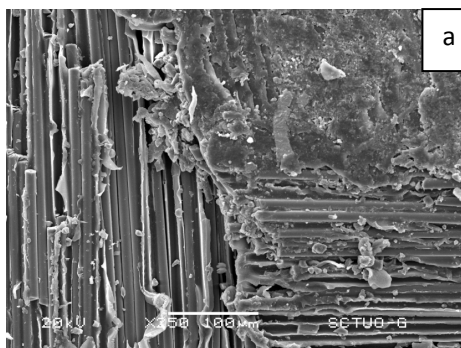


Figure 9. Fracture zones of material SS303 (250×)

Figure 10 (a) and (b) showed the damaged zones of the material CD342. We note the initiation of crack propagation and the interlaminar failure. In fig.10 (a), we observe plasticization zones of the matrix.

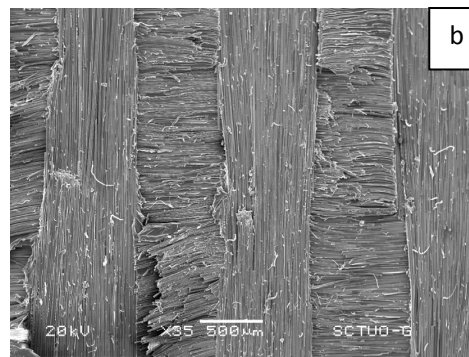
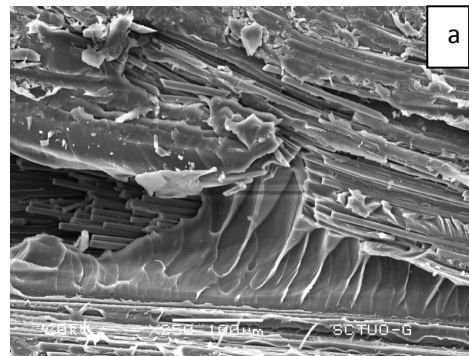


Figure 10. Fracture zones of material CD342 (250×)

5. Conclusions

The aim of this investigation was to evaluate the effect of a central circular notch and the hygrothermal aging on the ultimate tensile strength behaviour of two woven composite materials. The composite materials were made of 8H satin glass fiber and 8H satin carbon fiber. The composites were subjected into a room temperature during 6 month under a temperature of 70°C and a relative humidity of 95%. Circular notches of diameter 2, 4 and 6 mm were drilled at the centre of the two composites. After the hygrothermal aging, the glass fiber presents a percentage of lost of tensile strength about 44%, while the

carbon fiber present 24%. The increase in drilled diameter, the tensile load decrease quickly specially at the diameter 6 mm as function of the hygrothermal aging. The glass fiber composite present a more decrease in the tensile strength in comparison of the carbon fiber. Also, micrographs were taken near the damaged zone of the two composites. We remark a catastrophic zones with a fracture of fiber bundles. In the case of the material CD342, we observe plasticization zones of the matrix.

ACKNOWLEDGEMENTS

All the mechanical tests were performed at the Department of material sciences of the University of Oviedo (Spain). I would like to thanks all the Staff of the Department for all facilities during the realization of the investigation.

REFERENCES

- [1] Baker AA, Jones R., Bonded Repair of Aircraft Structures. Martinus Nijhoff. Dordrecht, (1988).
- [2] Atluri SN., Structural Integrity & Durability, Tech Science Press, Forsyth, Georgia, USA, (1997).
- [3] Rose LRF., A cracked plate repaired by bonded reinforcement. *Int. J. Fracture* 18: 135–144, (1982).
- [4] Hart-Smith LJ., The design of repairable advanced composite structures. Douglas Paper 7550, McDonnell Douglas, Douglas Aircraft Company Hill Book Company: London, (1985).
- [5] Chow WT, Atluri SN., Composite patch repairs of metal structures: adhesive nonlinearity, thermal cycling, and debonding. *AIAA J.* 35(9): 1528–1535, (1997).
- [6] Lena MR, Klug JC, Sun CT., Composite patches as reinforcements and crack arrestors in aircraft structure *J. Aircraft* 35(2): 318–323, (1998).
- [7] Baker AA. Repair of cracked or defective metallic aircraft components with advanced fibre composites Dan overview of Australian work. *Comput. Struct.* 2 pp. 153-1581, (1984).
- [8] Baker AA., & Chester R.J., Recent advances in composite repair technology for metallic aircraft components. In: *Advanced composites 93*. Chandra T, Dhingra AK, editors.
- [9] Proceedings of the International Conference on Advanced composite Materials. pp 45-49, (1993).
- [10] Baker AA., Growth characterisation of fatigue cracks repaired with adhesively bonded boron/epoxy patches. In: *Proceeding of International Conference on Fracture, ICF-9*.pp 117-28, (1997).
- [11] Bachir Bouiadjra B., Belhouari L., & Serier B., Computation of the stress intensity factor for repaired cracks in mode I and mixed mode. *Comp. Struct.* 54, pp. 401-406, (2002).
- [12] Heung Soo Kim, Maenghyo Cho, Jaehun Lee, Antoine Deheeger, Michel Grédiac, Jean-Denis Mathias, Three dimensional stress analysis of a composite patch using stress functions, *International Journal of Mechanical Sciences* 52 (2010) 1646–1659.
- [13] Harald Osnes, Dag McGeorge, Jan R. Weitzenböck, Geir O. Guthu, Predicting failure of bonded patches using a fracture mechanics approach, *International Journal of Adhesion & Adhesives* 37 (2012) 102–111.
- [14] S.-P. Ng, K.J. Lau, P.C. Tse, 3D finite element analysis of tensile notched strength of 2/2 twill weave fabric composites with drilled circular hole, *Composites: Part B* 31 (2000) 113–132.
- [15] U.A. Khashaba *, A.I. Selmy, I.A. El-Sonbaty, M. Megahed, Behavior of notched and unnotched [0/±30/±60/90]_s GFR/EPOXY composites under static and fatigue loads, *Composite Structures* 81 (2007) 606–613.
- [16] Lee W. Kohlman, Justin L. Bail, Gary D. Roberts, Jonathan A. Salem, Richard E. Martin, Wieslaw K. Binienda, A notched coupon approach for tensile testing of braided composites, *Composites: part A* 43 (2012), 1680-1688.
- [17] ASTM 2004, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, D3039/D3039M, edition 2004.