Mitigations of Machine Damaged Fiber Reinforced Composites for Improved Mechanical Strengths and Educational Practices for Engineering Students

A. Kunza, K.A. Brauning, A.S.A. Shairi, and *R. Asmatulu
Department of Mechanical Engineering
Wichita State University
1845 Fairmount St., Wichita, KS 67260
Email: ramazan.asmatulu@wichita.edu

Abstract

Fiber reinforced composites have been used in a number of different industrial applications, such as aircraft, wind turbine, automotive, defense and many other manufacturing industries because of their high strength to weight ratio, low coefficient of thermal expansion, fatigue and corrosion resistance, ease of manufacturing larger parts, design flexibility and high and low temperature applications. During the manufacturing and machining (e.g., curing, cutting, trimming, drilling, and fastening) processes of composites, some surface damages and free edges are formed around the composites. These defects on the fiber reinforced composites are considered to be major flaws and can reduce overall mechanical properties of those composites. In this study, pre-preg carbon fiber laminate composites were produced in a vacuum oven at different fiber orientations and then test coupons were extracted from the prepared composite panels. Two different edge treatment adhesives (cyano-acrolate and epoxy resin) were applied on the machined sides of the composite surfaces and the tensile test results were compared with the bare samples without any treatment. The test results indicated that edge treatments could improve the mechanical properties of the composites about 11%. This may be useful for the future design of composite products for different industrial applications. Through the studies, undergraduate and graduate students were involved in these studies and gained a lot of hands-on experiences and team work abilities.

Keywords: Fiber Reinforced Composites, Machine Damages, Free Edge Effects, Mitigations, Hands-on Experiences, Engineering Education.

1. Introduction

Fiber reinforced composite materials offer enormous potentials for use in a wide number of engineering applications, ranging from sports goods to advanced aircraft structures. The superior stiffness and strength properties of long fiber composites can be utilized to manufacture complex components with lower weight at reduced cost, and also create complex challenges to analysts and designers. In particular, advanced composites structures have been adopted in the aerospace application. For instance, The Boeing 787 Dreamliner, a mid sized jet airplane consist of 80% composite material by volume [1-5].

Fundamentally, a composite mainly consists of two constituents: the fiber and the matrix associated with the interphase region of finite thickness responsible for assuring adhesion between the fiber and matrix. Fibers should be well impregnated (embedded) within the matrix to maximize the physical properties of fiber reinforced composites. The orientation of fibers mainly influences the mechanical, thermal and other physical properties. During the manufacturing of composite components, thin layers of pre-impregnate fibers, typically 0.125 mm in thickness, are stacked in the desired orientations and the whole laminate is then processed to yield a structural-

© American Society for Engineering Education, 2019

ly sound component exhibiting the anticipated physical properties. The longitudinal arrangement of fibers depicts the maximum properties compared to any other angles [6-11].

The unique characteristics of fiber reinforced composites leads to better vibrational energy absorption, high damping capacity, non-corroding behavior, and creep properties, and are superior than metallic materials because of their extraordinary properties. The fatigue strength of composite laminates are excellent and used as substitution for metals in aerospace, automobile and other industries. Manufacturing and processing techniques of composites is based on production rates, equipment cost, reliability, and tolerances. Manual and automated processes are the two refined categories for composite manufacturing. The common method is usually implemented in laboratory practice as manually hand-laid composites [12-17].

During the manufacturing and machining, such as curing, cutting, trimming, drilling, transportation, fastening, and assembling processes of composites, some surface damages and free edges are formed around the composites, which may cause premature failures and lower the service life [1]. This study addresses some of the surface damages and free-edges of fiber reinforced carbon fiber composites using specific adhesives and fabrication techniques.

2. Experiment

In the present study, unidirectional pre-preg carbon fiber composites (CYCOM 5320), which are partially cured prior to the fabrication, has been selected. This pre-preg composite has a relatively flexible cure cycle recommended by the company for the manufacturer with complex curvatures. The pre-preg composites were cut in an appropriate direction (for 30° fiber orientation), stacked at desired orientations and transferred to the vacuum curing oven to cure under vacuum following the curing cycles [1]. Before the cutting and trimming process, prepared composite panels were tested using the non-destructive inspection (NDI) technique. Figure 1 shows the images of NDI (C-Scan) tested fiber composite laminates. The NDI tests indicated that the prepared composite panels had very low cracks, voids, porosity, debris, fiber waviness and other sorts of defects in their structures (usually less than 2 % void defects).

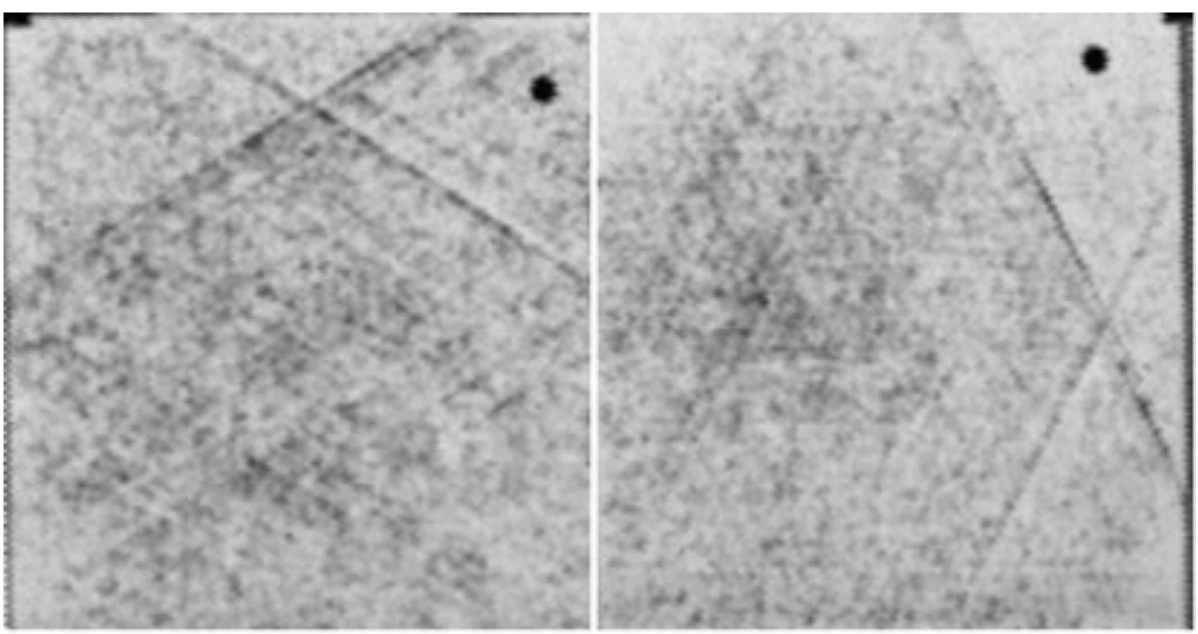


Figure 1: The images of NDI tests conducted on the fiber reinforced laminate composites.

© American Society for Engineering Education, 2019

The composite test coupons were extracted from the composite panels at different fiber orientations using a rotary diamond saw. This saw creates a lot of free edges and defects when compared to the water jet cutting process [1]. Edges of the extracted composite panels were carefully glued with cyano-acrolate super glue (SG) and epoxy glue (EG) to reduce the defects and free edge effects prior to the tensile tests and compare the test results with the bare (B) composite coupons (approximately 0.1x2.5x15 cm). All the specimens were cleaned properly, and tensile tested using a 22 kip MTS Alliance RF/100 tensile test machine under standard environment, ambient temperature and humidity levels. For each set of samples, at least five tensile tests were conducted and the test results were averaged for a comparison.

At the beginning of the fabrications and characterization steps, the PhD student trained MS and BS students about how to setup the experiments, layup the fiber composites with different orientations, vacuum bagging and composite curing, machining the composite edges, and edge sealing of the damages to eliminate the free edge effects on the composite structures. In the later part of the experiments, the BS and MS students preformed the experiments independently under the PhD student guidance. During the experiments, safety rules and regulations were strictly followed to minimize the possible accidents and experimental errors.

3. Results and Discussion

3.1 Testing and Analysis

Figure 2 shows the stress vs. strain values of 30 degree pre-preg composite fiber orientations and their statistical error associated with 30 degree peak stress values. Cyano-acrolate treated and epoxy treated specimens demonstrated about 11% and 8% performance improvement when compared to the bare composite samples without any edge treatments. Peak stress values for epoxy and cyano-acrolate treated specimens are higher than the bare edge specimens. It was also noticed that elastic modulus is consistent for all specimens and slightly changed based on the surface treatment processes. Other mechanical behavior of the specimens are relatively consistent, with minor deviation in peak stress. It is important to note that for the test specimens, delimitation occurred outside of the grips to make visual observations of the crack surfaces.

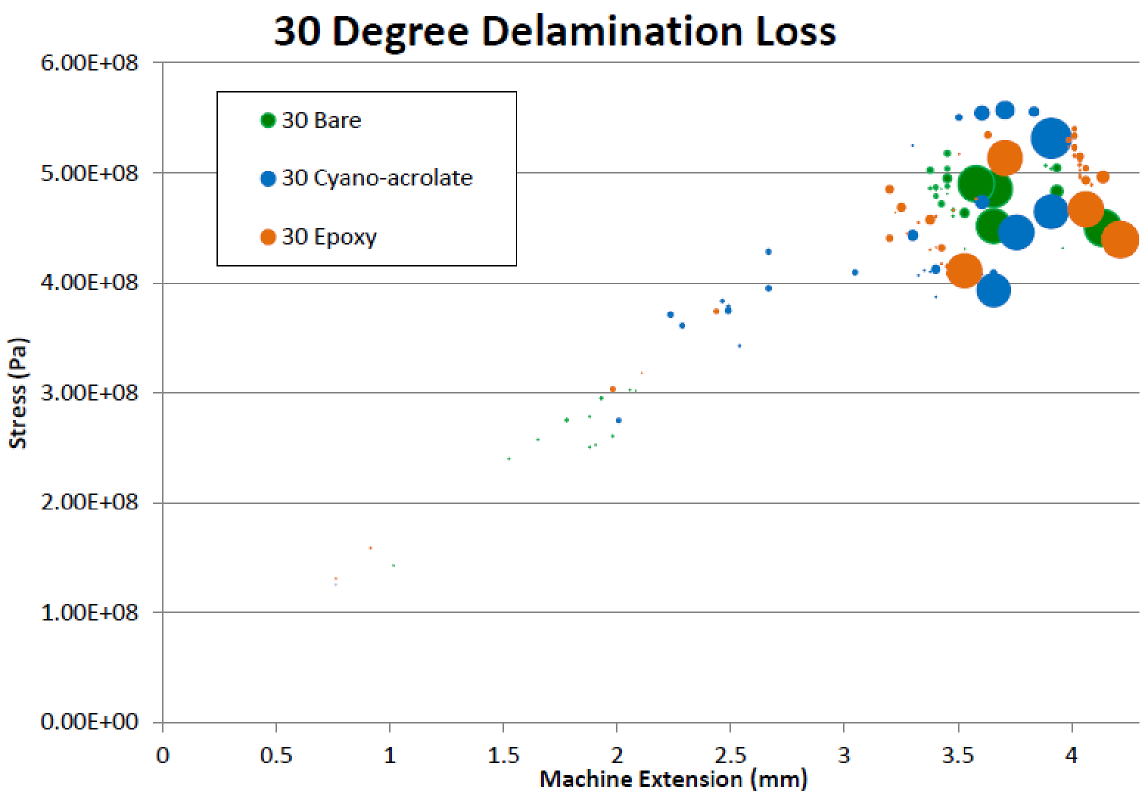
Based on the test results, statistical errors associated with the peak stress values were investigated in detail. The statistical analysis indicated that the all three composite samples (bare, super glue and epoxy glue treated samples) gave higher statistical error values, which is mainly common for the fiber composite materials. Generally, continuous fiber composite materials consist of a heterogeneous interphase regions, and the mechanical property may change from region to region sometimes based on the fiber and matrix locations and contents. Local damages and fiber waviness may also affect the inconsistences [1,11,17]. Overall, this study indicated that selected surface treatment method has a great impact on the mechanical strength improvements of the composite materials that have the extensive surface damages and free edge effects happened during the machining and assembly.

3.2 Training Engineering Students

Composite science and technology has been gaining much attention worldwide because of the requirements and new demands of aircraft and wind turbine companies. Surface treatment of the fiber reinforced composites may solve some of the issues of the composite industries, such as free edge effects and other defect formations created during the manufacturing and assembly. Engineering student involvements in composite technology are critically important for the future

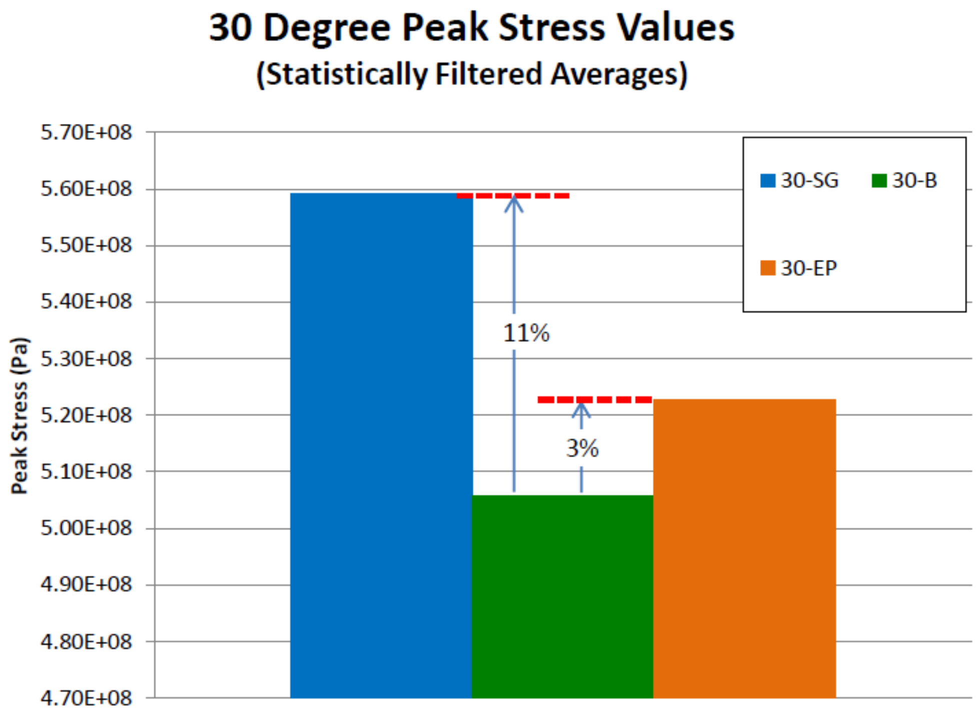
© American Society for Engineering Education, 2019

developments. Undergraduate and graduate students in the Department of Mechanical Engineering at Wichita State University (WSU) were involved in every step of this work, learned many new techniques and gained a lot of new skills and knowledge about composite manufacturing, NDI evaluation, machining, edge and other defect treatments, testing, evaluation and report writing and presentation. At the end of the experiments, undergraduate and graduate students learned about the data collections, analysis, presentations, technical report writing and conference paper preparations. This is one of the most intensive activities for both undergraduate and graduate students in engineering. Some of the students joined our group used these research activities as their own Engineer 2020 requirements in the College of Engineering at WSU. One of the undergraduate students (A.S.A. Shairi) is also a co-author of this work and made a lot of contributions during the fabrication, testing and evaluation part. We strongly believe that hands-on experiences on the new and exciting subjects will drastically improve the engineering knowledge of the undergraduate and graduate students (mainly MS students) to perform more detail studies in these fields for their future educations.



(A)

© American Society for Engineering Education, 2019



(B)

Figure 2: A) Stress vs. strain values of 30 degree fiber composites treated with the EG and SG adhesives, and B) statistical errors associated with the peak stress values.

4. Conclusions

In the present study, pre-preg composites (CYCOM 5320) were manufactured using uni-directional carbon fibers in a vacuum oven, and then inspected using the NDI technique. The test coupons extracted from the composite panels were cut with 30° angle of fiver orientations using the diamond saw prior to the edge treatment using super glue and epoxy glue. The tensile test results indicated that super glue and epoxy glue samples provided 11 and 8% higher tensile strengths when compared to the bare samples without any edge treatments. The edge treatment may be a quick solution for the free edge effects of fiber composites after the machining. During the fabrication, testing and characterizations parts of the project, engineering BS, MS and PhD students were involved in every step and gained huge hands-on experiences on composite technology. These activities also synchronized the team work ability among different levels of engineering students to enhance the engineering educations.

Acknowledgement

The authors greatly acknowledge Wichita State University for financial and technical support of the present study.

References

1) Brauning, K. A. "Mitigation of Machining Damage on Delamination of Fiber Reinforced Composite Tensile Coupons," M.S. Thesis, Wichita State University, May 2013.
2) Shirvanimoghaddam, K., Hamim, S. U., Karbalaei Akbari, M., Fakhrhoseini, S. M., Khayyam, H., Pakseresht, A. H., Naebe, M. (2017). Carbon fiber reinforced metal matrix

© American Society for Engineering Education, 2019

composites: Fabrication processes and properties. *Composites Part A: Applied Science and Manufacturing*, Vol. 92, 2017, pp. 70–96.

3) Das, T.K., Ghosh, P., and Das, N.C. "Advanced Composites and Hybrid Materials, 2019. Preparation, development, outcomes, and application versatility of carbon fiber-based polymer composites: a review"
4) Kasaragadda, S. Alarifi, I.M., Gorji, M., and Asmatulu, R. "Investigating the Effects of Surface Superhydrophobicity on Moisture Ingression of Nanofiber-Reinforced Bio-Composite Structures," *Microsystem Technologies*, 2019 (in press).
5) Uddin, M.N., Gandy, H.T.N., Rahman, M.M., and Asmatulu, R. "Adhesiveless Honeycomb Sandwich Structures of Pre-Preg Carbon Fiber Composites for Primary Structural Applications," *Advanced Composites and Hybrid Materials*, 2019 (in press).
6) Swarna, V.S., Alarifi, I.M., Khan, W.A., and Asmatulu, R. "Enhancing Fire and Mechanical Strengths of Epoxy Nanocomposites for Metal/Metal Bonding of Aircraft Aluminum Alloys," *Polymer Composites*, 2019 (in press).
7) Jawaid, M., Thariq, M., and Saba, N., *Failure Analysis in Biocomposites, Fiber-Reinforced Composites and Hybrid Composites*, Woodhead Publishing Series, Cambridge MA, 2018.
8) Uddin, M.N., Le, L.N., Nair, R., and Asmatulu, R. "Effects of Graphene Oxide Thin Films and Nanocomposite Coatings on Flame Retardancy and Thermal Stability of Aircraft Composites" *Journal of Engineering Materials and Technology*, Vol. 141, pp. 1-7, 2019.
9) Van, T. T., Abedin, F., Usta, A., and Asmatulu, R. "Polyurethane Nanocomposite Coating with Silanized Graphene and Hexagonal Boron Nitride as Nanoadditives for Improved Resistance against UV Degradation," *Journal of Composite Materials*, 2018, https://doi.org/10.1177/0021998318799402.
10) Kumar, S .S. A., Uddin, M. N., Rahman, M. M., and Asmatulu, R. "Introducing Graphene Thin Films into Carbon Fiber Composite Structures for Lightning Strike Protection," *Polymer Composites*, 2018, https://doi.org/10.1002/pc.24850.
11) Campbell, F., *Structural Composite Materials*, USA: ASM International, 2010.
12) Rahman, A.K.M.S., Mathur, V. and Asmatulu, R. "Effect of Nanoclay and Graphene Inclusions on the Low-Velocity Impact Resistance of Kevlar-Epoxy Laminated Composites," *Composite Structures*, Vol. 187, pp. 481-488, 2018.
13) Ghazinezami, A., Khan, W. S., Jabbarnia, A., and Asmatulu, R. "Impacts of Nanoscale Inclusions on Fire Retardancy, Thermal Stability, and Mechanical Properties of Polymeric PVC Nanocomposites," *Journal of Thermal Engineering*, Vol. 3, pp. 1308-1318, 2017.
14) Kececi, E., and Asmatulu, R. "Effects of Moisture Ingressions on Mechanical Properties of Sandwich Structured Fiber Composites for Aerospace Applications," *International Journal of Advanced Manufacturing Technology*, Vol. 88, pp. 459-470, 2017.
15) Mahat, K. B., Alarifi, I. M., Alharbi, A., and Asmatulu, R. "Effects of UV Light on Mechanical Properties of Carbon Fiber Reinforced PPS Thermoplastic Composites," *Macromolecular Symposia*, Vol. 365, pp. 157-168, 2016.
16) Asmatulu, R., Diouf, D., Moniruddin, M., and Nuraje, N. "Enhanced Antiweathering Nanocomposite Coatings with Silanized Graphene Nanomaterials," *International Journal of Engineering Research and Applications*, Vol. 6, pp. 79-91, 2016.
17) Hyer, W.H., and White, S.R., *Stress Analysis of Fiber-reinforced Composite Materials*, DEStech Productions, Inc., Lancaster, PA, 2010.

© American Society for Engineering Education, 2019