International Journal of Advancements in Technology
Kebede et al., Int J Adv Technol 2017, 8:2
DOI: 10.4172/0976-4860.1000180

Research Article Open Access

Tensile Strength Assessments of CFRP Adhesive Bonded Joint

Henok Yilma Kebede[1], Tae Min Kim[1] and Dong Ho Bae[2*]

[1]*Graduated School, Mechanical Engineering, Sungkyunkwan University, Korea*

[2]*School of Mechanical Engineering, Sungkyunkwan University, Korea*

[*]**Corresponding author:** Dong Ho Bae, School of Mechanical Engineering, Sungkyunkwan University, Korea, Tel: +82 -31-290-7443; Fax: +82-31-295-1937; E-mail: bae@yurim.skku.ac.kr

Received date: February 06, 2017; **Accepted date:** February 19, 2017; **Publication date:** March 1, 2017

Abstract

In this paper, stress distribution analysis and tensile strength assessment of CFRP bonded joint were studied. First a mixture of Epoxy adhesives and MWCNT was fabricated. Since failure is initiated at the ends of overlap, the stress distribution at the ends of the overlap and bonded joint was numerically analyzed. After the stress distributions were analyzed based on the result obtained the experimental steps were followed to assess the tensile strength of bonded joint. The stress distribution analysis and the tensile strength assessment results showed an agreement that the geometrical factors directly affect the reliability of the bond.

Keywords: Adhesive bonding; Finite element stress analysis; Tensile strength; Stress distribution; Multi-wall carbon nanotubes; Composites (CFRP)

Introduction

Joining technology is widely used for assembling of aerospace and automotive structures. Compared to mechanical fastened, riveted joints and spot welds, adhesive bonding have the following advantages such as structural integrity, higher strength to weight ratio, ease of applicability, join dissimilar materials, reduced stress concentration, and improved fatigue resistance [1-3]. Epoxy resin is an engineering adhesive that has outstanding mechanical and thermal properties [4].

Reinforcements are mostly used in the development of composite materials ranging from macro to nano-scale. Nanofillers are commonly added as reinforcement to enhance the performance of the adhesive properties of Epoxy resin. Due to their excellent stiffness and strength and exceptional high aspect ratio combined with low density, Carbon nanotubes are considered as an ideal candidate for the reinforcement of conventional adhesives [5-7]. The electrical, thermal and mechanical property of CNT provides a new perspective for improving the conducting performance of the mechanical adhesives.

On this study the Epoxy resin was mixed with multiwall carbon nanotubes (MWCNT) as a reinforcement to increase the mechanical, thermal and electrical properties of Epoxy adhesives.

Single-lap joint is used as standard test specimen used to determine the mechanical properties of adhesives. Adhe-sively bonded single-lap joint is widely used for connecting composite structures [8]. Since almost 70% of failures initiated in the joint, it's very important to analyze the stress distribution in the joints to resolve such kinds of failures. Stress distribution of single-lap joint was numerically and experimentally studied by many scholars but still needs further research to clarify the controversial ideas and to obtain optimized adhesive bonded joint [9-11].

Stress distribution analysis

Analysis model

When the external tensile shear load is applied to the adhesive bonded joint of Figure 1, two kinds of internal forces act on bonded part, in-plane shear force (Pt) and out-of-plane bending moment (M), as illustrated in Figure 2. These internal forces cause a very complicated deformation and stress concentration which results failure of adhesive bond at the edge of the bonded joint. Therefore, it is very important to calculate the accurate stress and strain distribution of the bonded joint for a reasonable strength assessment of the adhesively bonded CFRP sheets. FEM was used for stress distribution analysis of single-lap joints [12,13].

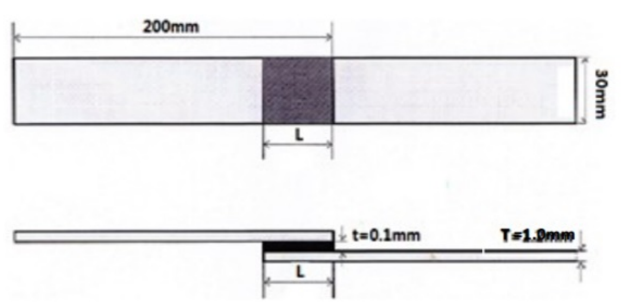

Figure 1: Configuration of adhesive bonded joint: T- thickness of adherend, L- lapped length, t- thickness of adhesive.

In this paper, 3D solid brick elements were used for FEA (Finite element analysis) model. The upper and lower plates as well as the bonding layer have each layer of solid brick element. Boundary condition and load condition of the FE modeling is the same as of the tensile tests.

Citation: Bae DH, Kebede HY, Kim TM (2017) Tensile Strength Assessments of CFRP Adhesive Bonded Joint. Int J Adv Technol 8: 180. doi: 10.4172/0976-4860.1000180

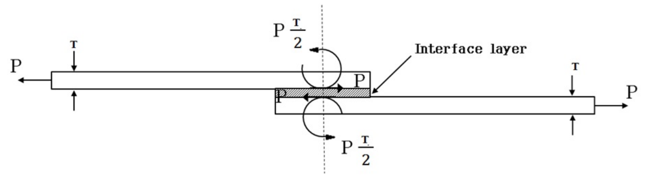

Figure 2: Schematic of internal forces in the adhesive bonded joint by the tensile shear load: P- applied load.

ABAQUS, a commercial FEA package, was used for the modeling and stress analysis of adhesively bonded CFRP. The geometrical dimensions of the FEM (Finite element model) were the same as the experimental evaluation of the CFRP bonded joint. The modeling of CFRP were done based on the mechanical properties obtained from manufacturers specification and test results of tensile strength of CFRP, as shown on the Table 1.

Material	Tensile strength (MPa)	Young's modulus (GPa)	Ultimate elongation (%)	Poisson's ratio	Thickness (mm)
CFRP	598.83	38.05	1.638	0.22	1
Epoxy (Araldite AW106)		2.937		0.33	0.1

Table 1: CFRP and epoxy material properties.

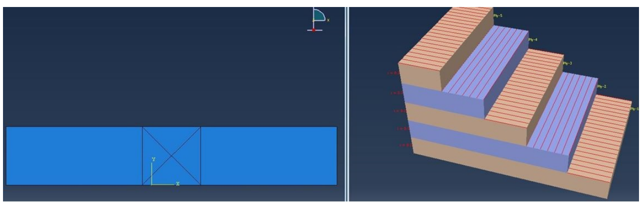

Figure 3: Finite element model of CFRP.

On this study five layers of CFRP with a thickness of 0.2 mm each layers were modeled. Figure 3 shows the FEM of CFRP and its fiber direction. The material properties of composites and damage initiation are also analyzed during model modeling of CFRP in the material property section of FEM (Abaqus modeling). Damage initiation and propagation are analyzed for CFRP bonded joint on the FEA and the analysis result illustrates the maximum stress generated at the free ends of the overlap.

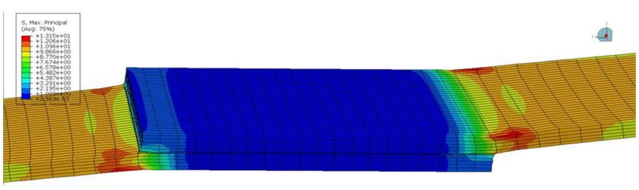

Figure 4: Finite element analysis of CFRP joint.

For the FEM stress analysis of adhesives the cohesive property and damage analysis are also considered on the material property section of modeling. The adhesive bonded area was super fine meshed for better assessment of stress distribution. Since mesh refinement has the direct impact for the accuracy of Finite element analysis. Generally, the stress distribution contour proves that the maximum stress concentration area and failure points. The finite element analysis result shows the point of maximum stress concentration which is responsible for adhesive failure.

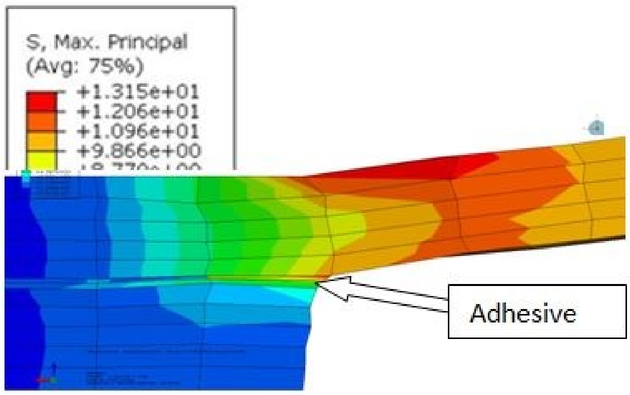

Figure 5: Finite element analysis of CFRP bonded joint.

Results of numerical analysis

Figures 4 and 5 shows, when MWCNT %=1 and applied load (P)=100 N, the result of stress contour around the outer surface of adhesive bonded joint. It shows that stress concentration occurs at the joint edge on the loading side due to in-plane shear force and out-of-plane bending moment. It is known that the geometrical factors such as the plate thickness, adhesive thickness, the width of the plate, and lapped length of adhesive bonded joint affect stress concentration around the joint edge.

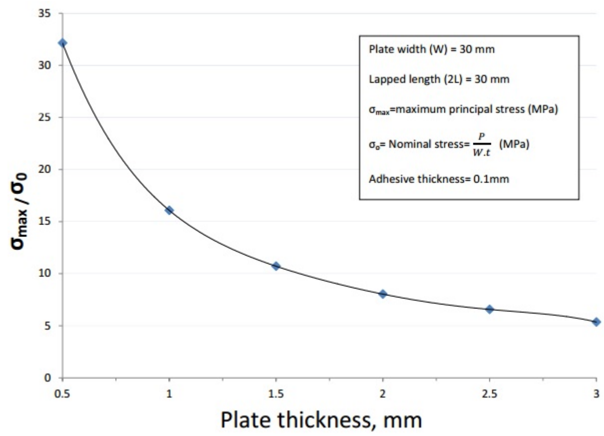

Figure 6: Stress vs. CFRP plate thickness ratio.

In this paper, for systematic tensile strength evaluation of adhesive bonded joints subjected to tensile shear load, the effects of the

Citation: Bae DH, Kebede HY, Kim TM (2017) Tensile Strength Assessments of CFRP Adhesive Bonded Joint. Int J Adv Technol 8: 180. doi: 10.4172/0976-4860.1000180

geometrical factors of the joint on stress distribution and concentration were evaluated.

The influence of geometrical factors on stress distribution of adhesive bonded joint

Figures 6-9 shows, when MWCNT %=1 and applied load (P)=100 N, the results showed the effects of the geometrical factors of joint on the maximum stress. Figure 6 shows the relationship between the maximum stress and plate thickness of adhesive bonded joint. The maximum stresses decreased as plate thickness increases this is because of bending stiffness increment.

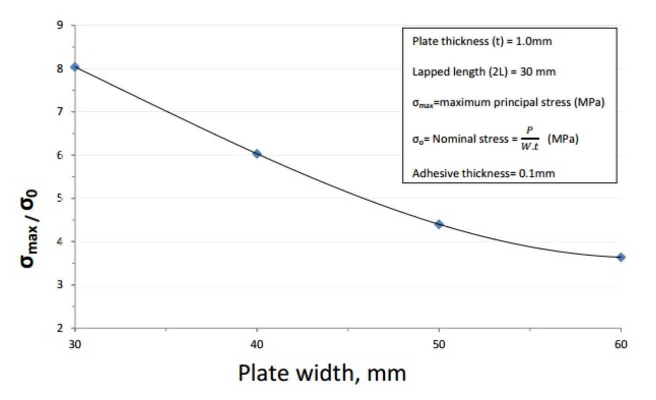

Figure 7: Stress vs. plate width relations.

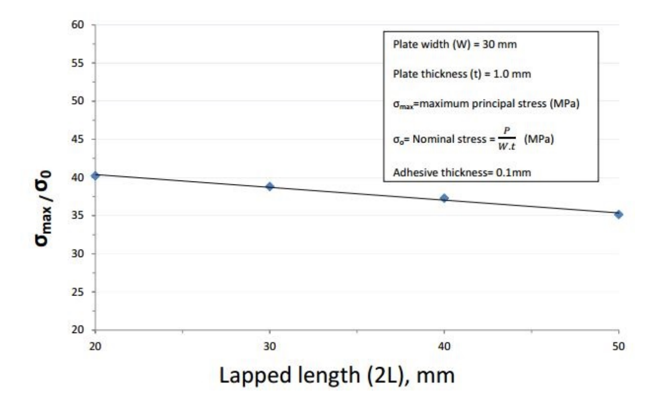

Figure 8: Stress vs. lapped length relations.

Figure 7 shows the relationship between the maximum stresses and the width of the plate. Since the adhesive bonded area of joint increases as the width of the plate increases, the maximum stresses remarkably decreased. Showing this difference between lapped length and width of the plate is due to the difference of deformation mechanism this is because of tension shear load as shown on Figure 2. Out-of-plane bending results due to the deformation of the upper and lower plate of adhesive bonded joint decreases as the lapped length increased, however it is not remarkable due to increase of bonded area. When width of the plate increases, deformation mechanism becomes more complicated than lapped length increment. In this case, beside of out-of-plane bending as shown in Figure 2, out-of-plane bending deformation on the width direction (transversal direction) of the plate also increases as width of the plate increased. Therefore, the maximum stress decreases by out-of-plane bending deformation which is in the combined longitudinal and transversal directions.

Figure 8 shows the relationship between the maximum stress and lapped length of adhesive bonded joint. The maximum stress decreases due to the adhesive bonded area of joint increase, as the lapped length increased.

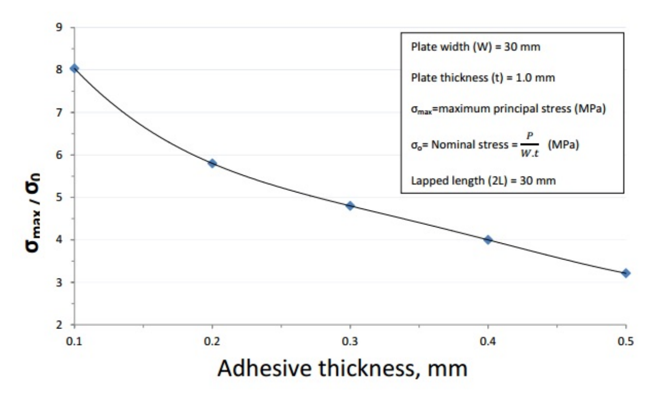

Figure 9: Stress vs. adhesive thickness relations.

Figure 9 shows the relationship between the maximum stress and the thickness of adhesive layer of adhesive bonded joint. The maximum stress decreases as thickness of adhesive layer increases. However, when the thickness of adhesive layer becomes more than 0.3 mm, decreasing rate of the maximum stress is not remarkable due to decrease of out-of-plane bending deformation as in-plane shear deformation increases.

Experiment (MWCNT Composite Adhesives)

Materials characterization

Carbon fiber reinforced plastic (CFRP) was selected for the adherend, characterized by its high tensile strength (598.7 MPa) obtained from the Tensile strength assessment. This specific composite material has the following characteristics: (1) light weight (2) the strongest and stiffest material (3) corrosion resistant (4) better damping property. Therefore, CFRP is the promising composite material for the automobile and aerospace body structure.

On this study the tensile strength of the CFRP sheet is tested Based on the tensile strength result the stress-strain curve was plotted and the material properties are calculated accordingly.

The tensile properties of the CFRP material were deter-mined according to the ASTM D3039 [14]. Four CFRP tensile specimens were prepared with a dimension of, width=15 mm and length=250 mm and tested in tension using an 840 KN MTS hydraulic testing machine and results brittle failure because of the nature of composite materials. The measured stress-strain relationships of the CFRP plate up to failure is shown on the Figure 10. The measured elastic modulus, tension strength and failure strength of the CFRP plate is shown in Table 1.

An Epoxy resin (Araldite AW106) was used as substrate to fabricate MWCNT. In general, because of its high impact, peel strength and environmental resistance Epoxy resin is widely used for automobile body manufacturing process.

Citation: Bae DH, Kebede HY, Kim TM (2017) Tensile Strength Assessments of CFRP Adhesive Bonded Joint. Int J Adv Technol 8: 180. doi: 10.4172/0976-4860.1000180

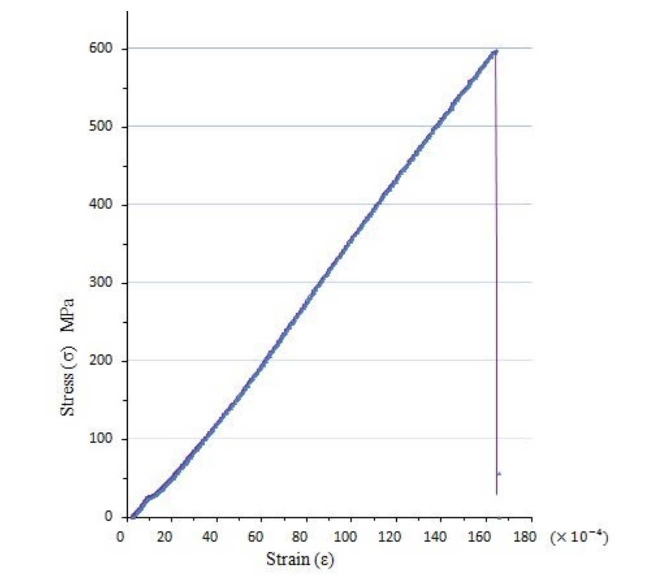

Figure 10: Stress vs. strain relation of CFRP.

The properties of Epoxy resin which was shown on the Table 1 used as input for the FEM analysis. The reinforcement (MWCNT) is synthesized by catalytic CVD process [5-7,15]. The reinforcement has the purity of above 95% without any purification and a high oxidation temperature of 600°C.

Joint fabrication and testing

First the epoxy resin is heated and MWCNTs are added to the heated Epoxy resin. The mixture of Epoxy resin and MWCNT are kept at temperature of 40˚C to reduce the viscosity of the epoxy and enhance the fluidity of the mixture [6,16,17]. The mixture is stirred by a directly driven stirrer (Model PL-SS20) for 3 hours with a speed of 100-500 rpm to ensure the separation of entangled MWCNT and uniform distribution of MWCNTs in Epoxy, and vacuumed in Varian DS402 vacuum chamber for 1 hour with a maximum pressure of 60 mmHg. As the mixture is vacuumed the steering process is kept constant to remove the entrapped air from Epoxy resin/MWCNT mixture.

After the mixture of MWCNT and Epoxy resin are cooled at room temperature, the curing agent were added and stirred at a speed of 300 rpm for 30 minutes within the vacuum chamber for uniform distribution of mixtures and extracting the entrapped air. Finally the Epoxy/MWCNT mixture will be kept at room temperature for 10 minutes, and then the MWCNT/Epoxy mixture is applied by spatula on the CFRP plate. After the MWCNT/Epoxy mixture is applied on the CFRP sheet, the bonded CFRP sheet in lap guide was gripped for 3 hours until the jelly structure of adhesive bond hardened. And then trimming was followed to remove unwanted adhesives from the joint. On this study for the alignment of lapped joint, lap guide was designed with a dimension of length 200 mm , width 30 and thickness of 3 mm, 4 mm, 5 mm according to adhesive thickness difference. For the lap guide design the tolerance of 0.01 mm included for ease of extracting the bonded joint after the lapped joint hardened.

Finally, the CFRP bonded joint is put into oven (Forced convection oven) and heated at 50˚C for 5 hours to cure the bonded joint. The cured CFRP bonded joint is cooled down at room temperature for 2 days before the tensile test.

The single-lap joint geometry and dimensions are shown on the Figure 2. The joints are fabricated by the following steps: (i) The surfaces to bonded were roughened by manual abrasion with 800 grit superfine sand paper and cleaned with acetone, (ii) The joints were bonded in lap-guide for the correct alignment, and the desired value of adhesive thickness was achieved during assembly with a dummy adherend and 0.1 mm calibrated spacer under the upper adherend, jointly with the application of pressure with grips and (iii) Tabs were glued at the specimen edges for a correct alignment in the testing machine.

Static tensile strength testing

The static tensile test was conducted based on the ASTM D5868 standard test method for plastics and polymers [18]. The tensile testing to the joints was carried out in an Instron MTS hydraulic testing machine with 840 KN load cell, at room temperature and under displacement control (0.5 mm/min).

Results and Discussion

In this study, MWCNT/Epoxy mixture is fabricated and the tensile strength of CFRP bonded joints was tested. From the test result two kinds of failures occurred: adhesive failure (at the adhesive-adherend interface) and light fiber tear failure.

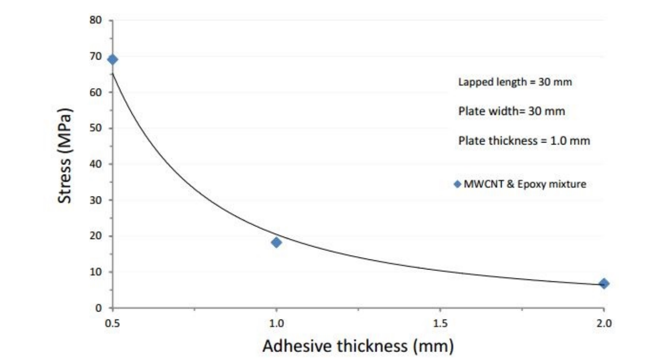

Figure 11: Tensile test result of CFRP bonded joint.

The CFRP bonded joints test result showed that as the geometry of the bonded joint varies the values of tensile strength also varied (Figure 11). The lapped length difference shows an inverse relation with the tensile strength which shown on Figure 12. As the lapped length increased from 30 mm to 60 mm the experimental result decreased. As the thickness of the adhesive increased it also showed the decrement of tensile strength, the tensile strength of CFRP bonded joint with respect to different adhesive thickness was shown on Figure 11.

Increasing the time of stirring showed better distribu-tion of MWCNT into Epoxy resin, Figures 13 and 14 shows the SEM images of 3 and 5 hours stirring of MWCNT/Epoxy mixture. The addition of MWCNTs in Epoxy improves the tensile strength of Epoxy.

Citation: Bae DH, Kebede HY, Kim TM (2017) Tensile Strength Assessments of CFRP Adhesive Bonded Joint. Int J Adv Technol 8: 180. doi: 10.4172/0976-4860.1000180

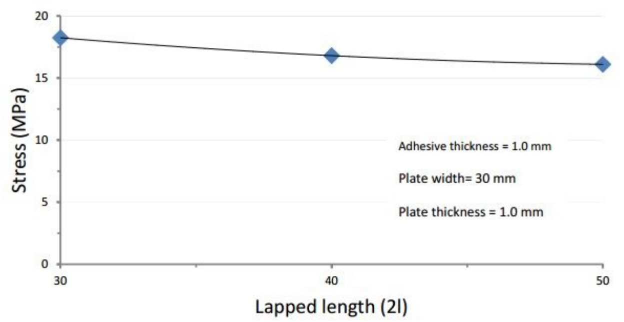

Figure 12: Tensile test result of CFRP bonded with respect to lapped length.

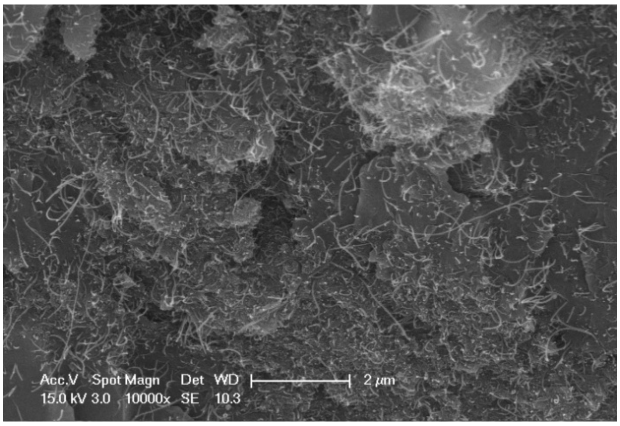

Figure 13: SEM images of 3 hours stirred Epoxy/MWCNT mixture bond.

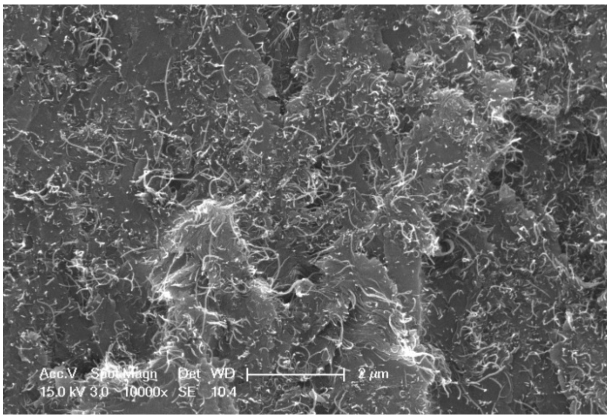

Figure 14: SEM images of 5 hours stirred Epoxy/MWCNT mixture.

Conclusion

A composite adhesive bond which mixed CNT (carbon nanotubes) and EPOXY bond was developed. Adhesive bonded CFRP joint was fabricated using this composite bond. For the purpose of safe design of adhesive bonded thin sheet structures, the stress distribution and static tensile strength of adhesive bonded CFRP joint are analyzed. Summarized results are obtained.

As the tensile shear load applied to composite adhesive bonded CFRP joint, the maximum stresses are generated at the free edges of the joint. The maximum stress decreased with thickness of adhesive bonding layer and lapped length of the joint increase

The tensile strength of adhesive bonded CFRP joints decreased with thickness of adhesive bonding layer and lapped length of the joint increase.

As the stirring time of Epoxy resin/MWCNT mixture increases the distribution of MWCNT increased across the Epoxy resin.

References

1. Kinloch AJ (1987) Adhesion and adhesives: Science and technology.
2. Adams RD (2005) Adhesive bonding: Science, technology and applications.
3. Wilson RG (1990) Practical applications of structural adhesives. Adhesion 15: 224-225.
4. Brewis DM (1986) Critical assessment of factors affecting bonding of materials. Master Sci Technol 2: 761-767.
5. Thostenson ET, Chou TW (2003) On the elastic properties of carbon nanotube-based composites: modeling and characterization. J Phys D Appl Phys 36: 573-582.
6. Li, Chou TW (2003) Elastic moduli of multi-walled carbon nano-tubes and the effect of vander Waals forces Compose. Sci Technol 63: 1517-1524.
7. Yu MF, Lourie O, Dyer MJ, Moloni K, Kelly TF, et al. (2000) Strength and breaking mechanism of multiwall carbon nano-tubes under tensile load. Science 287: 637-640.
8. Oplinger JW (1998) Mechanical fastening and adhesive bonding. In: Peters ST (ed). Handbook of composites. Springer, NewYork.
9. Grant LDR, Adams RD, da Silva LFM (2009) Experimental and numerical analysis of single-lap joints for the automotive industry. Int J Adhesion & Adhesives 29: 405-413.
10. Li G, Sullivan PL, Thring RW (1999) Nonlinear finite element analysis of stress and strain distributions across the adhesive thickness in composite single-lap joints. Composite structures 49: 395-403.
11. Kumar RLV, Bhat MR, Murthy CRL (2014) Analysis of composite single lap joints using numerical and experimental approach. J Adhesion Sci Tech 28: 893-914.
12. Li G, Sullivan PL (2001) Finite element and experimental studies on single-lap balanced joints in tension. Int J Adhesion and Adhesives 21: 211-220.
13. Wang ZY, Wang L, Guo W (2009) An investigation on strain/ stress distribution around the overlap end of laminated composite single-lap joints. Composite Str 89: 589-595.
14. ASTM D3039 (2014) Standard test method for tensile properties of polymer matrix composite materials.
15. Andrews R, Jacques D, Qian D, Rantell T (2002) Multiwall carbon nanotubes: Synthesis and application. Acc Chem Res 35: 1008-1017.
16. Feng L, Bae DH (2013) Joining STS3041 sheets by using nano-adhesives. J Mech Sci Tech 27: 1943-1947.
17. Yu N, Zhang ZH, He SY (2008) Fracture toughness and fatigue life of MWCNT/epoxy composites. Materials Sci Engg A 494: 380-384.
18. ASTM D (2004) Standard test method for lap shear adhesion for fiber reinforced plastic (FRP) bonding, Annual book of ASTM standards.