STRENGTHENING ANALYSIS OF BONDED, RIVETED AND HYBRID JOINT IN GLASS FIBRE EPOXY COMPOSITES BY ANSYS

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ABSTRACT

The composite structural members are highly used in the following applications such as aerospace, automobiles, robotic arms, architecture etc., has attracted extensive attention in the past decades. One of the important issues in the composite technology is the repairing of aging aircraft structures. In such applications and also for joining various composite parts together, they are fastened together either using adhesives or mechanical fasteners. Modelling, static analysis of 3-D models and Manufacturing of the composite joints (bonded, riveted and hybrid) were carried out using FEA software. The results were interpreted in terms of Von Misses stress. A parametric study was also conducted to compare the performance of the hybrid joint with varying adherent thickness, adhesive thickness and overlap length. To utilize the full potential of composite materials like Glass Fibre - epoxy as structural elements, the strength and stress distribution of these joints namely, bonded, riveted and hybrid joints must be understood while conducting experimental works. Various joint like bonded , riveted and hybrid joint were prepared by glass fibre epoxy composite laminates. And then undergo for tensile test by universal testing machine with data acquisition system. The results will compared with the joints.

Keywords: Adhesive joint, carbon black, particle embedded composite

INTRODUCTION

The development of reliable joining methods for composite assemblies has become an important research area because large or complex composite structures are usually required to be joined to other metallic or ceramic parts to enhance their performance. The efficiency of composite structures with joints is largely dependent on these joints rather than their structures, because the joint is usually the weakest part among the components of assembled structures.

Generally, joining methods for composite assemblies are classified into adhesive bonding and mechanical fastening. The adhesive joint distributes the load over a larger area than the mechanical joint, requires no holes, adds very little weight to the structure and has superior fatigue resistance.

In order to get a strong and durable joint between composite assemblies, surface treatment is necessary prior to bonding. Several methods to improve the bonding strength of the composite assemblies have been investigated. Niem et al. studied the joint strength with respect to the surface roughness and surface treatment direction of the adherends. Roizard et al. investigated the alkaline etching treatment of glass/epoxy composite substrate for micro-scale roughness. Kim and Lee studied plasma surface treatment on carbon fiber/epoxy composites to improve the load capabilities of composite adhesive joints.

Although these surface treatments yielded reliable adhesive joints, they increased the preparation time of composite components, emitted fiber dusts and used toxic chemicals. Therefore, some researchers investigated alternative fabrication methods for composite structure which did not require surface treatment for adhesive joining. Benard et al. studied the peel ply surface treatment and its surface characteristics for composite assemblies, where surface roughness in micro scale was generated on the composite assemblies. Some researchers investigated carbon black reinforced composites to improve wear characteristics and carbon black reinforced adhesives for better adhesion. However, there are only a few researches on the surface characteristics of the particle reinforced polymeric composites, specially nano particle reinforced and their relations to the adhesion characteristics.

Therefore, in this work, the surfaces of glass/epoxy composite materials were embedded with nano-size carbon black which was diluted in methyl ethyl ketane (MEK) during curing process to enhance the adhesion characteristics of the glass/epoxy composite structure. In order to observe the surface modification of the composite due to the dilution of resin during curing process by MEK, the surface morphology of the composite was observed with a SEM (scanning electron microscope) and the surface roughness of composite surface was measured with respect to the amount of MEK. Then, the static tensile load capability of the adhesively bonded double lap joint whose adherends were composed of the MEK treated glass/epoxy composite was investigated with respect to the amount of MEK. The mechanical properties of the glass/epoxy composite were measured to investigate the minimum amount of MEK which did not degrade the composite due to the dilution of resin during curing process.

LITERATURE REVIEW

Composite flush end plate connections: Various options of steel connection are readily available to attach a steel girder to a column section (Hogan and Thomas, 1994). One of the more popular types used in construction is the flush end plate connection, in which the end plate is usually welded to the beam before being bolted to the column section on-site (Figure 1). Apart from being economical and easy to be fabricated, this connection type is characterised to be behave as semi-rigid and is able to provide an appreciable level of stiffness and moment resistance. The connection properties are further enhanced if the beam is designed as a composite system, due to the contribution from the reinforcement. Extensive research has been conducted to investigate composite flush end plate connections by Benussi et al. (1989), Aribert and Lachal (1992), Anderson and Najafi (1994), Xiao et al. (1994), Li et al. (1996), Shanmugam et. al (1998), and Brown and Anderson (2001). The design guidelines of these connections to H-columns have been published by The Steel Construction Institute (1998).

Blind bolting technique: It is believed that to provide an economical solution to connect beams to CFHS, there should not be additional effort in its constructability than a conventional steel connection. With this in mind, the flush end plate type connection was chosen to be used in the current test series. Although it may seem impossible to bolt to the face of a hollow section since there is no access to the inside to tighten the bolt, the advent of blind bolting products has made this possible.

In the current moment connection tests, the Hollo-Bolt product was used (Figure 2). It was preferred over the Flowdrill due to its availability and simplicity in the fixing process. Tightening the Hollo-Bolt only requires a torque wrench as compared to its counterpart which requires special equipment to drill through the wall and a separate tool to thread the holes. No other experimental tests were found in the literature regarding moment connections of flush end plate type connected to CFHS via the blind bolting technique. The lack of test results which impede the development of design guidelines was also highlighted by Barnett et al. (2001). Hence, apart from the novelty it presents, the research work described herein intends to contribute to fill in this deficiency.

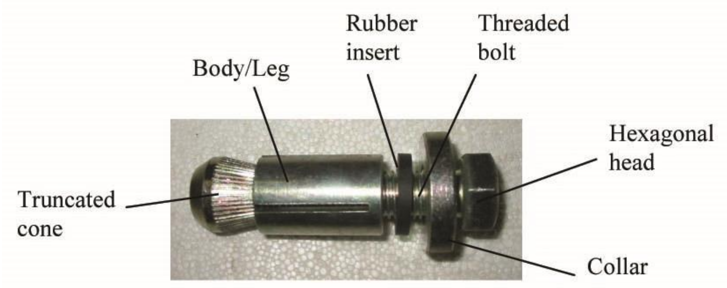

Fig.1.Hollo-Bolt

DESIGN OF COMPOSITE JOINTS

The experimental programme comprised of a total of six cruciform beam-to-column arrangements. Five specimens were constructed using a composite slab system with one specimen a bare steel beam section. A flush-end plate connection was adopted to connect the steel beams to the concrete-filled square hollow sections. For the composite beams, the concrete slab was supported by the profiled sheet decking placed longitudinally. The sheeting acted as formwork and was also considered to contribute as longitudinal reinforcement. Welded-through stud shear connectors bonded the concrete slab and steel beam compositely. The degree of shear connection and the percentage of reinforcement were the two main parameters investigated. These were varied to evaluate the response of the beams in terms of stiffness, moment resistance and rotational capacity.

Design of Specimens: The composite joints were designed to replicate an earlier test series of composite beams tested under hogging bending. Details of the experimental programme and results were reported by Loh et. al (2003). The beam-tocolumn composite joints were designed to simulate the internal joints of a typical composite frame of 9 x 9 metre bays.

The current composite joint specimens were only subjected to static, monotonic loading. Without large load reversals, the specimens and the connections are believed not be significantly affected by lateral forces characteristic of wind and moderate earthquake action. This was earlier found from the experimental tests by Loh et. al (2003) that the prescribed uni-directional repeated loading, had negligible effects on the behaviour of the composite beams. Broderick and Thomson (2002) also tested steel beam-to-column joints using flush end plate connections under monotonic and reverse cyclic loading. When compared, there was only a slight reduction in moment capacity due to the cyclic loading but without any adverse effects on the ultimate rotation.

Design of Connection: The design of the composite flush end plate connections followed several specified guidelines and recommendations provided by the Steel Construction Institute (1998). Although the guidelines only account for columns of open sections, some general design rules are similarly applicable for concrete-filled hollow sections. An important design criterion is to ensure that non-ductile failure modes do not govern the strength of the connections. These include tension failure of the column face, buckling of the column webs, bearing failure in the

Journal of Chemical and Pharmaceutical Sciences ISSN: 0974-2115

column web, and premature reinforcement fracture, particularly mesh reinforcement. The use of a concrete-filled section implicitly prohibits the non-ductile failure modes in the column, and also avoids the requirement of additional stiffeners.

The vertical shear resistance of the connection was designed to be mainly resisted by the Hollo-Bolts. For the top bolt row which was subjected to tension, the shear strength of the bolts was reduced to 40% of the full shear capacity (Steel Construction Institute, 1998). For bolt rows located in the compression zone, full shear strength of the bolts was utilised. Contribution of the shear capacity from the concrete slab and reinforcement was not included in the design. The size of the Hollo-Bolts used was M20 of Grade 8.8, in which the design shear capacity and tensile capacity was specified as 100 kN and 110 kN respectively (British Tubes and Pipes, 1997).

As part of the requirements, the reinforcing bars were ensured to be at least 16 mm in diameter and were placed at a minimum clear cover of 20 mm. In the detailing aspect for the shear connection, the first shear connectors were ensured to be at least 100 mm from the column faces, in accordance with the guideline. This is considered to allow for the reinforcing to be strained over a sufficient length such that sufficient rotation may be developed. The recommendations that the end plate thickness should be less than 12 mm when using M20 bolts were followed. The horizontal gauge spacing of the bolts was also ensured to be not less than 90 mm.

Table 1. Mechanical properties of the glass/epoxy composite (UGN 200)

E_1 (GPa)	E_2, E_3 (GPa)	G_{12}, G_{13} (GPa)	G_{23} (GPa)	υ^{12}, υ^{13}	υ^{23}	α_1 (10^{-6}/°C)	α_1, α_3 (10^{-6}/°C)
37	8.6	3.8	1.86	0.28	0.4	7.0	21

E_1: Modulus in the fiber direction
E_2, E_3: Moduli in the transverse and thickness directions
G_{12}, G_{13}, G_{23}: Shear moduli, υ_{12}, υ_{13}, υ_{23}: Poisson's ratios
α_1 :CTE in the fiber direction, α_2, α_3 CTEs in the transverse and thickness directions

Table 2. Properties of the carbon black particle used

Density	Nominal size	Shape
1800kg/m^3	30nm	Sphere

Table 3. Mechanical Properties of the epoxy used

Young's Modulus	Poisson's ratio	Tensile strength
3.8 GPa	0.37	39MPa

Table 4. Surface free energy components (mJ/m^2) of the liquind

	γ_L	γ_L^{LW}	γ_L^{AB}	γ_L^{+}	γ_L^{-}
Water	72.8	21.8	51.0	65.0	10.0
Ethylene glycol	48.0	31.4	16.4	1.58	42.5
Diiodomethane	50.8	50.8	0	0	0

Table 5. Arithmetic surface roughness (R_a) of the glass/epoxy composite with respect to the amount of embedded CB particle

Amount of embedded CB (g/m^2)	0	1.3	2.0	8.9	13.3
Arithmetic surface roughness(R_a, μm)	0.53	0.55	0.50	0.58	0.51

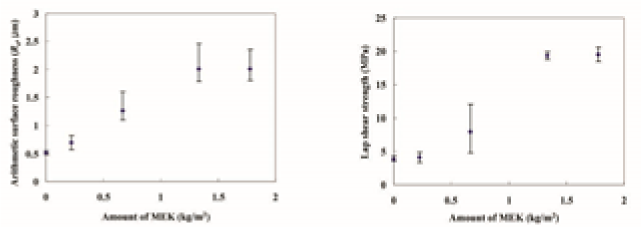

Fig 1. SEM micrographs of composite; (a) without MEK treatment; (b) treated with MEK of 1.3 kg/m^2; (c) schematic diagram of the process of MEK treated composite.

Fig.1 shows the SEM photograph of the composite surface on which the MEK was sprayed on the prepreg before curing. Since the MEK diluted the epoxy resin in the prepreg, the resin rich layer on the surface of cured composite became thinner and some bare fibers were exposed to the surface. The arithmetic surface roughness (R_a) of the composite increased as the sprayed amount of MEK was increased due to exposed fiber on the composite surface as shown in Fig. 5 (a). Fig. 5 (b) shows the lap shear strength of the composite adherend with respect to the amount of MEK. The maximum lap shear strength of the adhesive joint was 19.3 MPa, where the amount of MEK was 1.3 kg/m^2. Then, the lap shear strength was almost constant when the amount of MEK was lager than 1.3 kg/m^2, which

Journal of Chemical and Pharmaceutical Sciences ISSN: 0974-2115

was similar trend to the surface roughness. Fig. 6 shows the failure surface of the MEK treated composite adherend. When the amount of MEK was lower than 0.7 kg/m^2, the interfacial failure occurred at the interface between the adhesive and the adherend. However, partial interfacial and partial cohesive failure modes occurred at the adhesive layer when the amount of MEK was larger than 1.3 kg/m^2. From these results, it may be concluded that the thin epoxy layer and exposed fibers on the surface as shown in Fig. 4 (b) increased the lap shear strength of the composite adherend. Fig. 7 shows the stress-strain curve of the MEK treated composite with respect to the amount of MEK. The stiffness of the composite adherend slightly increased as the amount of MEK was increased, because the matrix content of composite adherend was reduced due to the dilution of epoxy resin of the prepreg. The tensile strength of the composite adherend was almost constant regardless of the amount of MEK, while the failure strain decreased slightly as the amount of MEK was increased.

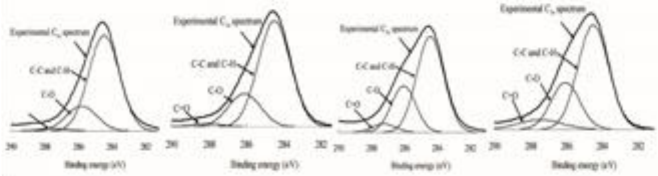

Fig 2. Arithmetic surface roughness of the epoxy adhesive composite joints with respect to the amount of embedded.

CONCLUSIONS

In this study, the surfaces of glass/epoxy composites were embedded with carbon black and their adhesion characteristics were investigated with respect to the amount of embedment. From the investigation, the following conclusions were drawn.

The lap shear strength of the joint increased about 4 times without degrading the tensile strength of the composite, when the glass/epoxy composite prepreg was diluted with MEK of 1.3 kg/m^2 before curing process of the composite, which increased the surface roughness by the exposed fibers.

The lap shear strength of the joint increased about 3.5 times when the composite adherend was embedded with CB particle of 8.9 g/m^2 due to the increased surface roughness and surface free energy by the embedment.

The lap shear strength of the joint whose adherends were embedded with CB particle which were diluted in MEK increased about 40% compared to the composite adhesive joint whose adherends were grit blasted.

ACKNOWLEDGMENT

We would first like to thank Dr.A.S.Ganesan, Honourable Chancellor, Vinayaka Missions University for giving us the opportunity to carry out this project.We are grateful to our beloved Principal Dr.A.Prabakaran, for all the encouragement and support extended to us during the tenure of this project. We express our profound gratitude and our heart filled thanks to Mr.K.V.Krishna Sastry, M.E.,PGDHRM,(PhD), Professor and Head of the Department, Mechanical Engineering, who contributed his valuable time and gave suggestions, encouragement, support and valuable guidance for the completion of this project.We thank our project co-ordinator and guide Mr.J.Senthil, B.E., M.E., M.B.A., Associate Professor, Department of Mechanical Engineering for his espousal and for having instilled in us the confidence to complete our project on time.

We would also like to thank all teaching and non-teaching staffs of the Mechanical Engineering Department for their constant support and encouragement given to us.

REFERENCES

Beamson, G. and Briggs, D., in: High Resolution XPS of Organic Polymers- The Scienta ESCA 300 Database, Chichester : John Willey & Sons (1992).

Benard Q., Fois M. and Grisel M., "Peel ply surface treatment for composite assemblies: Chemistry and morphology effects," Composites- Part A, Vol. 36, p. 1562-1568 (2005).

Chang L, Zhang Z, Breidt C, Friedrich ., "Tribological Properties of Epoxy Nanocomposites: I. Enhancement of the Wear Resistance By Nano-TiO2 Particles," Wear, Vol. 258, p. 141–48 (2005).

Choi, J.H. and Lee, D.G., "An Experimental Study of the Static Torque Capacity of the Adhesively-Bonded Tubular Single Lap Joint," Journal of Adhesion, Vol. 55, p. 245-260 (1996).

Della Volpe C. and Siboni S., "Some Reflections on Acid–Base Solid Surface Free Energy Theories," J. Journal of Colloid and Interface Science, Vol. 195, p. 121-136 (1997).

Roizard X., Wery M. and Kirmann J., "Effects of alkaline etching on the surface roughness of a fibre-reinforced epoxy composite," Composite structures, Vol. 56, p. 223-228 (2002).