23rd Australasian Conference on the Mechanics of Structures and Materials

2014

Bond properties of rubber modified epoxy

Amad-Adeen Baiuk
Deakin University

Riyadh Al-Ameri
Deakin University

Bronwyn Fox
Deakin University

Publication details

Baiuk, AA, Al-Ameri, R & Fox, B 2014, 'Bond properties of rubber modified epoxy', in ST Smith (ed.), *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, vol. I, Byron Bay, NSW, 9-12 December, Southern Cross University, Lismore, NSW, pp. 175-180. ISBN: 9780994152008.

23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)
Byron Bay, Australia, 9-12 December 2014, S.T. Smith (Ed.)

BOND PROPERTIES OF RUBBER MODIFIED EPOXY

Amad-Adeen Baiuk*
PhD student, School of Engineering, Deakin University,
Geelong, VIC 3220 abaiuk@deakin.edu.au (Corresponding Author)

Riyadh Al-Ameri
Senior Lecturer in Structural Engineering, School of Engineering, Deakin University,
Geelong, VIC 3220. r.alameri@deakin.edu.au

Bronwyn Fox
Associate Professor, Institute for Frontier Materials, Deakin University,
Geelong, VIC 3220. bronwyn.fox@deakin.edu.au

ABSTRACT

In this paper, the bond integrity of unmodified and rubber-modified epoxy used for bonding the carbon fibre sheets to the hosting steel surface was investigated. The rigidity of the bonding agent is one of the factors that have a significant role in the premature failure (debonding) of this application. In order to overcome this issue, a series of experiments were conducted on the steel plates using the epoxy resin modified by CTBN and ATBN reactive liquid polymers, in addition to the unmodified epoxy resin. The interface between the carbon fibre matrix and the hosting surface is subjected to a longitudinal shear force for which the corresponding displacement is recorded. The shear stress-strain relationship for the tested specimen is plotted. The result shows that, the bond behaviour of modified epoxy using CTBN and ATBN reactive liquid polymers was improved in terms of ductility and toughness.

KEYWORDS

Bond properties, rubber modified epoxy, steel plate, CFRP sheets.

INTRODUCTION

The carbon fibre reinforced polymer (CFRP) is now considered an efficient material for strengthening and rehabilitation of the existing and the new infrastructure members (Al-Ameri and Al-Mahaidi 2006, Alferjani et al. 2014, Ceci, Casas and Ghosn 2011, Kalfat, Al-Mahaidi and Smith 2013). The reliability of this material depends on the integrity of the bonding agent to transfer stress between the retrofitted member and the CFRP laminate (Al-Ameri 2011, Sayed-Ahmed, Bakay and Shrive 2009). The brittleness and poor toughness properties of the epoxy resin are responsible for the premature failure in this application (Chataigner et al. 2011) due to a highly cross-linked density nature (May 1988). To reduce the cross-linked density and improve the toughness, the epoxy resin modified by a proper reactive liquid rubbers (Sobrinho, Calado and Bastian 2012, Bagheri, Marouf and Pearson 2009). In this paper, the MBrace epoxy resin modified by the CTBN and ATBN liquid rubber in order to enhance the toughness properties and improve the overall ductility of the resin matrix by reduced the cross-linked of the resin matrix. Which, consequently prevent or delay the premature failure. The prepared samples of different types of resin were tested in a shear-lap test setup and found to fail at bond level. Test results showed that, the toughness and ductility of the modified resin were improved compared with the unmodified epoxy.

MATERIALS

CF Laminates

CFRP laminates have dimensions (1mx1m) supplied from Ironbark Composites. This laminate was cut into pieces of dimension (100mmx75mm) to use in single-lap shear test.

Steel Plates

The steel plates (Figure 1) used in this study made from mild steel and have dimensions of (150mmx150mm). The bonded surface area is (80mmx80mm) and was prepared in a way to enhance the adhesive bond between the CFRP and steel plate. Then the test sample setup on the Universal testing machine (Figure 2).

Figure 1. CFRP sheet bonded to the Steel plate

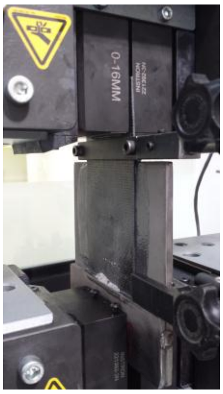


Figure 2. Setup of test sample

Epoxy System (Unmodified Epoxy)

The MBrace epoxy system was used in this study consisted of two parts. The first part is the Primer, which consist of a low viscosity polyamine cured epoxy to provide a high bond base coat for the epoxy system on the steel surface. It consists of Primer and hardener, mixed with a ratio of 100:30 by weight. The second part of system is the Saturant, which consist of a low viscosity epoxy material based on a unique amine curing agent technology (Bisphenol A). It has a resin and hardener mixed with a ratio of 100:30 by weight.

Hypro Reactive Liquid Polymers

In order to improve flexibility of the MBrace Saturant resin, two types of reactive liquid polymers are used. The first is Carboxyl Terminated Butadiene-Acrylonitrile (1300X13 CTBN); while the second is Amine Terminated Butadiene-Acrylonitrile, (1300X16 ATBN). These materials are a family of butadiene homopolymers and butadiene-acrylonitrile copolymers with functionally at the chain ends.

SPECIMENS PREPARATION

Surface Preparation

The bonded area of the steel plate was prepared using the electrical rotary disc in order to remove the scales and roughness the surface to enhance the bonding quality of the carbon fibre sheets on the steel plate surface.

Epoxy Resin Modification

The MBrace Saturant was modified using different ratios of ATBN and CTBN in order to improve the ductility and toughen of the final epoxy matrix to overcome any issues with debonding for this application.

Using ATBN

Three different ratios of ATBN were used with the unmodified epoxy in order to identify the ratio for the optimal combination of ductility and toughness. Three samples were prepared from each ratio of 20, 25 and 30 g of ATBN and 30 g of the unmodified epoxy hardener. After mixing using a low speed paddle (600 rpm), the mixture heated in the vacuum furnace at 60˚C for 20 minutes to get a homogenous mixture. Thereafter, a total of 100 g of the unmodified epoxy resin was added to the three different mixtures.

Using CTBN

Using the same philosophy as above, three different samples have a ratio of 15, 20 and 25 of CTBN was added to the 100g of the unmodified epoxy resin. The mixture was heated in a vacuum furnace at 60˚C for 20 minutes to get a homogenous mixture. The 30 g of the unmodified epoxy hardener was added to the three different mixtures.

SPECIMEN SETUP AND TEST PROGRAM

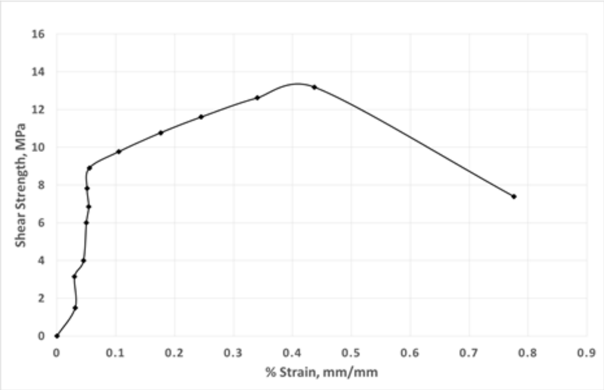
Once the surface of all samples was prepared as described, the ATBN and CTBN modified resin was applied using a small paintbrush. Then the CFRP laminate was attached to the applied area using a metal clamp to provide uniform bonding and this also maintained the alignment direction. After the samples were cured for 24 hours at room temperature, the shear-lap test was conducted by using the Instron 100 kN universal testing machine with a displacement control of 0.1 mm/min until failure. The interface between the carbon fibre matrix and the steel plate was subjected to a longitudinal shear force and the corresponding displacement was recorded. The stress-strain relationship for the tested specimens was plotted and analysed.

RESULTS AND DISCUSSION

The aim of this work is to study the properties of different modified epoxy resins in terms of ductility and toughness and compared with the unmodified epoxy. The percentage of elongation for any material under the axial or shear tensile force is an expression of how the material deforms plastically before failure, which known as the ductility. Whilst the term toughness expresses the ability of the material to absorb the energy of the plastic deformation before it failed via both strength and ductility and it is measured by the area under the curve (Smith et al. 1999, da Silva et al. 2006, Khan et al. 2013). Hence, the toughness is the most appropriate property for comparing the three resins used in this work. The shear-lap test was applied to the seven steel samples (1 for unmodified epoxy, 3 for different ratios of CTBN and 3 for different ratios of ATBN) until failure. All the samples failed by debonding the CFRP from the steel plate at different load and elongation.

Unmodified Epoxy

The unmodified epoxy specimen failed by debonding the CFRP from the steel plate at the max load of 84.4 kN and max shear strength was 13.19 MPa with a max percentage strain 0.87 before it failed. The estimated toughness was 54.4 kJ.m^{-3}. The data were used as a reference to compare the improvement of ductility and toughness of the modified epoxy resin. The shear strength vs. strain is plotted in Figure 3.



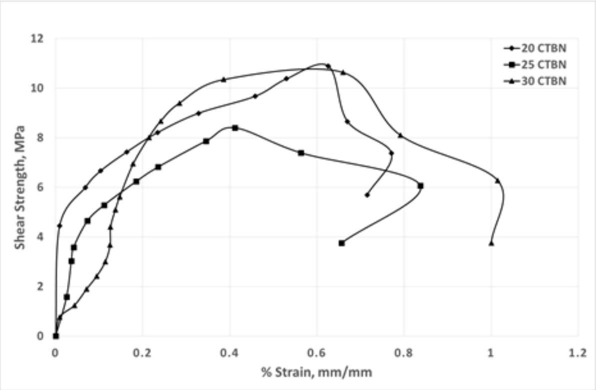


Figure 3. Shear strength vs. strain of unmodified epoxy

Figure 4. Shear strength vs. strain of epoxy modified by CTBN

Epoxy Resin Modified with CTBN

The three different samples of epoxy modified with different ratios of CTBN were tested under the same conditions of the unmodified epoxy sample. The test results of these samples are shown in Table 1 and Figure 4.

Table 1. Mechanical properties of epoxy modified by CTBN

Modifier g /100g unmodified epoxy	Max load, kN	Max shear strength, MPa	Max strain, %	Toughness, kJ.m^{-3}
20	69.7	10.89	0.77	65.3
25	53.7	8.39	0.84	56.9
30	68.0	10.63	1.02	83.6

In the samples modified by CTBN, the result shows that the sample containing 20 g had the higher sustained load and shear strength before it failed when compared to the other samples of 30 g and 25g by a 2.5% and 29.8% respectively. However, the sample of a 30 g had the higher plastic deformation (ductility) than the samples of 20 g and 25 g by 32.5% and 21.4% respectively. In the same manner, the sample of a 30 g had the higher toughness than the samples of 20g and 25 g by 28.0% and 46.9% respectively. Therefore, the sample modified by 30g having the better combination mechanical property than the others.

Epoxy Resin Modified with ATBN

Table 2. Mechanical properties of epoxy modified by ATBN

Modifier g /100g unmodified epoxy	Max load, kN	Max shear strength, MPa	Max strain, %	Toughness, kJ.m^{-3}
20	69.3	10.83	2.09	176.4
25	56.1	8.78	2.50	183.7
30	51.2	8.00	1.01	63.0

The test results of the group of ATBN modifier shown in Table 2 and Figure 5, the sample of a 20 g have the higher max load and shear strength before the bond failed than the other two samples of a 25 and 30 g by 23.5% and 35.4% respectively. However, the sample of a 25 g has the higher ductility than the other two samples of 20 g and 30 g by 19.6% and 147.5% respectively. By the same token, the sample of 25 g has the higher toughness than the samples of 20g and 30 g by 4.1% and 191.6% respectively. Through these figures, the sample of 25 g exhibit higher measured ductility and toughness than the others.

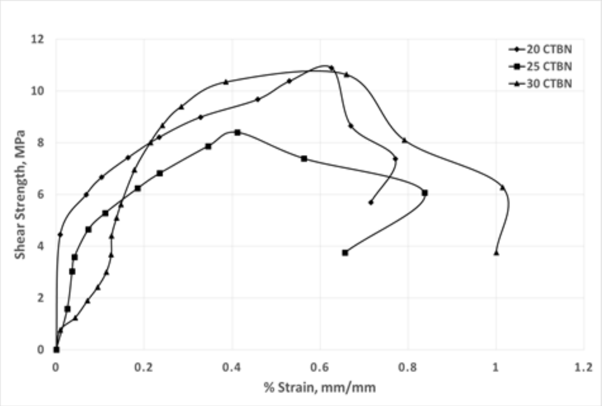


Figure 5. Shear strength vs. strain of epoxy modified by ATBN

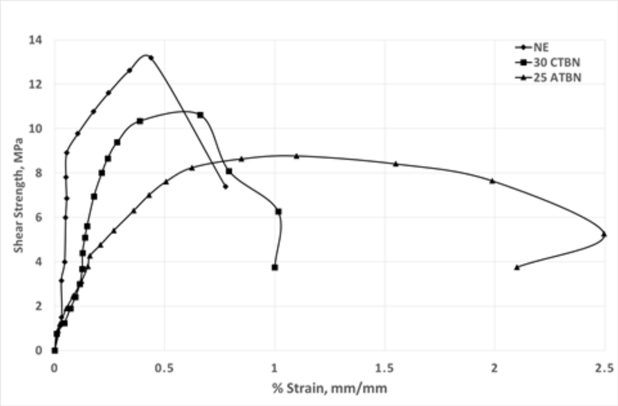


Figure 6. Shear strength vs. strain of the three different epoxies

The Table 3 and Figure 6 compare the mechanical properties of the best combination properties ratios that were selected from each epoxy. Although the unmodified epoxy was found to sustain a higher load than the two modified epoxies, the epoxy modified by 25g of ATBN has the highest combination of ductility and toughness than the epoxy modified by 30g of CTBN and the unmodified epoxy. The combination of ductility and toughness is critical for imparting good bond strength.

Table 3. Comparison of mechanical properties of three epoxies

Type of epoxy	Max load, kN	Max shear strength, MPa	Max strain, %	Toughness, $kJ.m^{-3}$
Unmodified epoxy	84.4	13.19	0.78	54.4
30 g CTBN	68.0	10.63	1.02	83.6
25 g ATBN	56.1	8.78	2.50	183.7

DISCUSSION AND CONCLUSIONS

In this paper, the MBrace epoxy was modified by two types of reactive liquid polymers (CTBN and ATBN) with different ratio in order to improve their mechanical property in term of ductility and toughness, thus return to prevent or delay the debonding problem in the retrofitting application.

In general, Structural Engineers are in favour of more ductile behaviour and delayed debonding failure for the retrofitted structures. The gain of energy will increase efficiency of the retrofitting system by maintaining additional strength for longer service live. The main observation is:

1. All the samples were tested under the shear-lap test conditions and the failure mode reported was debonding the CFRP sheet from the steel plate surface.
2. The ideal mixing ratio to modify the unmodified epoxy was 25 g and 30 g when using ATBN and CTBN modifier respectively in terms of ductility and toughness properties.
3. The ductility of modified epoxy resin matrix was improved by 2.2 times when the unmodified epoxy modified by 25 g of ATBN, and 0.3 times when modified by 30 g of CTBN.
4. The ability of unmodified epoxy resin to absorb the energy of the plastic deformation before it failed, was improved by 2.4 and 1.5 times when using 25 g of ATBN and 30 g of CTBN as a modifier.
5. In general, the 25 g of ATBN modified resin has the highest combined properties of ductility and toughness rather than the 30 g of CTBN modified resin.

ACKNOWLEDGMENTS

This work is a part of the PhD research of the first author under supervision of the second and the third authors. Furthermore, the staff of the Civil Lab at Deakin University acknowledged.

REFERENCES

Al-Ameri, R. 2011. Interface slip control for CFRP-concrete composite beams. In *Concrete 2011: Proceedings of the 25th Biennial Conference of the Concrete Institute of Australia: Building a Sustainable Future,* 1-10. Concrete Institute of Australia.

Al-Ameri, R. & R. Al-Mahaidi (2006) Coupled flexural-shear retrofitting of RC beams using CFRP straps. *Composite Structures,* 75**,** 457-464.

Alferjani, M. B. S., A. A. B. A. Samad, B. S. Elrawaff, N. B. Mohamad & M. H. B. Ahmad (2014) Shear strengthening of reinforced concrete beams using carbon fiber reinforced polymer laminate: A review. *American Journal of Civil Engineering,* 2**,** 1-7.

Bagheri, R., B. Marouf & R. Pearson (2009) Rubber-toughened epoxies: a critical review. *Journal of Macromolecular Science®, Part C: Polymer Reviews,* 49**,** 201-225.

Ceci, A. M., J. R. Casas & M. Ghosn (2011) Statistical analysis of existing models for flexural strengthening of concrete bridge beams using FRP sheets. *Construction and Building Materials*.

Chataigner, S., J.-F. Caron, K. Benzarti, M. Quiertant & C. Aubagnac (2011) Use of a single lap shear test to characterize composite-to-concrete or composite-to-steel bonded interfaces. *Construction and Building Materials,* 25**,** 468-478.

da Silva, L. F., T. Rodrigues, M. Figueiredo, M. De Moura & J. Chousal (2006) Effect of adhesive type and thickness on the lap shear strength. *The journal of adhesion,* 82**,** 1091-1115.

Kalfat, R., R. Al-Mahaidi & S. Smith (2013) Anchorage Devices Used to Improve the Performance of Reinforced Concrete Beams Retrofitted with FRP Composites: State-of-the-Art Review. *Journal of Composites for Construction,* 17**,** 14-33.

Khan, U., P. May, H. Porwal, K. Nawaz & J. N. Coleman (2013) Improved adhesive strength and toughness of polyvinyl acetate glue on addition of small quantities of graphene. *ACS applied materials & interfaces,* 5**,** 1423-1428.

May, C. A. 1988. *Epoxy resins: chemistry and technology*. CRC Press.

Sayed-Ahmed, E., R. Bakay & N. Shrive (2009) Bond Strength of FRP Laminates to Concrete: State-of-the-Art Review. *Electronic Journal of Structural Engineering,* 9.

Smith, B. L., T. E. Schäffer, M. Viani, J. B. Thompson, N. A. Frederick, J. Kindt, A. Belcher, G. D. Stucky, D. E. Morse & P. K. Hansma (1999) Molecular mechanistic origin of the toughness of natural adhesives, fibres and composites. *Nature,* 399**,** 761-763.

Sobrinho, L., V. Calado & F. Bastian (2012) Effects of Rubber Addition to an Epoxy Resin and Its Fiber Glass ‐ Reinforced Composite. *Polymer Composites*.