Experimental investigation on CFRP-steel bond properties using ionic liquid

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Abstract - Solving the problem of pre mature debonding of CFRP retrofitted structure is a main concern for most of structural engineers nowadays. Reducing the brittleness of the bonding agent at the CFRP/concrete interface is a major factor to avoid this behaviour. In this research, the effect of modifying the bonding agent using different percentages of ionic liquid (IL) is investigated. This paper reports on an experimental investigation on the behaviour of modified epoxy resin with IL. Steel plates were used as hosting surface of the CFRP laminates, the laminates were attached to the steel surface using the IL modified epoxy. The shear mechanism at the interface of CFRP laminates to steel plates is discussed considering the relationship between the shear and the slip at the interface. The shear stress- displacement are traced for all specimens, the results are compared with control test prepared using unmodified epoxy. A 20% IL modified epoxy shows improved Behaviour. The improvement is with respect to ductility enhancement of the overall behaviour.

Keywords: IL, CFRP, ATBN, CTBN, Two way slab.

I. INTRODUCTION

Using Carbon Fibre Reinforced Polymer (CFRP) in strengthening and rehabilitation of concrete structure had received consensus all over the world. Strengthening and retrofitting of week structure are main use of CFRP. In the United Kingdom, more than 10000 bridges made of concrete need to be strengthened or retrofitted. In USA, nearly one-third of 581000 reinforced and prestressed concrete bridges need an urgent repair due to steel reinforcement corrosion. In Europe, the cost of retrofitting reinforced concrete structures is more than $600 million every year due to the corrosion of steel reinforcement of these structures whereas the cost of retrofitting only the parking garages in Canada is approximately $6 billion [1].

Since 1930s, the United States of America have had a focus on FRP applications used in concrete structures. In fact, using this material started in the late of 1981; this had occurred when the use of FRP transferred from the state-of- art to the Actual mainstream applications. In 1980s, the use of FRP for repairing and strengthening the reinforced concrete structures began in Canada. As the Taylor bridge of Headingly was strengthened with CFRP stirrups [1], international researches were conducted in Japan as well as in Europe. The first application of FRP was developed in 1980. In Japan, even though FRP applications increased clearly after the Hyogoken Nanbu earthquake in 1951. At the end of 1997, more than 1000 projects used the Japanese FRP applications especially for seismic retrofitting after the Great Hanshin Earthquake as the number of falling concrete pieces from existing structures were raised, the codes provisions standard specifications were updated accordingly. In 1960, using FRP applications was researched in Europe. However, the applications of these composite materials took place in 1980s in Switzerland; many other successful applications, like using NSM Carbon Fibre Reinforced polymer strips technology for strengthening Ibach Bridge in 1991. Furthermore, GFRP was used for retrofitting Kattenbusch Roadway Bridge exiting in Germany.

Being a non-cheap material, the early deboding of CFRP reduces its benefit [2]. In a reinforced concrete section, it is assumed theoretically that the bond between concrete and reinforcement steel is fully rigid [3]. Accordingly, a strain compatibility resulted between the two materials is a base of analysis and design of the reinforced concrete section. Furthermore, the connection between concrete members strengthened with externally bonded CFRP composite and the composite CFRP material is not fully rigid. A connection layer, i.e. the adhesive, between concrete substrate and CFRP composite and a connection between CFRP layers are flexible; the separation and slip may occur at the interface. As a result, the connection exhibits deformations. A horizontal shear stress plays an important role of such composite action. A main concern is to avoid the vertical separation through ensuring adequate adhesive properties. Moreover, a partial interaction is a result of the flexible adhesive.

Most of codes and committees assume that there is no slip between CFRP and concrete. This is not the case since the failure mode of RC members externally strengthened by CFRP was de-bonding of CFRP layers [4]The process of laminate application as well as the surface preparation are main parameters affecting the bonding agent properties. Moreover, the quality of the work and the reliability of the material also play main effect on bond integrity [3]. The bonding epoxy properties play main role in the early debonding issue too[2]. Intensive studies are concerning with getting softer epoxy (of higher ductility) to be used in attaching the CFRP to the concrete structure, some researches [5]started using rubber liquids as an epoxy modifiers [6] suggested the use of rubber liquids of types (ATBN and CTBN) as an epoxy modifier, the results was very promising, as an improvement of the composite element ductility was achieved. Ongoing research are concerning with reaching best chemical component epoxy for this issue as well [7] Ionic liquids are considered as environment friendly materials used in different industrial applications [8]. Ionic liquids possess very interesting physical and chemical properties such as non-volatility, high electrochemical and temperature stability [8]. Ionic liquids have been used extensively in the past as a media for catalyses and as solvent for natural polymers [9-11]. Ionic liquids have also been investigated for its plasticising abilities in industrial plastics such as poly vinyl chloride [12]. In this study, the use of ionic liquid as an epoxy modifier to reduce the brittleness and improve the bonding of CFRP to steel and concrete substrates is investigated.

II. RESEARCH SIGNIFICANCE

The main goal of this study is to improve the properties of the bonding agent used in CFRP attachment to steel plates by adding IL to the epoxy resin. The modified epoxy was successful, as the ductility of the overall behaviour of the composite CFRP laminates / steel plates specimens been improved. Hence, overcoming the early debonding issue.

III. TEST MATERIALS

A. Ionic Liquid (type BMIMCL)

Ionic liquids in general are “ionic, salt-like materials” that are liquid below 100 °C. So they are in slats state, but in the liquid state. Actually, any substance which might melt without vaporizing or decomposing yields an ionic liquid. They can be used as process chemicals, mainly as separation media or as solvent. Also the ionic liquid can work as performance chemicals for example like lubricants. The ionic liquid (1-Butyl-3-methylimidazolium chloride) will be used in this research; its empirical formula is ($C_8H1_5CIN_2$), supplied by Sigma Aldrich company. And has chemical compound (chemical structure) as shown in Fig. 1 this material has a transmittance to yellowish colour, at the room temperature. The ionic liquid has no characteristic odour, it expose the liquid state, but in cold weather, it is solid.

B. MBrace Primer

MBrace primer used in this study is low viscosity polyamine is consisting of two parts: A and B to be mixed with ratio of 100:30 by weight respectively as in Fig. 2, the primer is used to be applied on and steel plates surfaces prior to the CF laminate attachment, in order to provide excellent adhesion between CF and the hosting surfaces (steel plates).

C. MBrace Saturant

MBrace epoxy used in attaching CF laminates has an ultimate tensile strength of 55.2 MPa, it is a low viscosity epoxy material basing on unique amine curing agent technology (Bisphenol A). It is consisting of two parts: resin (part A) and the hardner (part B), as in Fig 3, the mixing ratio for both parts is 100:30 by weight respectively.

The physical and chemical properties of MBrace Epoxy are summarized in Table 1

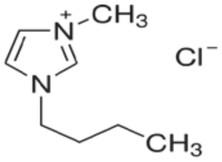

Figure 1: Chemical compound of ($C_8H_{15}CIN_2$).

Figure 2: MBrace epoxy resin parts A and B.

Figure 3: MBrace Primer parts A and B.

D.CFRP laminates

The CFRP laminates used in this study was of size 100 x 75 mm and 1 mm thickness. Been supplied by Ironbark Composites.

E. Steel plates

The steel plates which had been used as hosting surface were of 150mm x 150mm dimensions, and 5m thickness. The bonding area was 80 x 75 mm.

I. TEST PROGRAM AND PROCEDURE

A. Surface preparation

The surface of the steel plates was roughened using electrical rough disk. However, preparing the surface of the hosting material insure good adhesion with the CF laminate. The steel plate surface was cleaned from any dust prior to Primer application. The primer was applied to the steel Plates using simple painting brush, the curing time needed is at least 24 hours.

B. CFRP attachment

The hosting surface of the steel plates and the CFRP laminate surface which is to be attached were cleaned prior to the CFRP attachment, to insure that no dust could prohibit the bond between the steel plates and the CFRP laminates. The CFRP laminates were attached to the steel plates using the IL modified epoxy with different percentages, three specimens were prepared using unmodified epoxy for comparing purposes (as control specimens), another three specimens were prepared with 20% IL modified epoxy, and three specimens were glued using 30% IL modified epoxy, the epoxy resin was applied to the steel plates using a painting brush, Fig 4. The two parts of the primer as well as the epoxy components were properly mixed to gather to insure homogenous mix, the composite steel plates/ CF laminates were kept for curing 24 hours prior to the pull out test. Special clamp had been used to insure uniform bonding and also maintaining the alignment for the composite specimens as shown in Fig 5, the composite specimens were cured for 24 hours at room temperature, since the IL could be solid in cold temperature, in this study, IL was heated for 5 to 6 minutes in furnace at temperature of 60° C.

Table 1: THE PHYSICAL PROPERITIES OF THE BONDING MATERIALS (BASF COMPANY).

Material	Density (Kg/m^3)	*YS (MPa)	**UTS (MPa)	***E (MPa)	% Elongation
MBrace Primer	1102	14.5	17.2	717	40
MBrace Saturant	983	40.0	14.0	1138	5.3

* YS: Yeild strength,**UTS: Ultimate tensile strength, ***E: modulus of elasticity

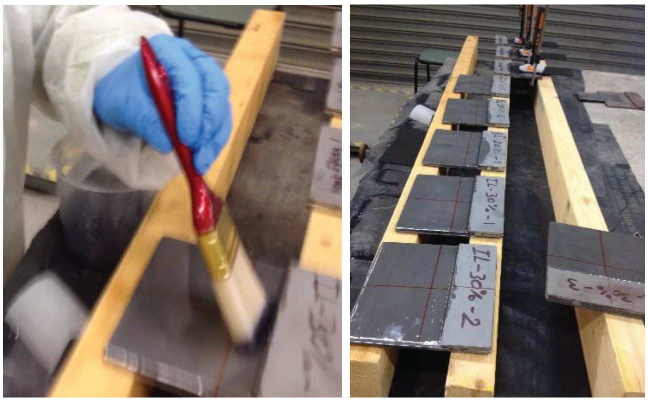

Figure 4: Applying the IL modified epoxy to the specimens.

Figure 5: Composite CFRP laminate/steel plate.

C. Direct tensile test

Universal direct tensile machine of 100 kN had been used in conducting the pull out test, the CFRP/ steel plate interface had been subjected to longitudinal tensile force. The test was conducted under displacement control of 0.1 mm/min until failure, an extensometer was used to measure the relative displacement between CFRP laminate and the steel plate, which indicates the interface slip, the load and slip was monitored during the test for all specimens until failure stage.

II. TEST RESULTS AND DISCUSSION

The ductility of the unmodified epoxy resin after been mixed with IL was improved. The improvement is presented from the trend of the load- displacement curve Fig 6 which shows that the modified resin using 20% IL gained the maximum ductility. As numerical value expressing the ductility, the ductility index was calculated for the three types of specimens, the ductility index could be defined as the ratio of the maximum deflection at maximum load to the elastic deflection. In Table 2, the higher ductility index of 14 .14 is for 20%IL modified epoxy, while 30%IL modified epoxy has ductility index of 2.85, which means that 20%IL improves the resins ductility seven times the 30%IL do, however, for the unmodified, the ductility index is not higher than 1. It is worthy to mention that, 20% IL did not affect the bond strength of the resin, as the average failure load is almost equal to the average load of control specimens. .Fig. 7 shows the CFRP/ steel plate specimen set up. The steel plate was thickened from the edge to enable clamping of the specimen in the universal testing machine The CFRP was debonded at the failure stage as in Fig. 8

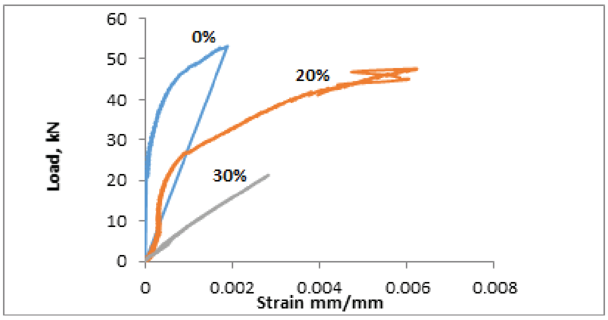

Figure 6: Load-strain curves for bonding test of CFRP laminate and steel plate using different percentages IL.

TABLE 2: TEST RESULTS.

Epoxy composition Ionic liquid / MBrace resin part A	Number of specimens	Average failure tensile load	Ductility Index
0:100	3	60	1
20:100	3	57	14.14
30:100	3	23	2.85

Figure 7: Pull-out test setup of CFRP/steel specimen.

. Figure 8: CFRP laminate debonding
With 20% IL modified epoxy.

III. CONCLUSION

- Early debonding of CFRP is regarded as a main setback for their use in strengthening and retrofitting structures.
- Modifying the bonding agent composition is an effective way to improve the behaviour of CFRP strengthened elements.
- The IL improved the toughness and the ductility of the unmodified epoxy resin.
- The results shows that 20% of IL to be mixed with the unmodified epoxy resin was the best ratio in terms of higher ductility index.
- 30% of IL is not recommended, as the ductility index was very low as well as the average failure tensile load.

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