proceedings

Proceeding

Numerical investigation of the thermomechanical behavior of steel RC elements strengthened with textile reinforced concrete in case of fire

Najib DOUK[1,*], Amir SI LARBI[1], Xuan Hong VU[2], Maxime AUDEBERT[1]

[1] University of Lyon, ENISE, LTDS (UMR 5513 CNRS), 42023 Saint-Etienne Cedex 2, France.

[2] Université de LYON, Université LYON 1; LMC2, 69622 Villeurbanne cedex, France.

E-mails: najib.douk@gmail.com, amir.si-larbi@enise.fr, xuan-hong.vu@univ-lyon1.fr, maxime.audebert@enise.fr *Correspondence : najib.douk@gmail.com +33 6 24 64 05 55

Presented at 18th International Conference on Experimental Mechanics (ICEM18), Brussels 1-5 July 2018.

Published:

Abstract: This study deals with the development of the knowledge about steel-reinforced concrete (RC) beams that are externally reinforced with textile reinforced concrete (TRC). During the last decades, TRC has been a subject of research, but few authors studied the use of TRC for a reinforcement of structural elements under fire or under combined elevated temperatures and mechanical loading. Reinforcement and protection of structures by a TRC solution under fire have got much potential but this subject is still not well studied. In this research, some aspects about the interaction between the TRC and reinforced concrete structure were numerically investigated in order to optimize the potential of TRC in fire-structural purposes.

Keywords : Textile reinforced concrete (TRC), ISO-834 fire, numerical modelling, concrete structure

1. Introduction

Authors have started to study concrete on fire since the 70's but after the tragic incidents of the tunnel under the Mont-blanc in 1999 and the Eurotunnel in 1996, there was renewed interest for this topic [1]. When a fire takes place, different aspects of concrete are affected due to physicochemical changes that happen inside the material. Consequently, structural elements exposed to fire long enough would hardly keep supporting the mechanical loads they were designed for. Among the solutions that have been proposed for mechanical resistance drop of concrete under fire is the reinforcement of structure by Carbon Fiber Reinforced Polymer (CFRP) [2]. CFRP has been used for decades for reinforcement of concrete structures at ambient temperatures. A recent study [2] has shown that the use of CFRP on concrete under fire is efficient at the first minutes of the fire exposure, as long as the temperature remains below 200 °C on the CFRP/concrete interface, which is the critical temperature for the adhesive used to attach the CFRP composite strips. Beyond this critical temperature, the reinforced structural element acts like a non-reinforced one. In addition, CFRP releases toxic fumes when exposed to high temperatures, which makes it hazardous for people living in the fired building [3]. For this purpose, a new method for reinforcing structural elements at high temperature is proposed in this paper. Textile Reinforced Concrete (TRC) has proved its efficiency on the reinforcement of structures in normal conditions [4-6]. And since TRC is attached to structures with a cementitious bond, its potential in fire reinforcing is interesting to be studied. In this paper, a numerico-experimental validation of reinforced concrete beams will be established in order to verify the reliability of the concrete elasto-plastic model. Numerical models of TRC reinforced concrete beams will be then established. Separately, two TRC reinforcement methods: NSM (Near Surface Mount) and EBR (External Bonded Reinforcement) will be explored numerically.

2. Numerical methods

This section respectively presents numerical approach, test specimens and numerical models.

2.1. Numerical approach

In this section, a finite element model is developed using the MSC Software MARC Mentat [6]. Approaching of the thermal aspect of concrete is a complex procedure. A quick state of art review has shown different approaches. The most used for structural elements is the Thermo-Mechanical approach in which the concrete is considered as a homogenous entity. The mechanical part is influenced by the thermal part by material properties degradation and thermal dilatation. Since the objective of this work is to explore the TRC reinforced elements behaviour on a structural scale, the Thermo-Mechanical approach is sufficient in our case. The thermal numerical calculation is established by implementing intrinsic thermal properties depending on temperature of each material. Concrete's and steel's thermal characteristics are taken equal to those of the EN1992-1-2 and EN1993-1-2 respectively [1]. EN1992-1-2 proposes 3 curves for the specific heat and 2 curves for the thermal conductivity of concrete. Specific heat curves change with the variation of the concrete's water content. In this case, a 3% water content is considered. The thermal conductivity varies according to the type of aggregate used for the concrete. Since this information has not been discussed in the experimental study, an intermediate curve for thermal conductivity has been considered. Thermal characteristics of TRC are taken equal to those of concrete. The structural specimen modelled is subjected to a thermal flux corresponding to the ISO-834 time-temperature procedure. The two classical heat transfer modes are taken into account: convection at the surfaces exposed to the thermal flux and conduction within the materials. Once the thermal calculations are done, a map of the temperature fields of the specimens is extracted from the calculations. Thermal degradation of mechanical properties of the constitutive materials (steel and concrete) are then calculated according to EN1992-1-2. During the thermal calculations, the thermal dilation is not taken into consideration. Steel and concrete are considered as elasto-plastic materials. Steel's behaviour is implemented by a Von-Mises plastic criterion. Concrete's plastic law is implemented using a Buyukuzturk criterion [8]. This is a criterion with a plasticity surface equal to (1) [7] which is very similar to the often used Drucker-Prager's criterion.

$$f = \beta\sqrt{3}\bar{\sigma}J_1 + \gamma J_1^2 + 3J_2 - \bar{\sigma}^2 \qquad (1)$$

Where : f is the surface of the criterion, $\bar{\sigma}$ is the limit defined by the user, J_1 is first invariant of the stress tensor, J_2 is the second invariant of the stress tensor.

2.2. *Test specimens*

Two experimental studies on structural elements under fire have been selected [2; 10]. On one hand, a numerico-experimental confrontation was done in order to validate the concrete's and steel's thermo-mechanical models. Once this validation is done, numerical models were implemented with a TRC reinforcement in order to witness the effect of the composite on the overall behaviour of the concrete structural element under fire. Table 1, Figures 4 and 5 summarize chosen test specimens. Figure 6 shows the mechanical behaviour of a TRC composite for different temperatures (varying from 25°C to 600°C). These curves were obtained by the help of the LMC2 laboratory [11].

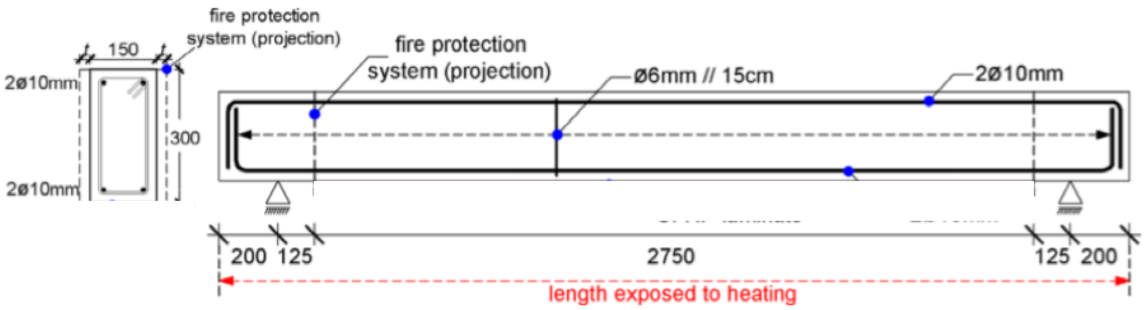


Figure 4. Geometry of the tested beam 1 "test specimen 1" [10]

Figure 5. Geometry of the tested beam 2 "test specimen 2" [2]

Table 1. Specific information about test specimen (experimental data sources: [2,10])

	Test specimen 1 [11]	**Test specimen 2** [2]
Concrete strength	30.1 MPa	32 MPa
Steel strength	500 MPa	542 MPa
Thermal load	ISO-834 (lateral and bottom faces)	ISO-834 (lateral and bottom faces)
Mechanical load	24 kN (4 point bending test)	10.2 kN (4 point bending test)

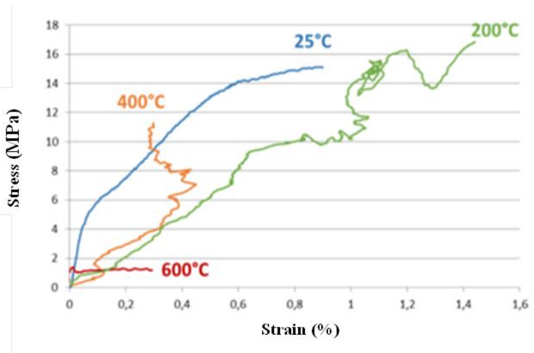


Figure 6. Thermo-mechanical behavior of TRC for different temperatures [11]

2.3. *Numerical models*

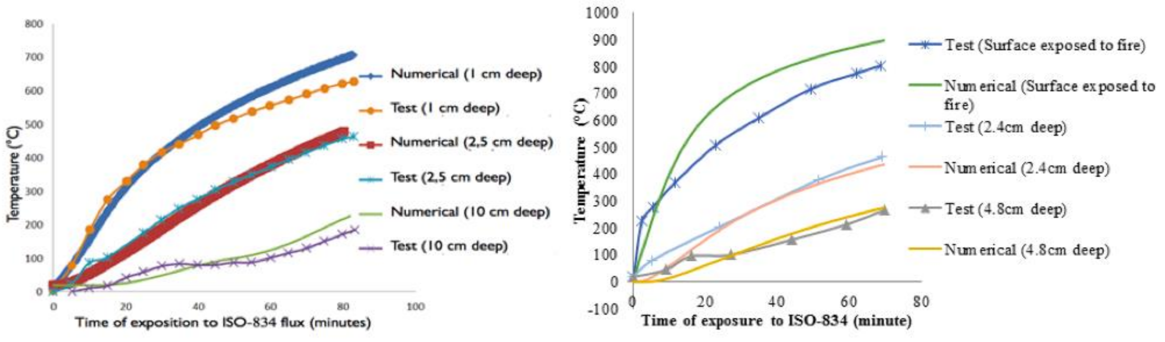
A cubic mesh is adopted for the models with 4 integration points each. Both of the models are loaded mechanically then thermally. The mechanical load consists of a 4 points bending load with a total load of 24 kN and 10.2 kN for specimens 1 and 2 respectively. Once the mechanical loads are applied, a thermal ISO 834 flux is applied on the specimen faces as described in Table 1.

3. Results

This section respectively shows thermal results and mechanical results obtained with numerical modelling of this study.

3.1. *Thermal results*

Since the temperature's evolution is the driving factor of all the thermo-mechanical phenomenon, a verification of the validity of the thermal fields with the experimental results should be done. Figures 7 shows a confrontation between numerical and experimental temperatures measured at different depths in the mid-span section of the specimens 1 and 2. Numerical thermal results showed a good agreement with the experimental measurements.

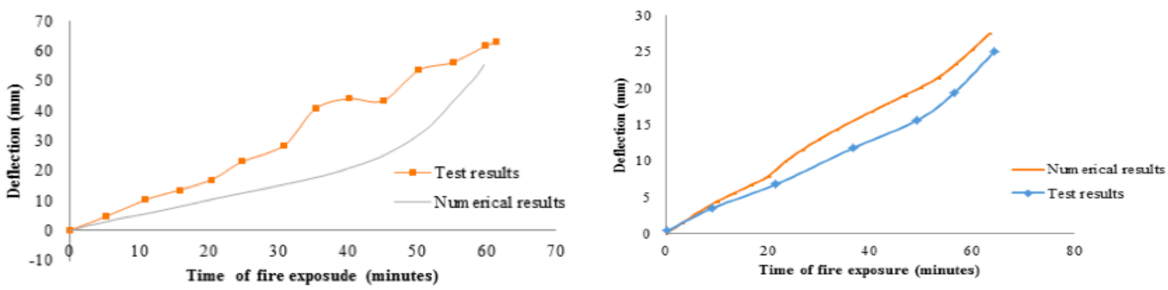


(a) (b)

Figure 7: Numerico-experimental confrontation of temperature fields: (a) Specimen 1 ; (b) Specimen 2

3.2. *Mechanical results*

For the thermo-mechanical analysis, the map of temperature fields is implemented in the calculations as a thermal boundary condition. The numerico-experimental confrontation of mid-span deflection (Figure 8) has shown that the numerical predictions of thermo-mechanical models implemented are in good agreement with the experimental tests. On this basis, the numerical model's prediction of the specimen reinforced with TRC shall be acceptable.



(a) (b)

Figure 8: Numerico-experimental confrontation of the mid-span deflection: (a) Specimen 1; (b) Specimen 2

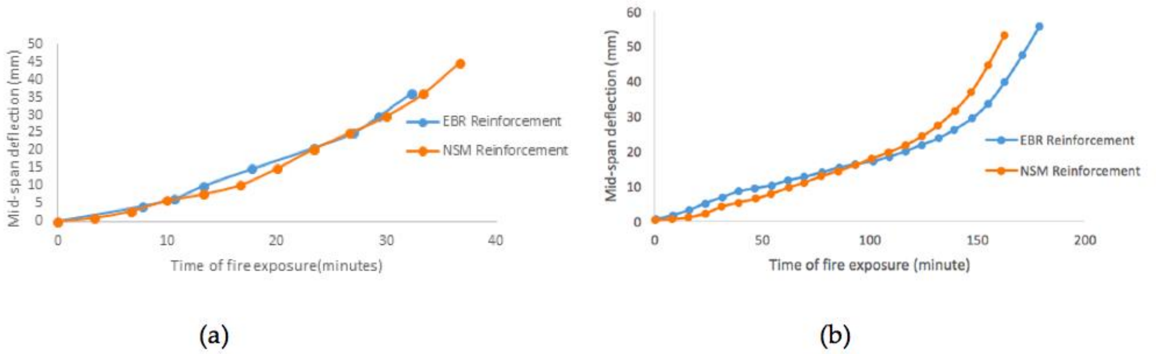


Figure 9: Numerical comparison of the reinforcement method (EBR vs NSM): (a) Specimen 1 ; (b) Specimen 2

Figures 9 shows a confrontation between numerical results of two reinforcement technics [externally bonding reinforcement (EBR) vs. near-mounted surface reinforcement (NSM)] for a structural element exposed to an ISO-834 fire. These findings show that a difference is hardly noticed between the behaviour of the two mounting configurations. A possible difference between the mechanical behaviours of the two mounting configurations can be observed if a fire-dependent contact law between the reinforcement and the beam is implemented in numerical models.

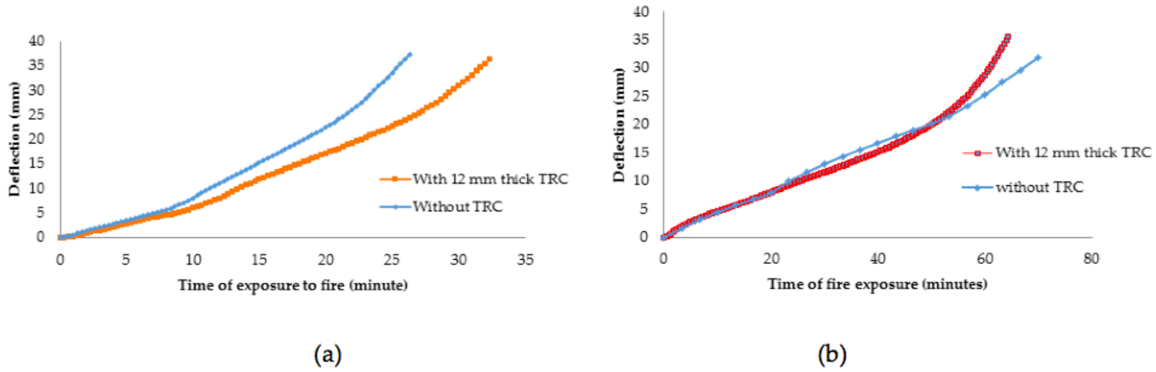


Figure 10: Numerical results: (a) Specimen 1 strengthened with TRC by EBR method and without TRC; (b) Specimen 2 strengthened with TRC by EBR method and without TRC

Figures 10 shows a confrontation between numerical results of the deflection versus the time of exposure to fire for the studied specimens strengthened with TRC by EBR method and without TRC. One can conclude the effect of the TRC on the overall behavior is absent at first: on the first minutes the behavior of the beams with and without TRC is practically the same. Once the concrete starts damaging, the reinforced specimens start having different overall behaviors. Even if the behavior of the specimen 2 with and without TRC is practically the same, it is worth saying that the TRC reinforced configurations (specimen 1) show less deflection for the same time of fire exposure. This aspect can't be noticed in specimen 2 probably because the calculation has stopped before concrete's damaging.

4. CONCLUSION

This paper showed the numerical modelling of the thermo-mechanical behavior of structural elements "beam" reinforced with TRC. The use of the intrinsic thermal characteristics of concrete and steel, featured in the Eurocode 2, ensures to obtain accurate thermal fields. The strengthening of a steel reinforced concrete beam with TRC changes the overall behavior of the specimen in case of fire. The TRC takes up the load after the concrete starts cracking in the lower part of the beam. Mounting technics only show different behavior for the reinforced beam if a fire-dependent contact law is introduced in the numerical modelling. Through this study, TRC has proven to be a good reinforcement solution in case of fire. This solution will be further developed to stand well against fire.

Acknowledgments: This research was performed with the financial subvention of the public investment bank of France (BPI France) for the lot 6 "Design method & normative aspects" of the PRORETEX II research project. This project is the collaborative research project between four industrial partners (SULITEC - project leader; FOTIA; ER2I; CIMEO) and two academic partners (ENISE/LTDS, UCBL/LMC2).

Author contributions: Najib DOUK extracted the necessary bibliography and implemented the numerical models, Amir SI LARBI, Xuan Hong VU, Maxime AUDEBERT helped to analyze and lead this work.

Conflicts of interest: The authors declare no conflict of interest, the founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

1. Eurocode 2 – Calcul des structures en béton armé [in French].
2. Joào P. Firmo, Joao R. Correira, P. França. «Fire behavior of reinforced concrete beams strengthened with CFRP laminates: Protection systems with insulation of the anchorage zones» Composites Part B: 43 (2012) 1545-1556.
3. Raphael Contamine « Contribution à l'étude du comportement mécanique de composites textile-mortier. Application à la réparation et/ou renforcement de poutres en béton armé vis-à-vis de l'effort tranchant » PHd thesis, 7 august. [in french]
4. Tala TLAIJI, Xuan Hong VU, Emmanuel FERRIER, Amir SI LARBI. Thermomechanical behavior and residual properties of textile reinforced concrete (TRC) subjected to elevated and high temperature loading: experimental and comparative study. Composites Part B 144 (2018) 99–110.
5. MSC Software Marc Mentat Volume C: Program Input
6. MSC Software MARC Mentat Volume A: theory and user information
7. Saad M.Raoof, Dionysios A.Bournas, Bond between TRM versus FRP composites concrete at high temperatures, Composites Part B: Engineering 127 (2017) 150-165.
8. Feiyru Liao, Zhaohui Huang. «An extended finite element model for modelling localized fracture of reinforced concrete beams in fire». Computers and structures 152 (2015) 11-26.
9. Zoi C. Tetta, Dionysios A. Bournas, TRM vs FRP jacketing in shear strengthening of concrete members subjected to high temperatures. Composites Part B: Engineering 106 (2016) 190-205.
10. Thiago B. Carlos, Joao P.C Rodrigues, Rogério C.A de lima, Dhionis Dhima«Experimental investigation on the flexural behavior of RC beams strengthened with CFRP laminate strips subjected to fire» IFiress2017-2nd International Fire Safety Symposium 2017.
11. Tala TLAIJI, Xuan Hong VU, Emmanuel FERRIER. Lois de comportement du composite RC-M100 en fonction de la température [in French]. Research report number 10 of the UCBL/LMC2 for the project PRORETEX II. April 2017.