



Fire Situation in Case of RC Members by Sika CFRP Strengthening

David Vazquez Cacho¹ and Yuriy Sobko²(✉)

¹ Sika Services AG, Calle Aragoneses 17, 28108 Alcobendas, Madrid, Spain

² Institute of Building and Environment Engineering (IBEE),
Lviv Polytechnic National University,
St. Bandery Street 12, Lviv 79000, Ukraine
sobko.yuriy@ua.sika.com

Abstract. The fire situation aspects especially in case of carbon fiber reinforce polymer (CFRP) strengthening of RC elements are one of major design factor in civil engineering today. Here the next options for CRFP strengthening is discussed. Option A1 when CFRP is not necessary under fire scenario and Option B - FRP is necessary under a fire scenario. Two parameters are related to the fire scenario. First parameter is reaction to fire and second parameter is structural members' fire resistance. The need for fire protection and fire resistance of RC structural elements is obtained by means of a calculating following a Eurocode procedures. Simplified expected temperatures profiles calculation process is presented. Structural analysis under fire situation of strengthened unprotected and protected member is shown as well. It is concluded that under fire scenario according to Eurocode calculation methodologies the requested fire resistance (R30–R240) can be fulfilled with no additional measure or protection at more than 80–90% of the real cases.

Keywords: Eurocode calculation · Reaction to fire · Fire resistance · Sika CFRP strengthening · Fire scenario · Structural members

1 Introduction

During the operation of buildings and structures, due to various negative effects, they suffer damage and need to be strengthened and restored (Blikharsky et al. 2019; Al Sherrawi et al. 2018; Selejdak et al. 2018; Kos et al. 2017). At present, the alternative to traditional methods of strengthening (Bobalo et al. 2018; Krainskyi et al. 2018a, b; Khmil et al. 2018) is the use of various composite materials (Vegera et al. 2018; Brózda et al. 2017). One of the most popular is the use of carbon fiber reinforced polymers (CFRP) (Blikharsky et al. 2018). The material has several advantages such as quick application, no need for special formwork, neglectable additional weight and high durability. Also the material has a number of disadvantages, such as the negative effects of ultraviolet radiation and insufficient fire resistance. However, there are ways to protect such structures from these negative influences. Therefore, the issue of fire resistance is relevant.

Two parameters are related to the fire scenario. Their limits are defined by the local regulations (national/regional/city regulations) in each country.

1-st Parameter - Reaction to fire is the measurement of how a material or system will contribute to the fire development and spread, as well as the emission of smoke/flaming droplets. According to their use, certain quantity and/or type of materials cannot be used for walls/floor/ceiling rendering. Concrete and steel do not contribute to the fire development, and do not generate smoke. In case of an adequate kind of polymer used as saturator/adhesive, the reaction to fire of the strengthening system is moderate.

According to Fire reaction tests (ITB) of multi-layer CFRP Sika systems show more than Euroclass B.

2-nd Parameter - Fire resistance of the structural member: The load bearing capacity of the member can be ensured for a specific period of time (30 to 240 min). The fire resistance is expected to provide time to the building occupants for emergency evacuation before the structure collapses (Fig. 1).

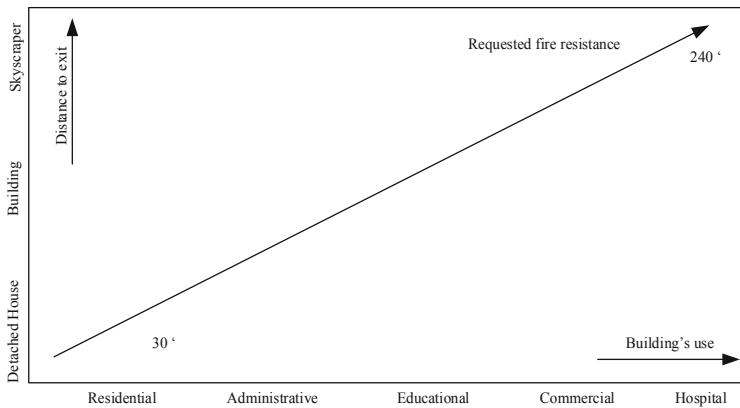


Fig. 1. Requested fire resistance vs distance to exit and building's use

Hence, the requested time to resist is commonly proportional to the quantity of people to evacuate and the distance to the exit. The fire protection for a structural member is therefore not directly oriented to the protection of the structure (e.g. the structure can collapse or be seriously damaged in case of fire, even when protected). In many cases, outdoor structures (e.g. bridges) may not need a satisfy a certain fire resistance as the evacuation is feasible in a few minutes.

2 Options for CRFP Strengthening Needing

Option A1 when CFRP is not necessary under fire scenario: requested fire resistance (R30–R240) can be fulfilled with no additional measure or protection. Option A2 when CFRP is not necessary under fire scenario as well: protection is necessary for the reinforced concrete section to meet a certain fire resistance. Those A1 and A2 options

cover > 90% of the real cases. Option B - FRP is necessary under a fire scenario: protection is necessary for the CFRP and the reinforced concrete section to meet a certain fire resistance. This Option cover < 10% of the real cases.

The need for protection and the resulting fire resistance must be obtained by means of a calculation following the Eurocode procedures.

2.1 Step 1. Need of CFRP in Case of Fire

The design of a structure is focused in ensuring the necessary strength under the expected loads. For safety reasons, the different codes take into account additional safety coefficients. Under those circumstances, an appropriate strengthening method must be displayed, so that the structural safety gap required the local regulation is achieved.

For example according to Eurocode (e.g. for residential building) for Design loads the expected loads are magnified by means of safety factors: x 1.5 for imposed loads; x 1.35 for permanent loads.

For Ultimate Strengths the material’s strengths are reduced by means of safety factors: $\gamma_c = 1.5$ for concrete; $\gamma_s = 1.15$ for steel.

The determination of the anticipated design loads under a fire scenario consists of two Rules. **General Rule** (*Eurocode 1: Actions on structures - Part 1–2: General actions - Actions on structures exposed to fire, section 4.3.1.*) is the fire loads taken as the service, un-factored loads (quasi-permanent combination of loads as usual). **Simplified rule** (*Eurocode 1: Actions on structures - Part 1–2: General actions - Actions on structures exposed to fire, section 2.4.2.*) tell us that fire loads taken as a reduced ratio of the design load (e.g. 70%).

The determination of the anticipated design strengths under a fire scenario the characteristic strengths for concrete and steel to be used (*Eurocode 2: Design of concrete structures - Part 1–2: General rules - Structural fire design, section 2.3.*). Materials safety factors: $Y_{c,fi} = 1$ for concrete; $Y_{s,fi} = 1$ for steel.

For example for the design strengths will be (Tables 1 and 2):

Table 1. Strength of concrete and steel for ULS in case of persistent & transient.

ULS, persistent & transient	Characteristic strength	Design strength
Concrete	25 MPA	25/1.5 = 16.6 MPa
Steel	500 MPa	500/1.15 = 434 MPa

Table 2. Strength of concrete and steel for ULS in case of fire situation.

ULS, fire situation	Characteristic strength	Design strength
Concrete	25 MPA	25/1 = 25 MPa
Steel	500 MPa	500/1 = 500 MPa

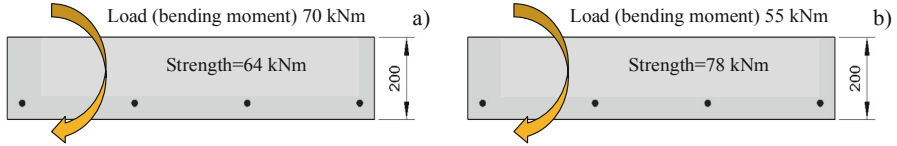


Fig. 2. Load and strength of RC slab member in case of normal design (a) and fire (b) situation

It means that when we have got normal design situation (no CFRP) and for example bending moment 70 kNm and strength of RC slab 200 mm thick equal 64 kNm the design loads exceed the design strength and CFRP is necessary to reach more than 70 kNm (Fig. 2a).

In fire situation for the same slab and load conditions the bending moment will 55 kNm and strength will 78 kNm. Design loads not exceed the design strength and CFRP is not necessary (Fig. 2b).

2.2 Step 2 (FRP not Necessary in Case of Fire). Determination of the Fire Resistance of the Section and Protection of the RC Member

A Concrete. The expected temperatures in a RC member can be evaluated by the simplified temperatures profiles existing in the Eurocode 2: Design of concrete structures - Part 1–2: General rules - Structural fire design (Fig. 3). Using the method of simplified temperature profiles, we have two possibilities. The first possibility is when it is necessary to determine the temperature at the any depth of the section of the reinforced concrete element and the time to reach this temperature. For example, (Fig. 3) for a depth of 30 mm the temperature reaches 500 °C after 90 min, and the temperature is about 760 °C will after 240 min.

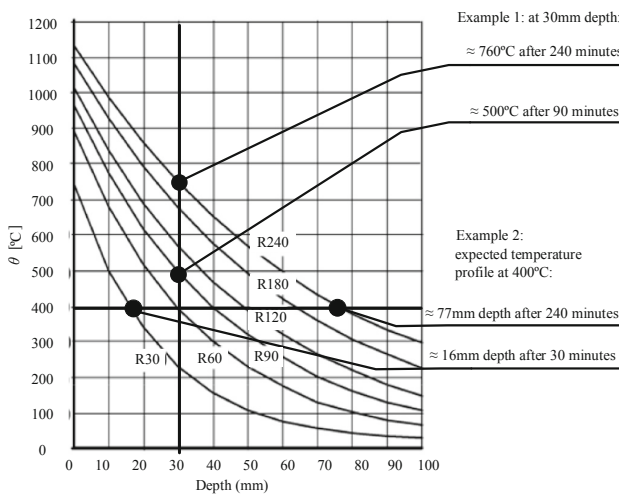


Fig. 3. Simplified temperatures profiles of RC members expected temperatures

The second possibility is when we have got the expected temperature, then we can determine at which depth from the surface of the element and through what period of time it will begin to appear. For example (Fig. 3) for the expected temperature of 400 °C we will have a depth of about 16 mm after 30 min, and about 77 mm after 240 min of fire.

The lost of concrete characteristic strength under fire loading is show at the diagrams (Fig. 4). As could be seen from the diagrams in (Fig. 4a), at 200 °C the concrete loses about 5% of its strength, at 400 °C the strength loss is about 20% and at 600 °C the concrete loses are about 50% of its characteristic strength.

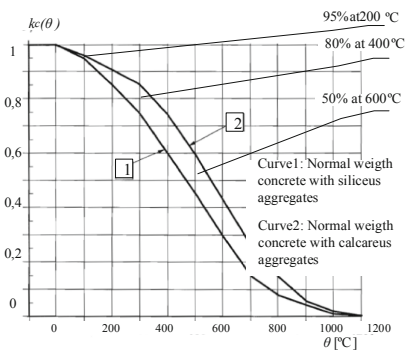


Fig. 4. Coefficient $k_c(\theta)$ allowing for decrease of characteristic strength (f_{ck}) of concrete

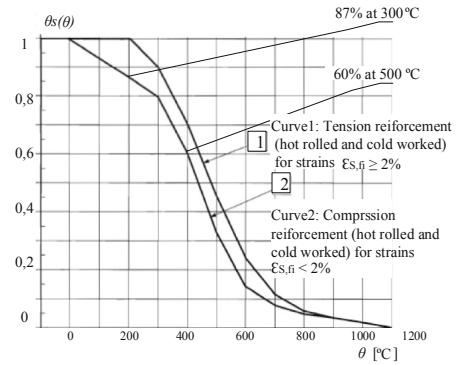


Fig. 5. Coefficient $k_s(\theta)$ allowing for decrease of characteristic strength (f_{yk}) of tension and compression reinforcement (Class X).

B Steel. The design strength is initially increased, as a consequence of the absence of safety factors. From this moment, the strength will decrease according to the fire temperature. As we see from the diagrams in (Fig. 5), at 300 °C the steel loses about 13% of its strength, at 500 °C the strength loss is about 40% of its characteristic value.

The expected temperature profiles calculation process is presented in Fig. 6. For example, first we determine the expected temperature distribution in depth of RC element by simplified temperature profiles (Fig. 3) and build the isotherms for 60 min (Fig. 6a) and for 90 min (Fig. 6b) respectively. Next, we find the losses of concrete strength, depending on the temperature (Fig. 6c, d), as well as the strength loss of the reinforcement. Then we can determine the bearing capacity of the new section of the reinforced concrete element after the fire effects. The simplified model of the 500 °C isotherm method is shown in Fig. 7.

After analysis of calculation results of load and strength development in not strengthened (Fig. 8a), strengthened by CFRP (Fig. 8b) members in case or ULS and load and strength development in protected and unprotected (Fig. 8c) members in case of SLS (fire scenario) show that strength is more than design load for RC member before and after strengthening by CFRP. In case of fire scenario we see the bigger gap

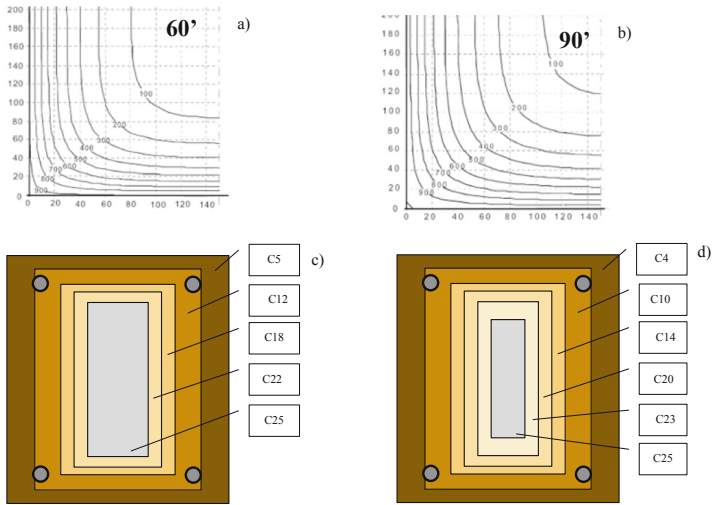


Fig. 6. The expected temperature profiles calculation process

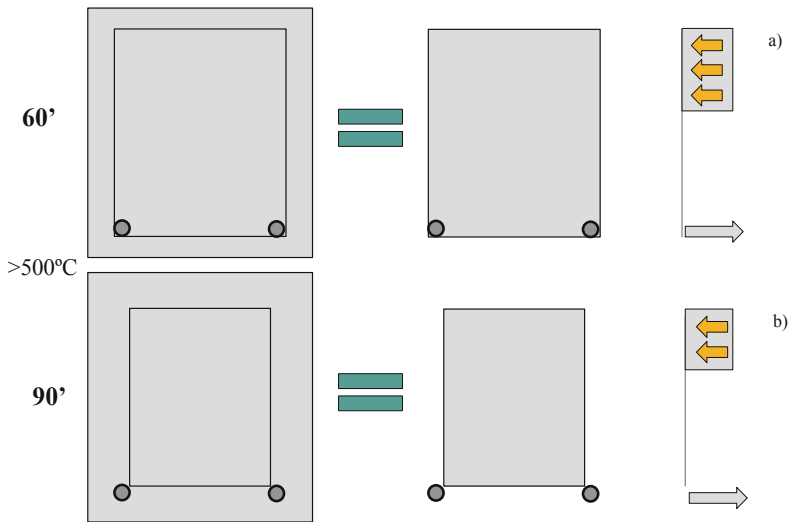


Fig. 7. The simplified 500 °C isotherm method

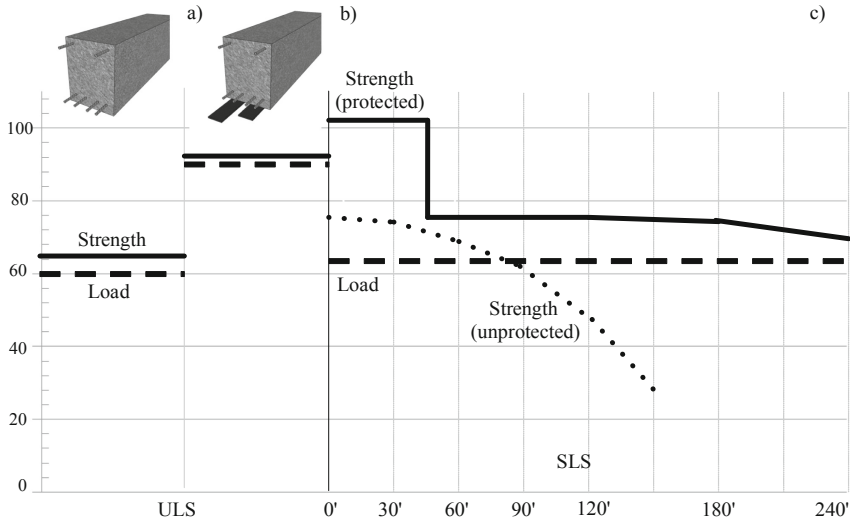


Fig. 8. Load and strength development in not strengthened (a) and strengthened by CFRP (b) members in case of ULS and load and strength development in protected and unprotected (c) members in case of SLS (fire scenario)

between strength and load that allow to have got from 60 min may be up to near 90 min time to achieve the equality between load and strength and this time will be the fire resistance of unprotected RC member.

3 Conclusions

A Eurocode calculation procedure in case of fire scenario for RC structural members strengthened by Sika CFRP has been presented. Load and strength of RC slab member in case of normal design and fire situation shows that load is decreasing and strength is increasing under fire influences with comparison of normal design case. Due to this fire resistance of RC member can reach up to R60–R90 without the fire protection measures.

References

- Al Sherrawi M, Lyashenko V, Edaan E, Sotnik L (2018) Corrosion as a source of destruction in construction. *Int J Civ Eng Technol* 9:306–314
- Blikharskyy Z, Selejdak J, Blikharskyy Y, Khmil R (2019) Corrosion of reinforce bars in RC constructions. *Syst Saf Hum Tech Facil Environ* 1:277–283. <https://doi.org/10.2478/czoto-2019-0036>
- Bobalo T, Blikharskyy Y, Vashkevich R, Volynets M (2018) Bearing capacity of RC beams reinforced with high strength rebars and steel plate. *Matec Web Conf* 230:02003. <https://doi.org/10.1051/mateconf/201823002003>

- Brózda K, Selejdak J, Koteš P (2017) The analysis of beam reinforced with FRP bars in bending. *Procedia Eng* 192:64–68. <https://doi.org/10.1016/j.proeng.2017.06.011>
- Khmil R, Tytarenko R, Blikharskyy Y, Vegera P (2018) Development of the procedure for the estimation of reliability of reinforced concrete beams, strengthened by building up the stretched reinforcing bars under load. *East Eur J Enterp Technol* 5/7(95). <https://doi.org/10.15587/1729-4061.2018.142750>
- Kos Ž, Gotal Dmitrović L, Klimentko E (2017) Developing a model of a strain (deformation) of a damaged reinforced concrete pillar in relation to a linear load capacity. *Tech J* 11(4):150–154 <https://hrcak.srce.hr/190990>
- Krainskyi P, Blikharskyy Y, Khmil R, Blikharskyy Z (2018a) Experimental study of the strengthening effect of reinforced concrete columns jacketed under service load level. *Matec Web Conf* 183:1–5. <https://doi.org/10.1051/mateconf/201818302008>
- Krainskyi P, Blikharskyy Y, Khmil R, Vegera P (2018b) Influence of loading level on the bearing capacity of RC columns strengthened by jacketing. *Matec Web Conf* 230:02013. <https://doi.org/10.1051/mateconf/201823002013>
- Selejdak J, Khmil R, Blikharskyy Z (2018) The influence of simultaneous action of the aggressive environment and loading on strength of RC beams. *Matec Web Conf* 183:1–6. <https://doi.org/10.1051/mateconf/201818302002>
- Vegera P, Vashkevych R, Blikharskyy Z (2018) Fracture toughness of RC beams with different shear span. *Matec Web Conf* 174:1–8. <https://doi.org/10.1051/mateconf/201817402021>
- Blikharskyy Y, Khmil R, Blikharskyy Z (2018) Research of RC columns strengthened by carbon FRP under loading. *Matec Web Conf* 174:1–8