University of Baghdad
College of Engineering
Department of Civil Engineering

Performance of Encased GFRP Pultruded I-Section Beams under Fire Exposure

By:

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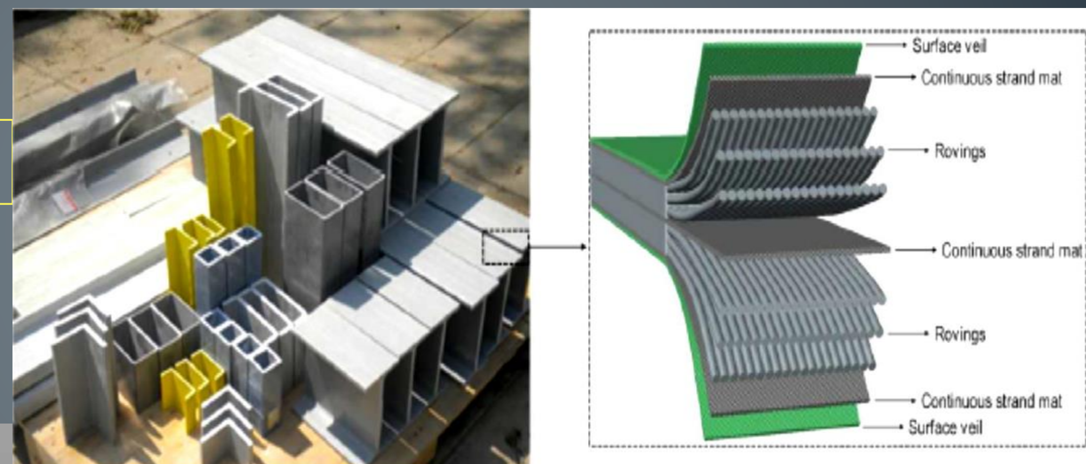
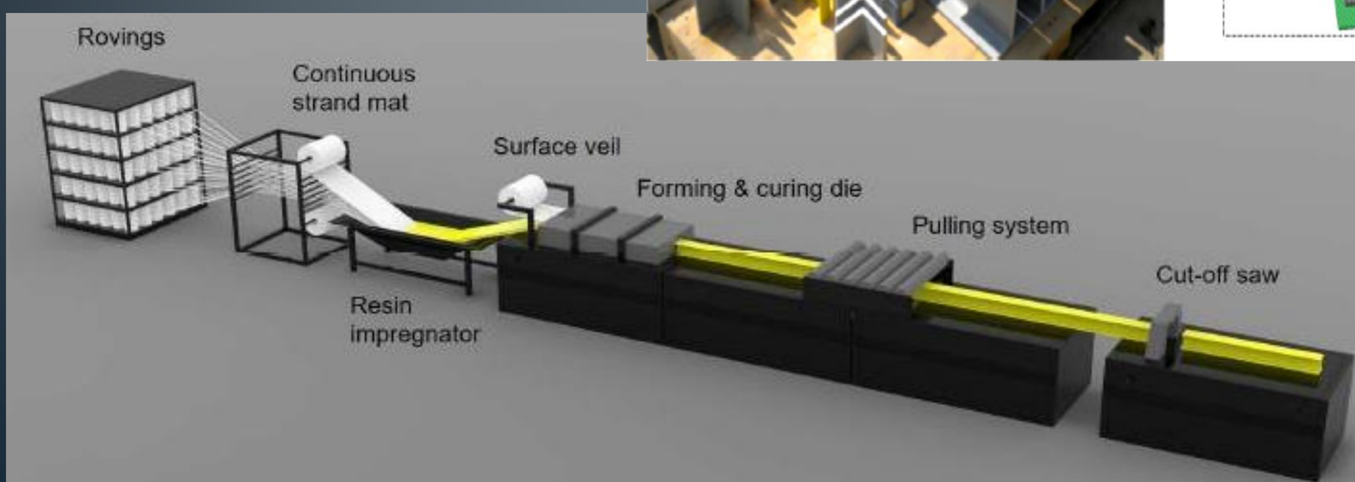
Introduction:

Glass Fibre Reinforced Polymer (GFRP) : is a composite material made of a polymer resin matrix reinforced by embedded glass fibres. GFRP is manufactured by pultrusion technology..

(GFRP) pultruded sections





Pultruded Process

Introduction:
Advantages and disadvantages of GFRP:

GFRPs are commonly used due to their advantages, such as

- High strength-to-weight ratio.
- Superior corrosion and chemical resistance,
- Low thermal conductivity,
- Electric insulation.
- Dimensional stability.
- A long life cycle.
- Low-maintenance.

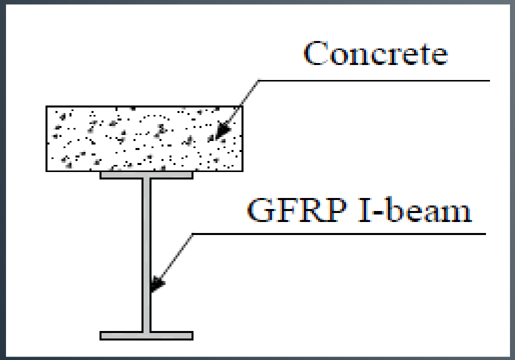
Disadvantages:

- Relatively low stiffness.
- Brittle behaviour.
- High initial costs of these advanced materials.
- Design constraints due to instability or large deformations.
- The lack of codes.

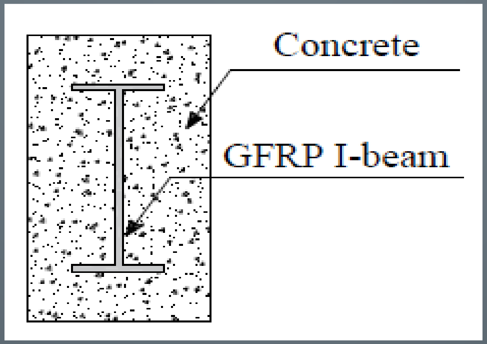
Introduction:

Types of composite section:

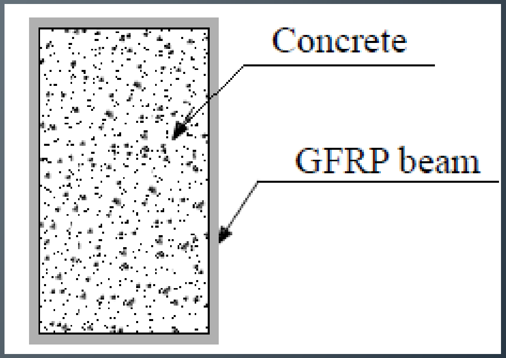
- The pultruded GFRP profiles are appropriate for the GFRP structures. Additionally, it is employed with various materials to create composite members.
- Most of the composite beams designed have been built by combining (GFRP) profiles with concrete because of their low cost and high structural efficiency. Concrete is also preferred because it can provide confinement, increase flexural stability, strength, and stiffness.



The composite GFRP beam- RC deck



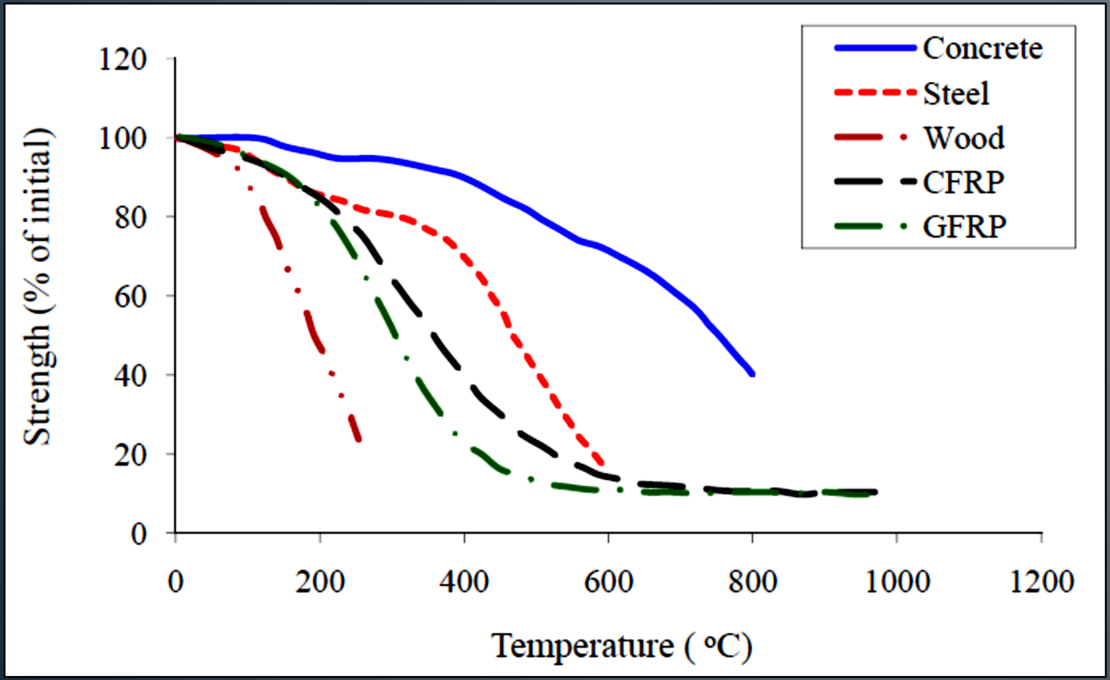
Encased beam



Concrete-filled GFRP tube

Introduction:
Behavior of FRP exposure to fire

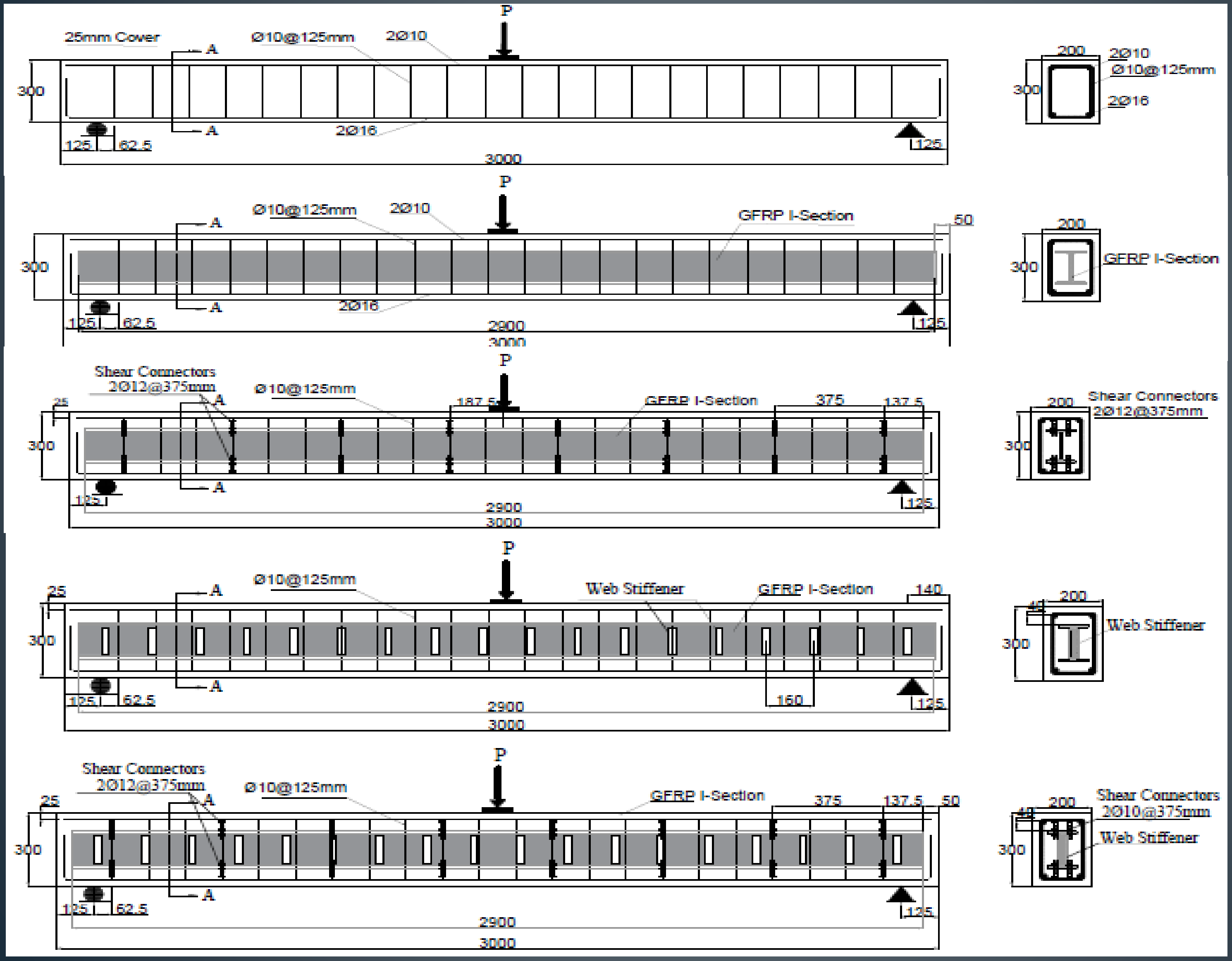
- Like other building materials, FRP loses stiffness and strength as the temperature rises. However, the FRP properties degrade more quickly when comparison to steel or concrete since the FRP matrix properties begin to degrade even at low temperatures. .



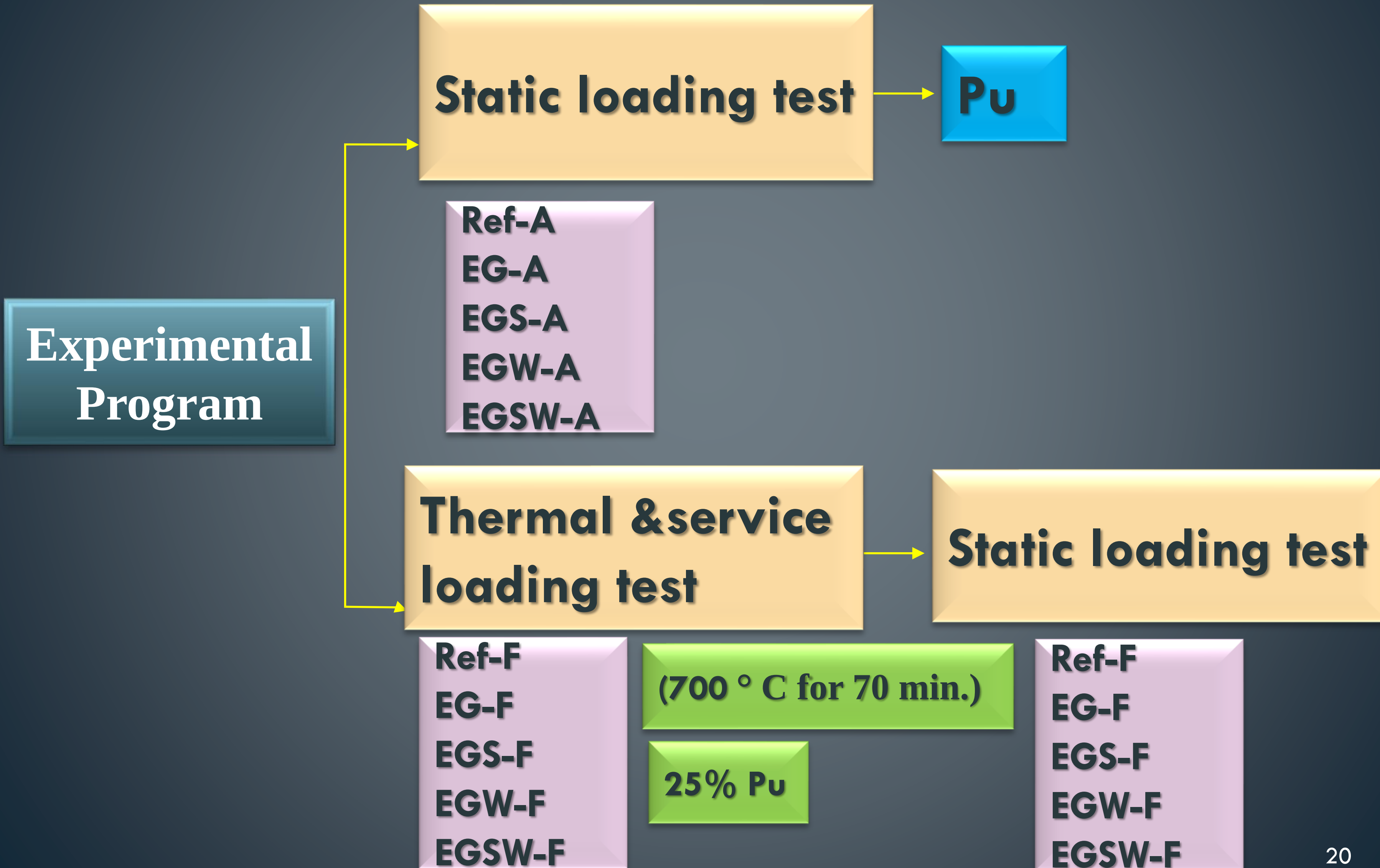
Objectives of the study

1. Study experimentally the performance of encased pultruded GFRP I-section beam with high-strength concrete under static and fire loading.
2. Comparative studies between the behavior of encased GFRP I-section beams and conventional reinforced concrete beams, and comparison between the response of encased beams at ambient and elevated temperature.
3. Evaluating the post-fire residual strength of the deteriorated encased beams at ultimate.
4. Enhancing the ductility and assessing the absorption energy capacity of encased beams by carrying out the experimental test.
5. To investigate some significant parameters in such as the effect of adding shear connector, web stiffeners, compressive concrete strength, and tensile strength of pultruded GFRP I-section beam.
6. Proposing Finite element models to simulate the performance of encased pultruded GFRP beam under static and fire loading. Static and thermal finite element analyses are developed using the ABAQUS program.

Experimental work



Experimental work



Experimental work

Mechanical Properties of Concrete at Ambient and Elevated Temperature

Compressive Strength Test

Splitting Tensile Strength Test

Modulus of rupture Test

Modulus of Elasticity Test

Temperature	Compressive Strength f_c' (Mpa)	Splitting Tensile Strength f_{ct} (MPa)	Modulus of Rupture f_r (MPa)	Modulus of Elasticity E_c (MPa)
Ambient	53.8	4.43	4.8	30631
700 °C	17.4	0.41	1.1	13917

Experimental work

Mechanical Properties of Steel at Ambient and Elevated Temperature

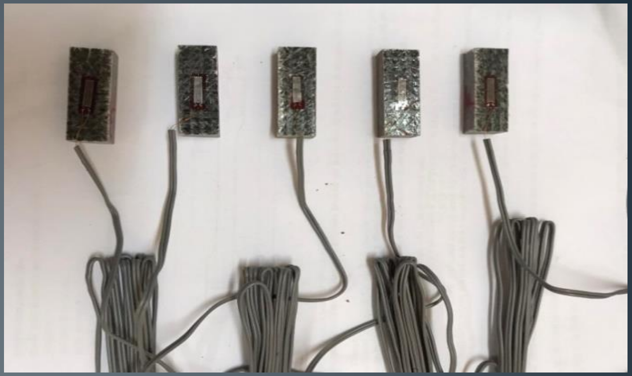
Steel specimens of tension test

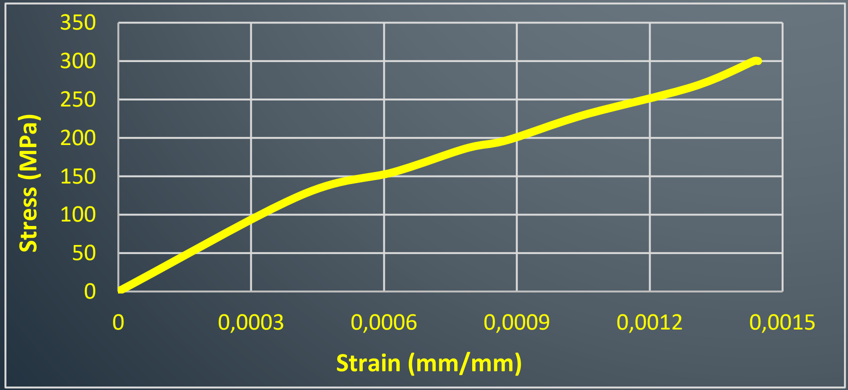
Steel tensile test

Steel bar diameters (mm)	Temperature (˚C)	Yield tensile stress f_y (MPa)	Residual yield tensile stress f_y (%)	Ultimate tensile strength f_u (MPa)	Residual ultimate ensile strength f_u (%)
Ø10	ambient	408	100	466	100
	700	339	83.1	361	77.5
Ø16	ambient	520	100	687	100
	700	434	87.1	551	80.2

Experimental work

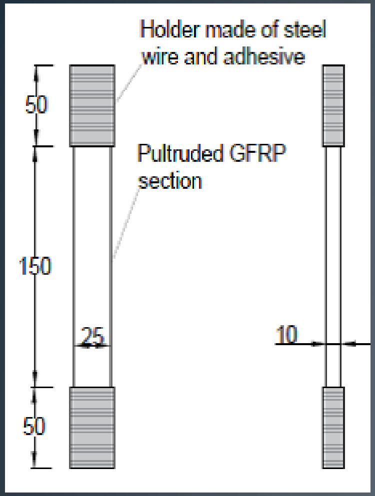
Compressive Properties of GFRP According to ASTM D 695–15

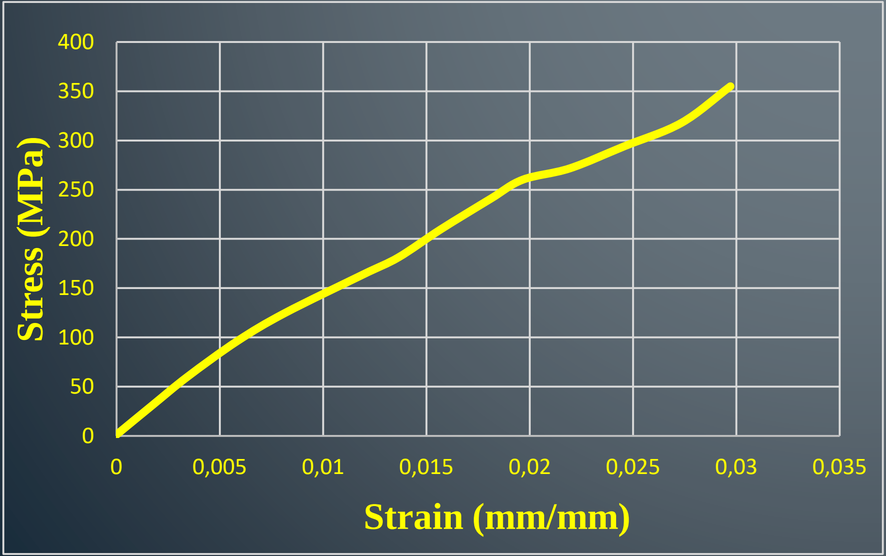




Experimental work

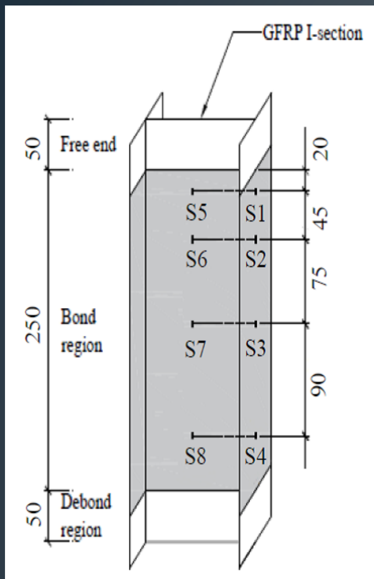
Tensile Properties of GFRP According to ISO 527-5 1997

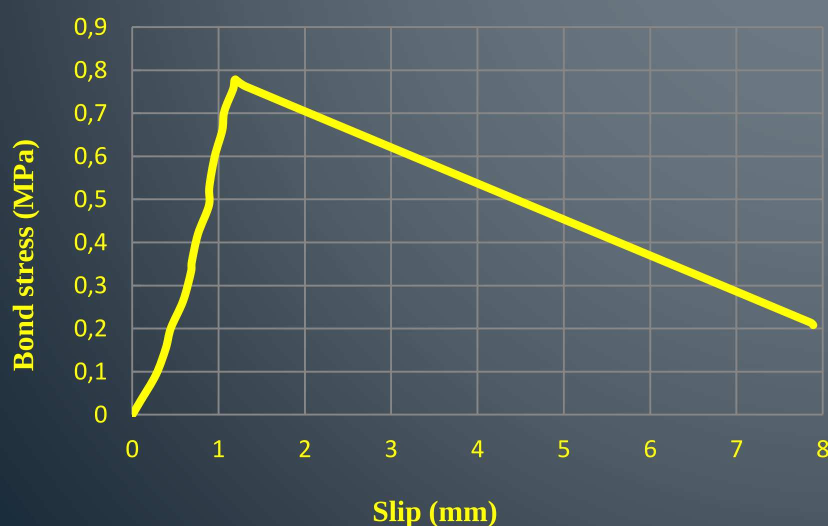




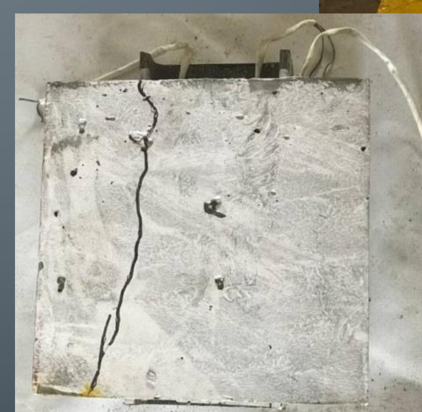
Experimental work

Push out test of GFRP





$$\tau = \frac{P_p}{L_p C}$$



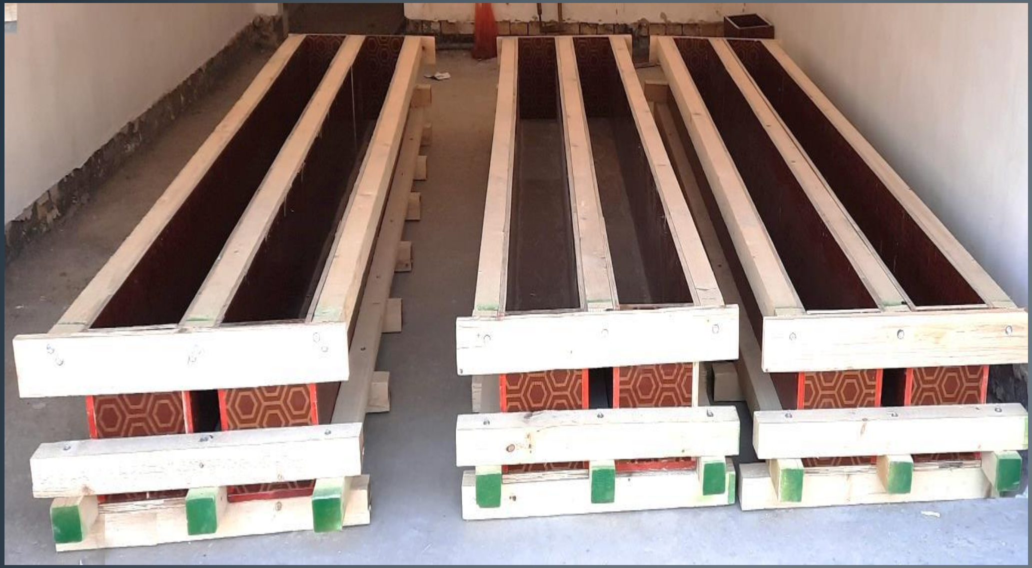
Experimental work

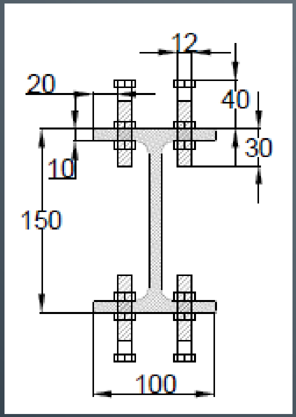
Properties of Pultruded GFRP I-Section Beam

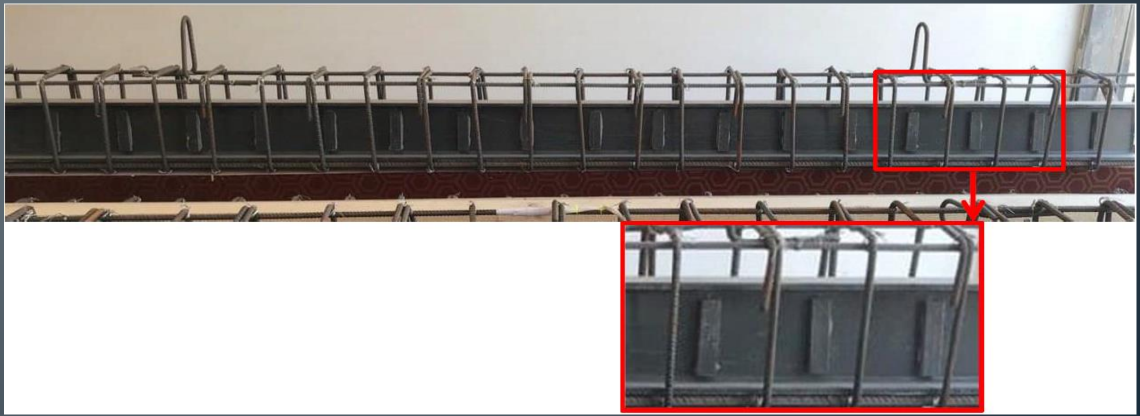
Mechanical properties data	
Transverse Compressive Strength (MPa)	118.3
Longitudinal Compressive Strength (MPa)	326.14
Longitudinal Tensile Strength (MPa)	347.5
Longitudinal Modules of Elasticity (MPa)	27100
Transverse Modules of Elasticity (MPa)	6800
Longitudinal Compressive Strain (%)	0.225
Transverse Compressive Strain (%)	0.93
Longitudinal Tensile Strain (%)	2.735
Longitudinal Compressive Confined Strength (MPa)	354.17
Longitudinal Confined Modules of Elasticity (MPa)	26.64
Longitudinal Compressive Confined Strain (%)	0.322
Geometrical properties data*	
Area (mm^2)	3300
Perimeter (mm)	680
Moment of inertia (mm^4)	11647500
Mass (Kg/m)	5.94
Web and Flange thickness (mm)	10
Physical properties data*	
Relative density	1.6-2.1
Water absorption (%)	0.5
Specific Heat (KJ)	1.5
Thermal Conductivity (W/mk)	0.37
Coefficient of thermal expansion (1/k)	1.3 E-5

Experimental work

Preparing of specimens

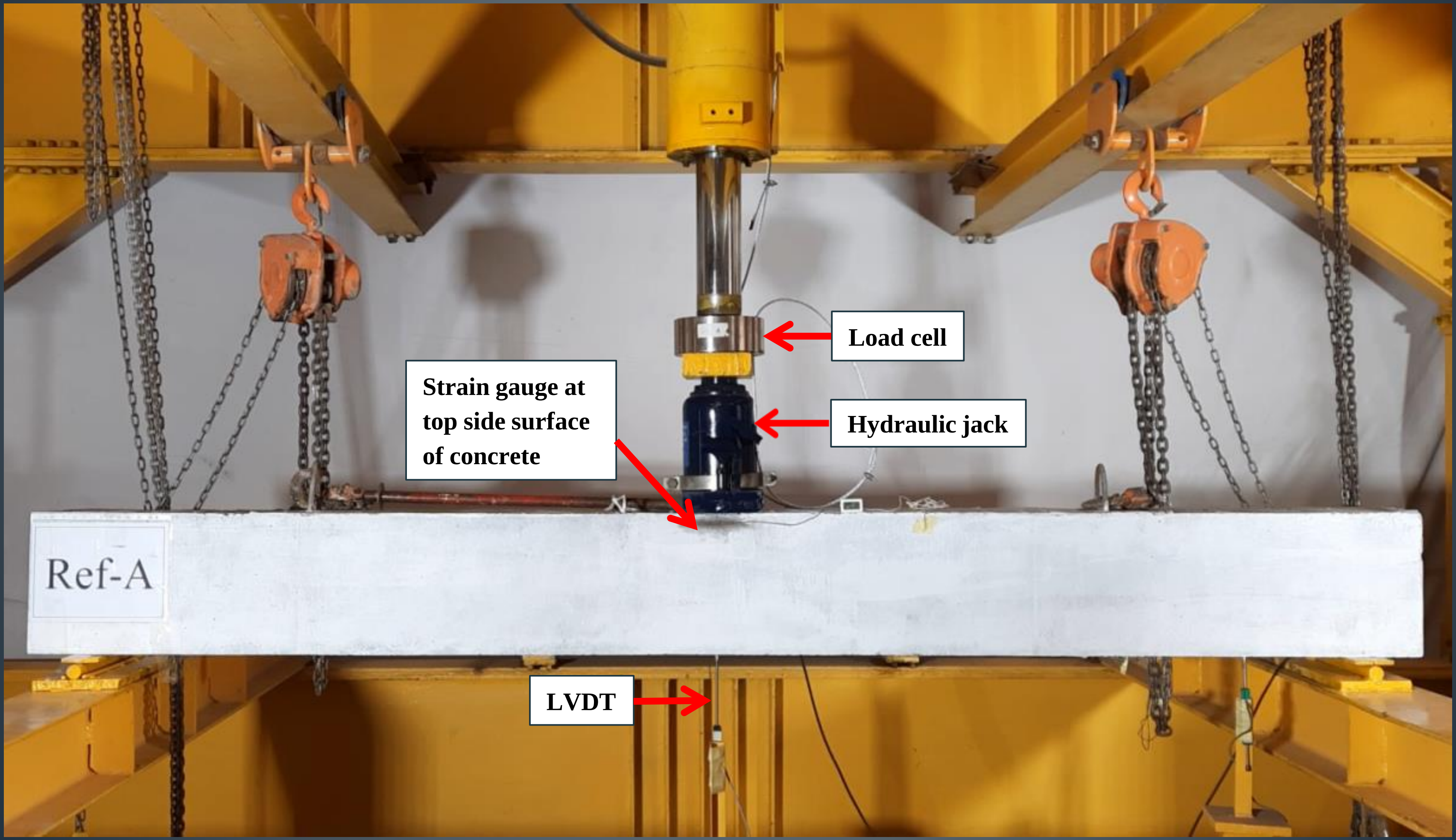




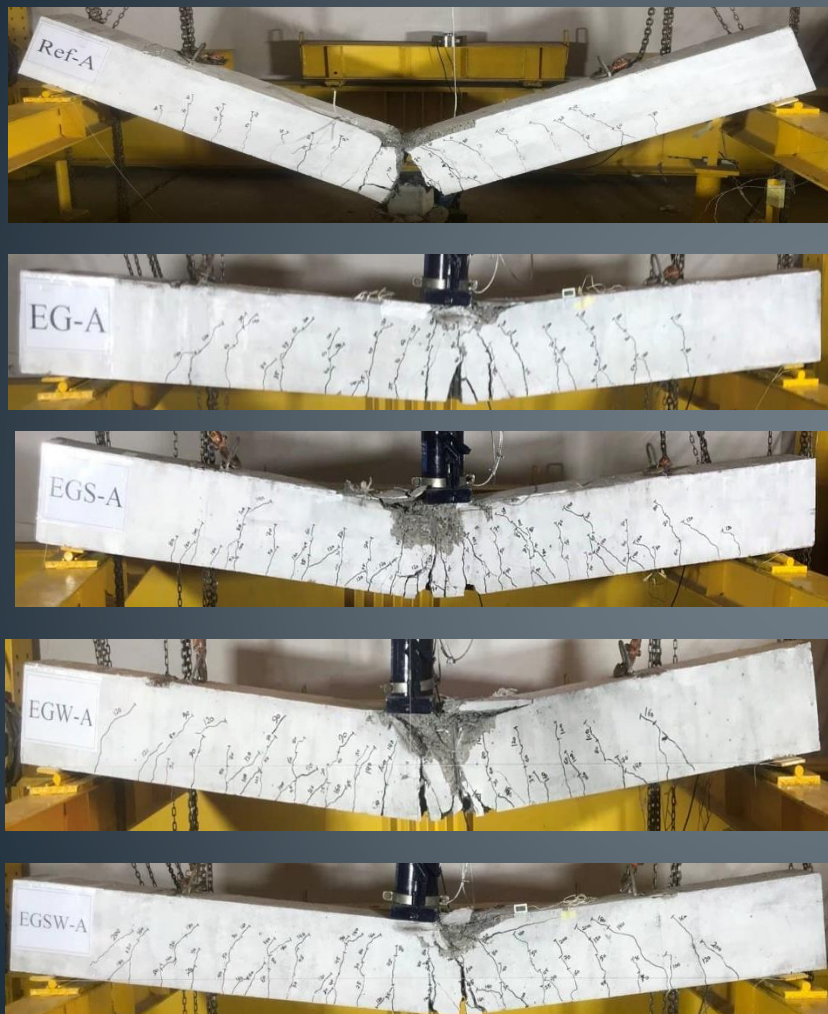


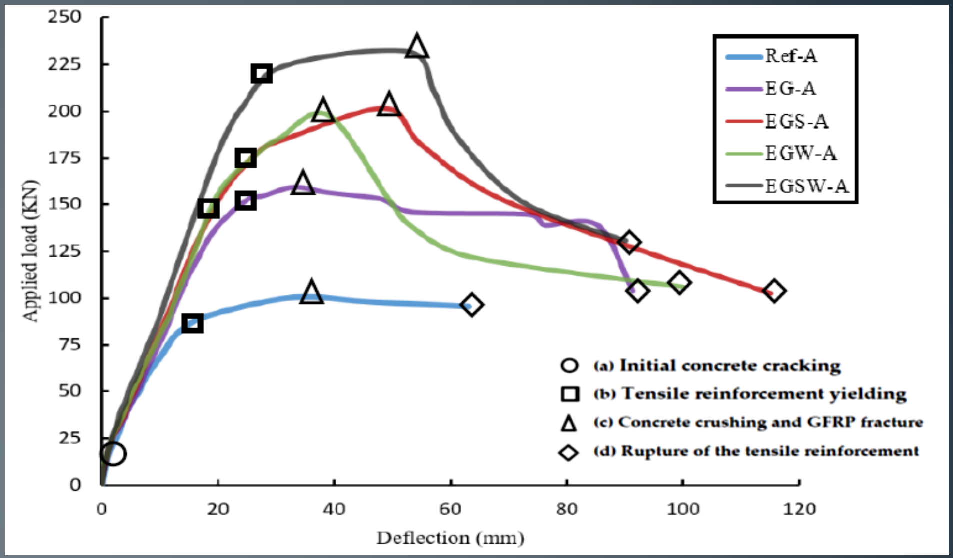
Experimental work

Static test results



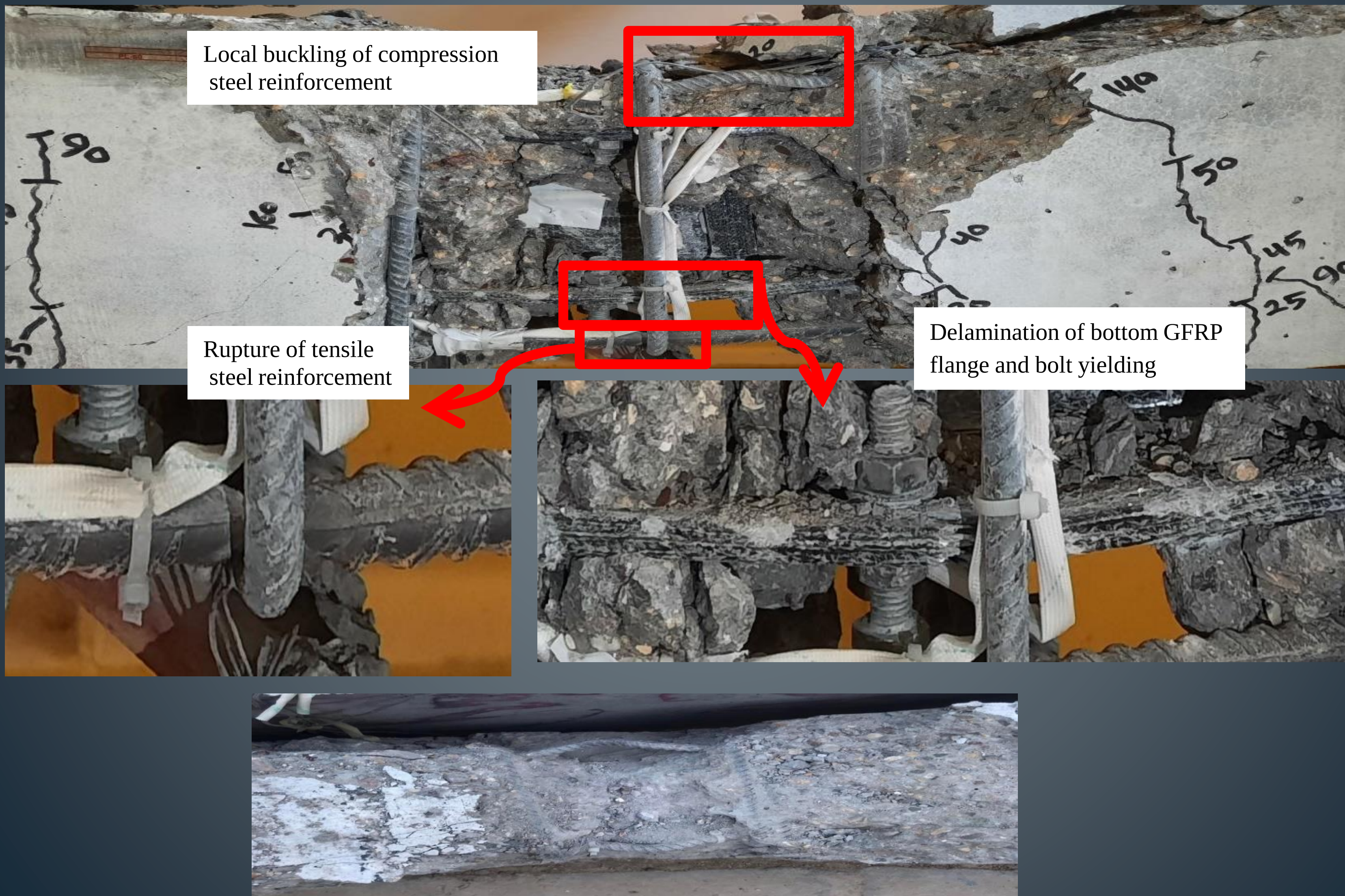
Static test results





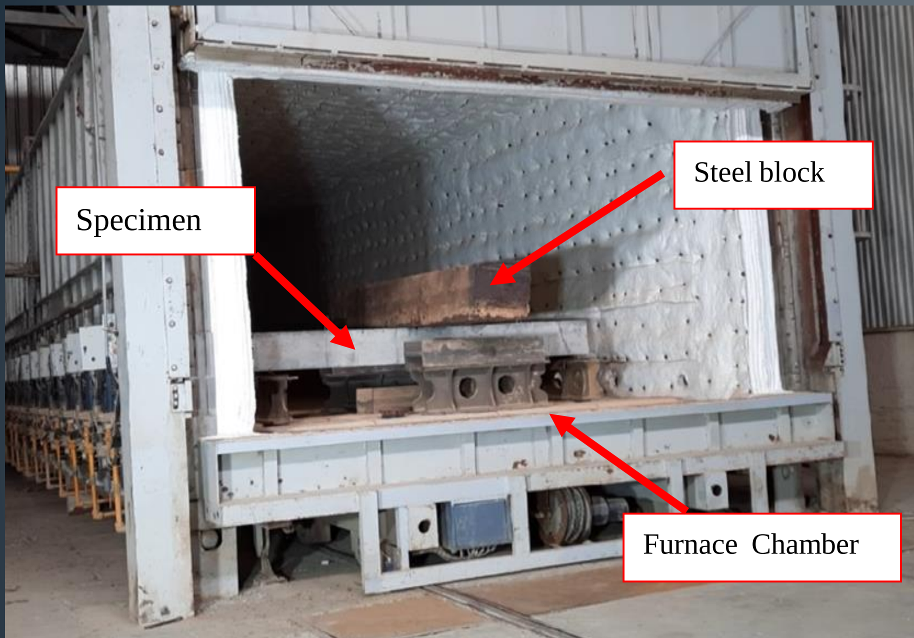
Specimens	Initial crack load (KN)	Yield load (KN)	Ultimate load (KN)	Change (%)	Central disp. (mm)	Change (%)
Ref-A	19.93	90.22	100.46	-	32.80	-
EG-A	20.24	151.81	159.04	+58.3	33.07	+0.8
EGS-A	19.73	148.26	201.54	+100.6	48.68	+48.4
EGW-A	20.12	175.20	198.24	+97.3	38.96	+18.8
EGSW-A	22.26	224.43	231.88	+130.8	52.56	+60.2

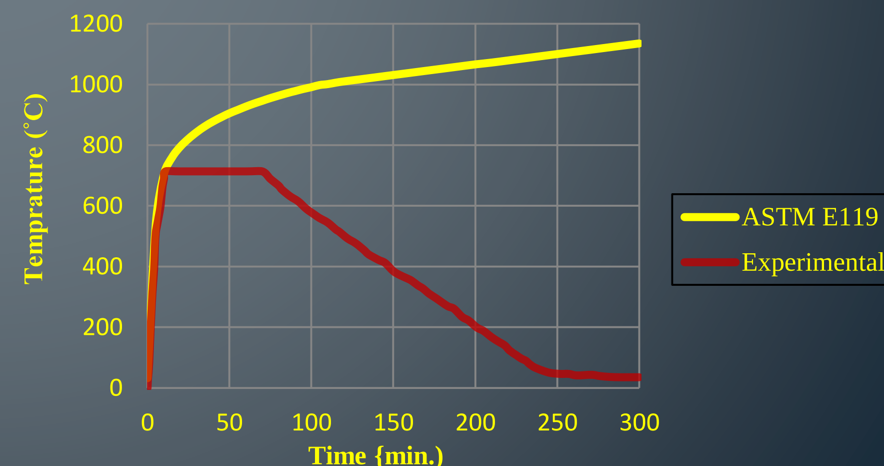
Static test results



Experimental work

Fire test





Experimental work

Fire damage beam test

25 KN

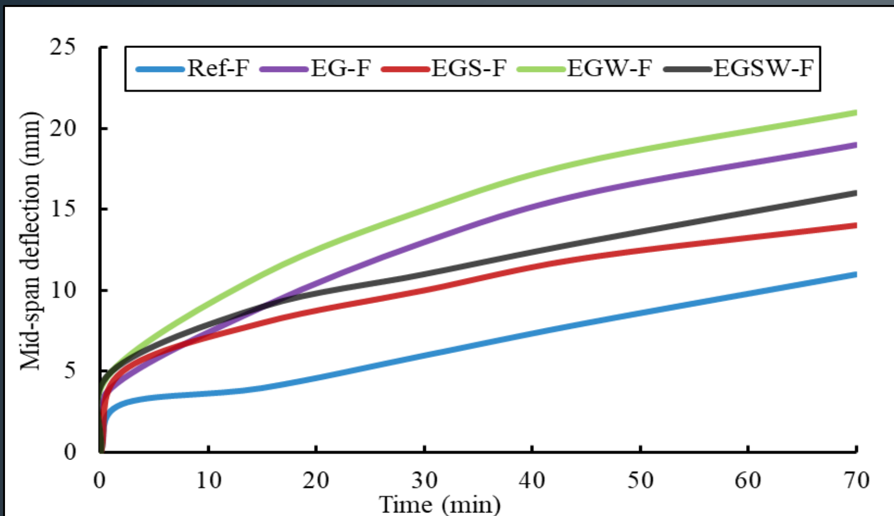
40 KN

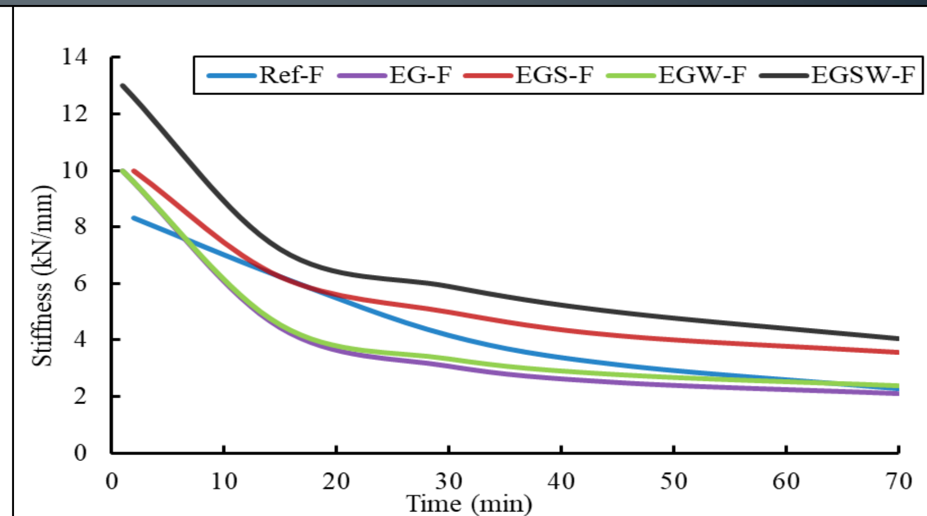
50 KN

65 KN

Experimental work

Thermal test

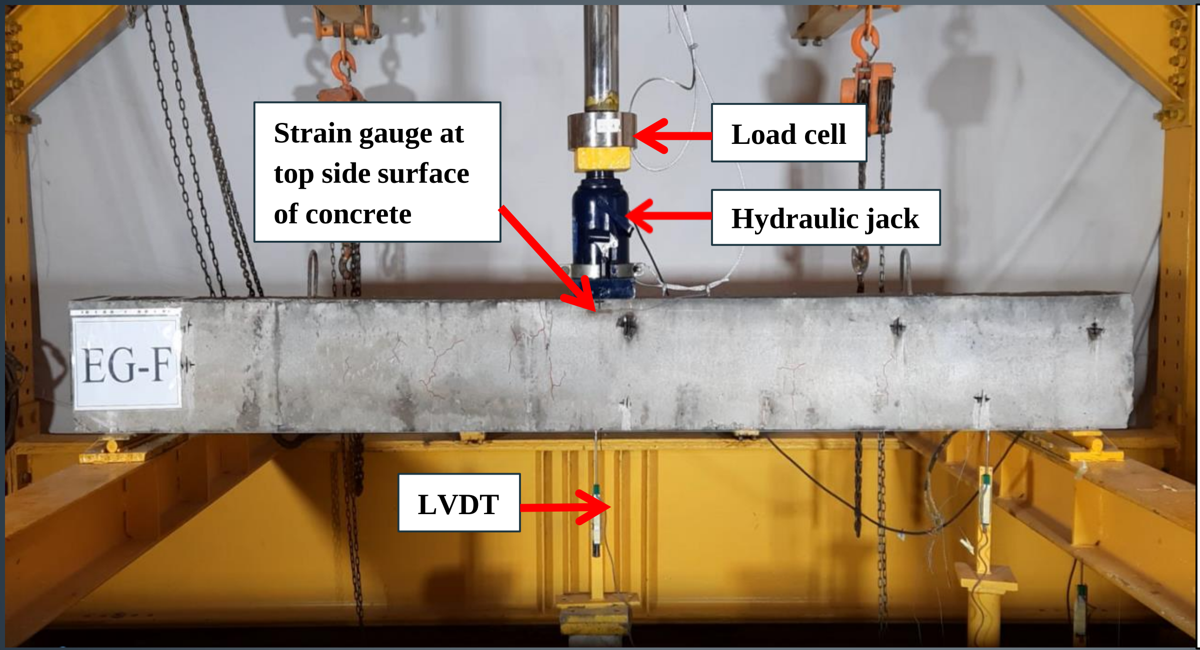


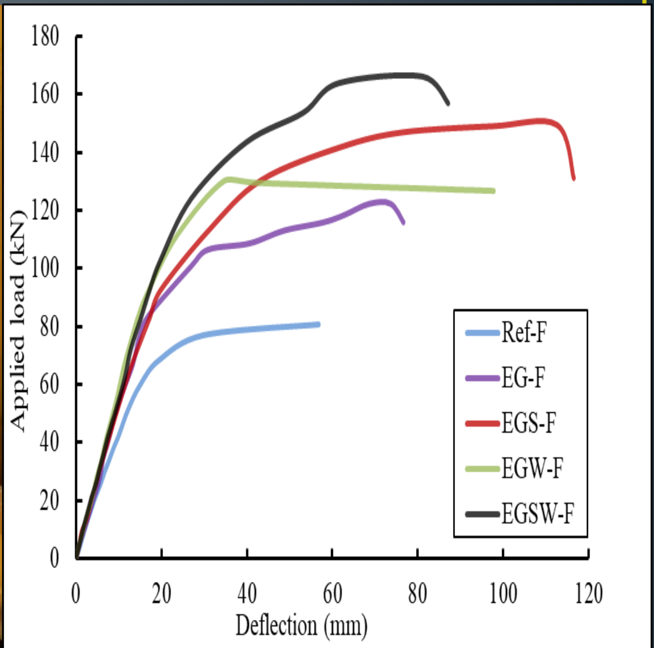


Specimens	Initial Deflection (mm)	Initial stiffness (KN/mm)	First period ASTM-E119 @ 10 min.		Second period Exposure 700°C @70 min.		Third period Cooling	
			Deflection (mm)	Stiffness (KN/mm)	Deflection (mm)	Stiffness (KN/mm)	Ultimate Deflection (mm)	Final deflection (mm)
Ref-F	3	8.33	4	6.25	11	2.27	16	1
EG-F	4	10	7	5.71	19	2.10	25	3
EGS-F	5	10	7	7.14	14	3.57	23	1
EGW-F	5	10	9	5.55	21	2.38	32	3
EGSW-F	5	13	8	8.13	16	4.06	27	2

Experimental work

Strength and Residual Response

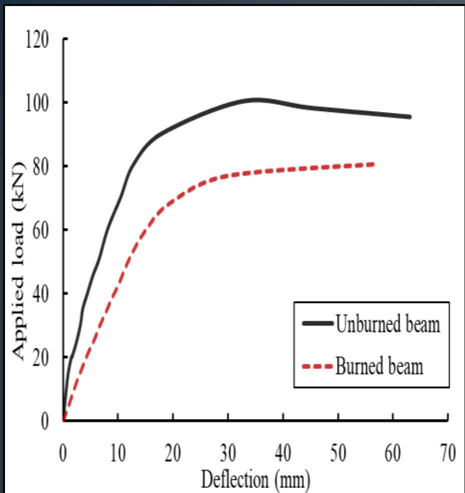




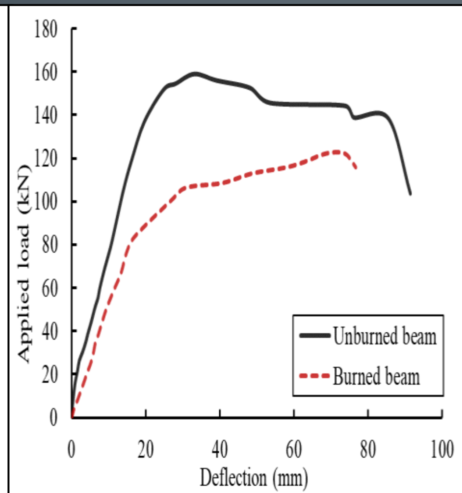
Specimens	Yielding load (KN)	Peak load (KN)	Ultimate deflection (mm)	Strain in concrete (mm/mm)	Change in strain (%)	Change in yielding load (%)	Change in peak load (%)
Ref-F	59.8	80.6	56.7	0.0029	-	-	-
EG-F	83.6	122.1	68.6	0.0032	+10	+39.7	+51.5
EGS-F	92.5	149.6	112.5	0.004	+38	+54.4	+85.6
EGW-F	93.1	130.1	34.7	0.0033	+14	+55.4	+61.3
EGSW-F	107.1	166.2	81.1	0.0033	+14	+78.7	+106.2

Experimental work

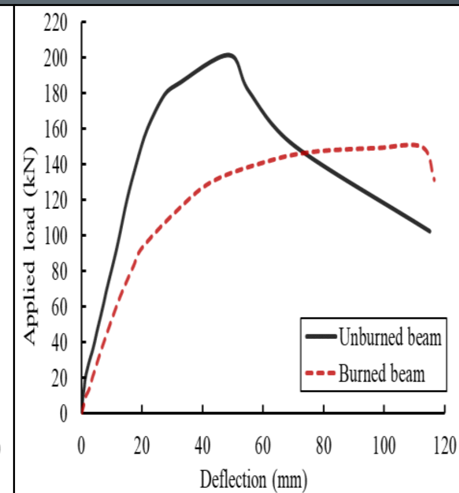
Residual behaviour comparison between unburned and burned beams



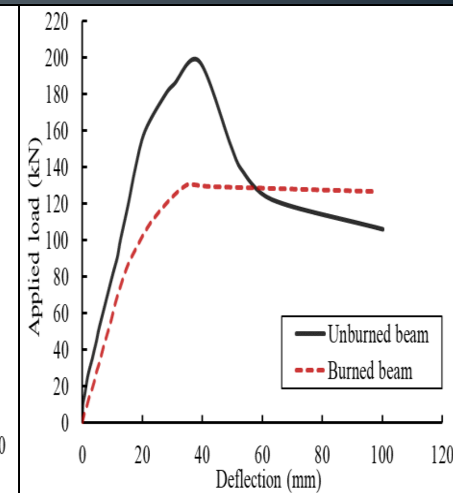
Ref



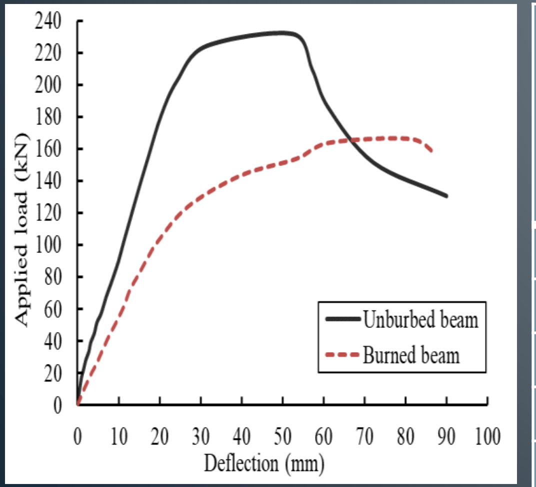
EG



EGS



EGW



EGSW

Specimen	Unburned		Burned		Change (%)	
	Peak load (kN)	Displacement @ peak load (mm)	Peak load (kN)	Displacement @ peak load (mm)	Peak load	Disp.
Ref	100.4	32.8	80.6	56.7	-19.7	+72.9
EG	159.1	33.1	122.1	68.6	-23.1	+107.7
EGS	201.5	48.6	149.6	112.5	-25.7	+131.2
EGW	198.2	38.9	130.1	34.7	-34.3	-10.8
EGSW	231.8	52.5	166.2	81.1	-28.3	+54.4

Experimental work

Thermal strain and failure mode

Experimental work

failure mode of fire damage beams

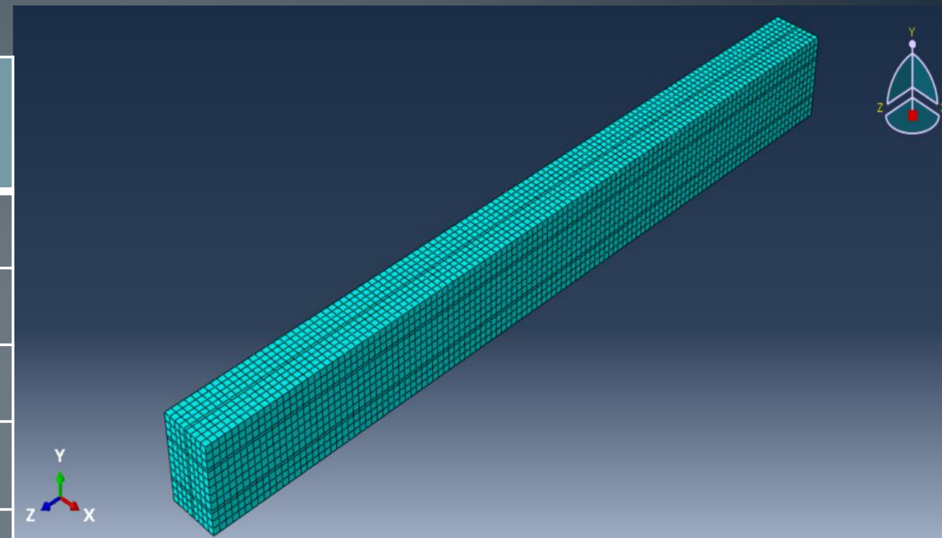
Numerical analysis

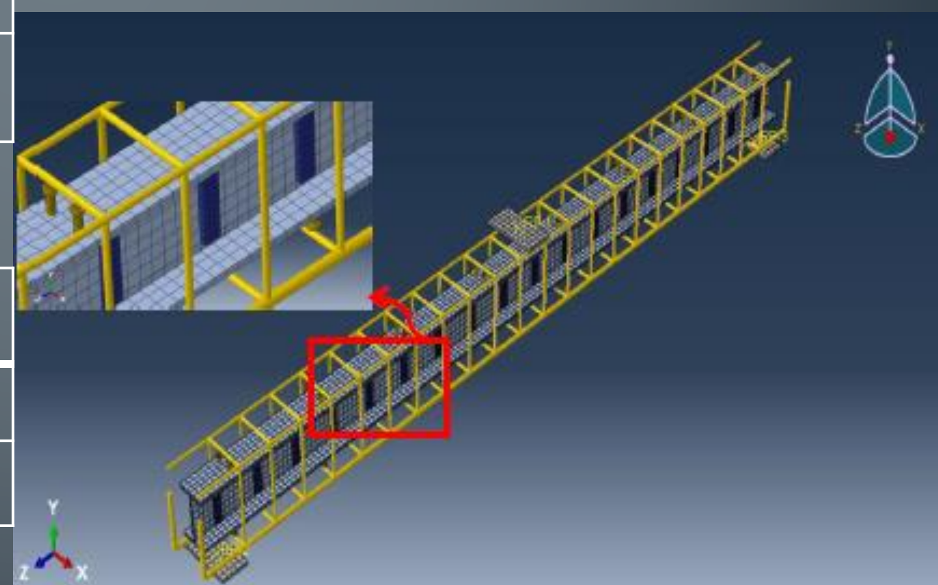
Element Type:

Instance	Static analysis	Thermal analysis
Concrete	C3D8R	C3D8T
Steel	T3D2	T3TD2
GFRP	S4R	S4T
Shear connector	C3D8R	C3D8T
Web stiffener	S4R	S4T
Steel Plate	C3D8R	C3D8T

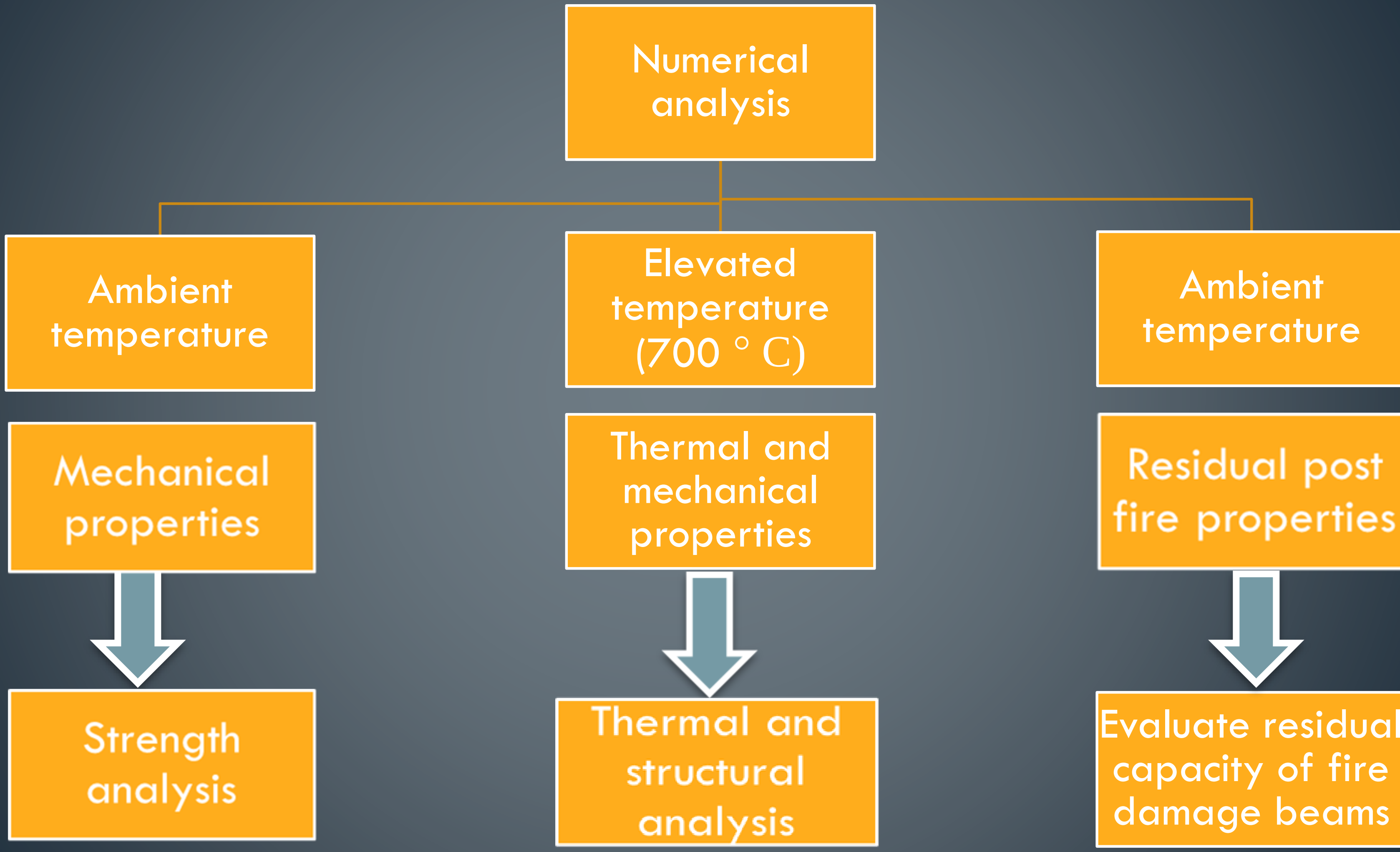
Material modelling

Concrete	Concrete damage plasticity
Steel	Elasto-plastic model
GFRP	Hashin’s criteria



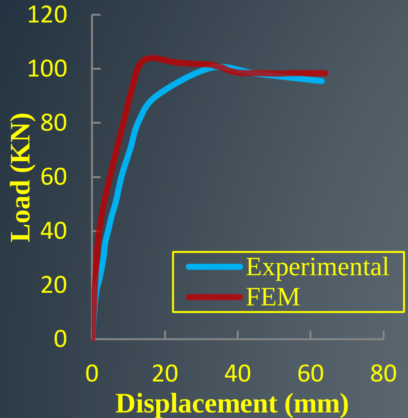


Numerical analysis

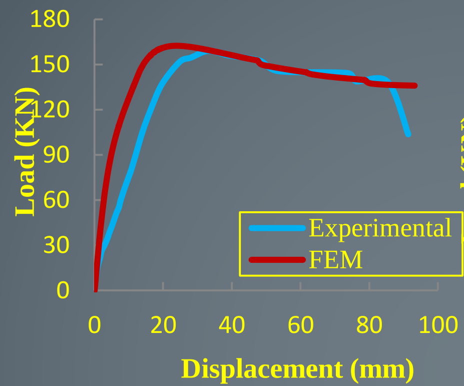


Numerical analysis

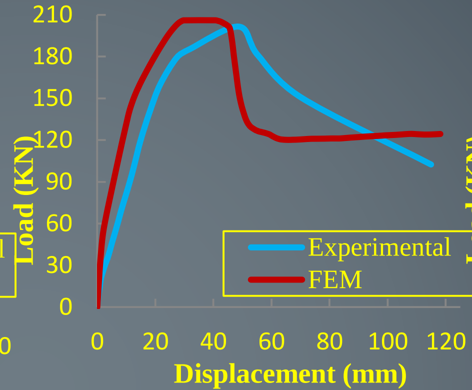
Static analysis:



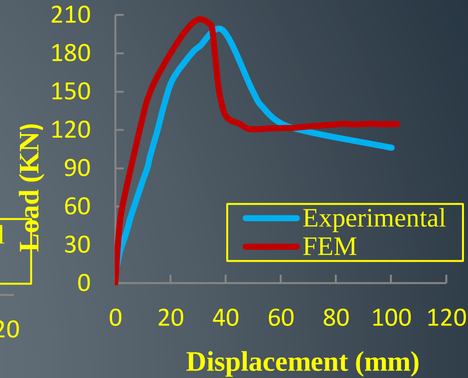
Ref-A



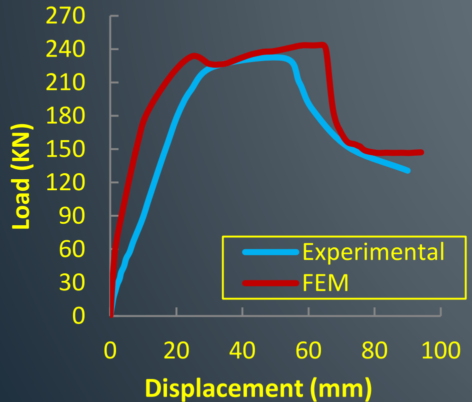
EG-A



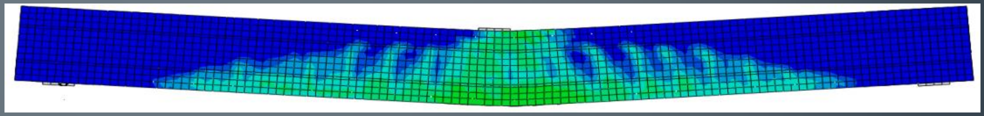
EGS-A

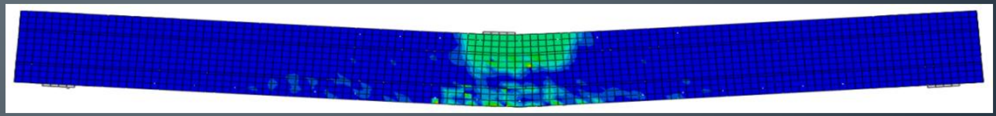


EGW-A



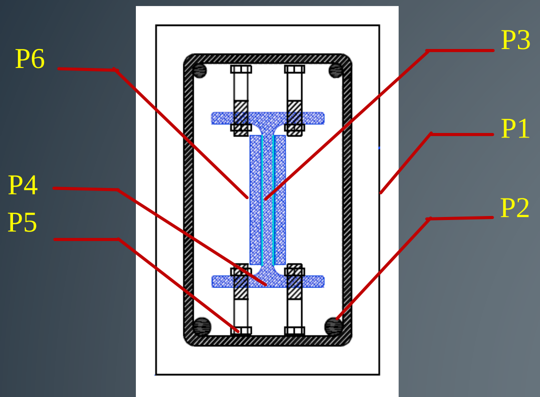
EGSW-A

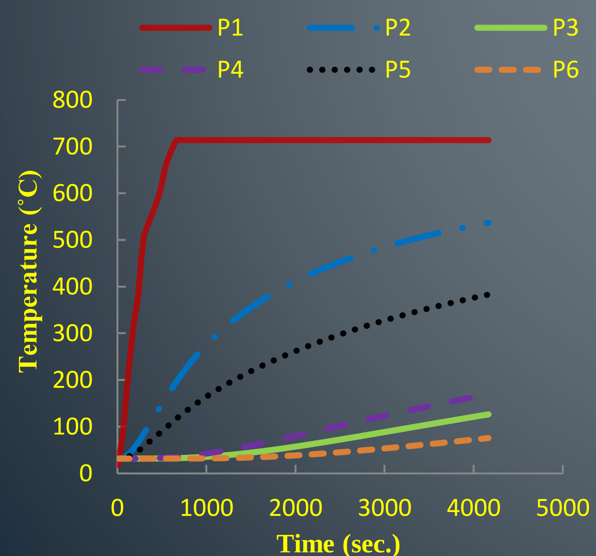


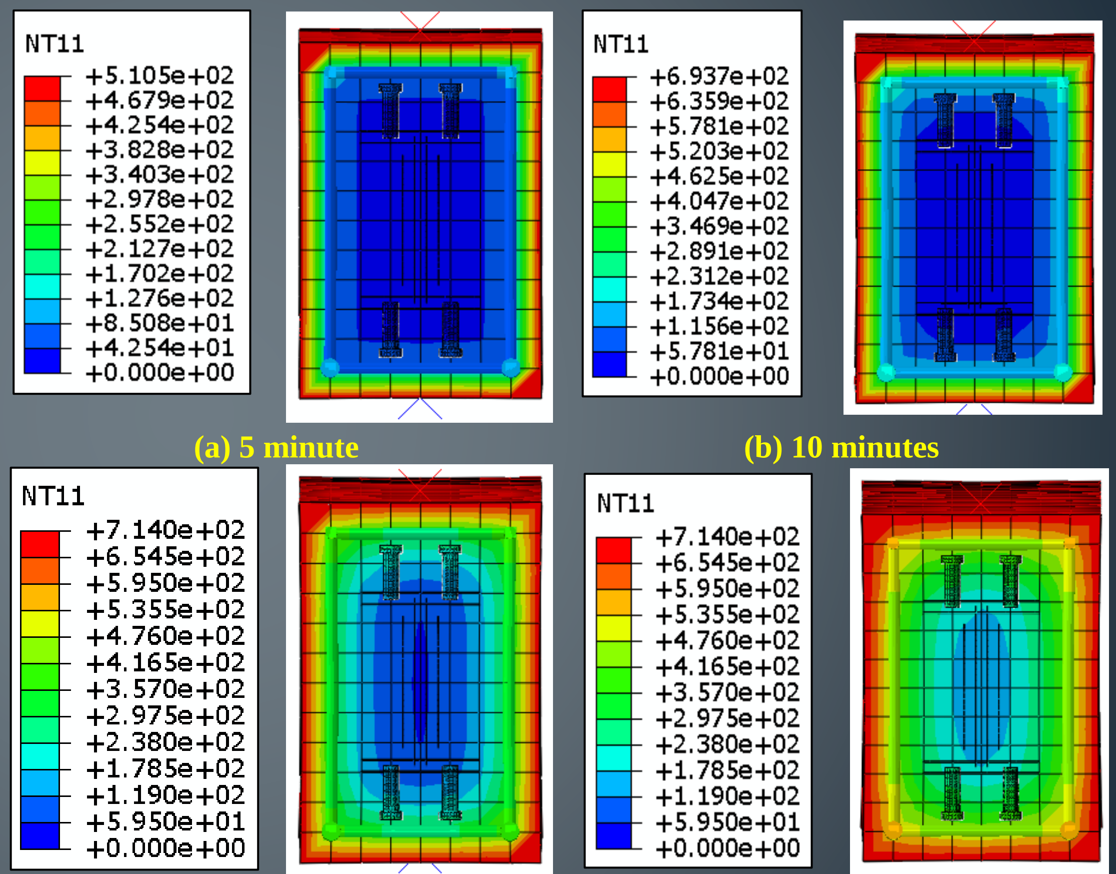


Numerical analysis

Thermal analysis:





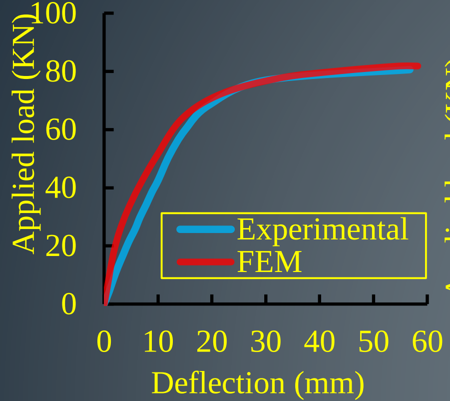


(a) 5 minute (b) 10 minutes

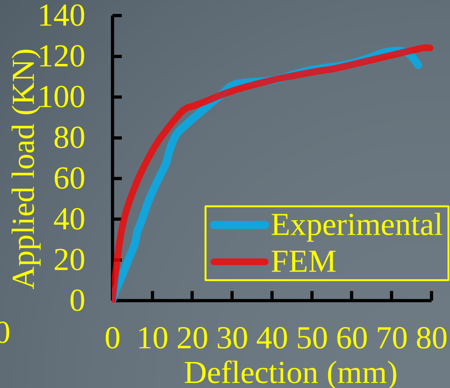
(c) 30 minutes (d) 70 minutes

Numerical analysis

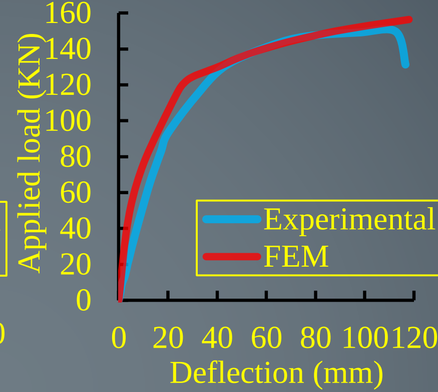
Residual Static Results:



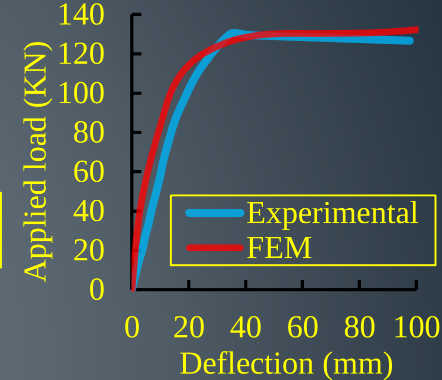
Ref-F



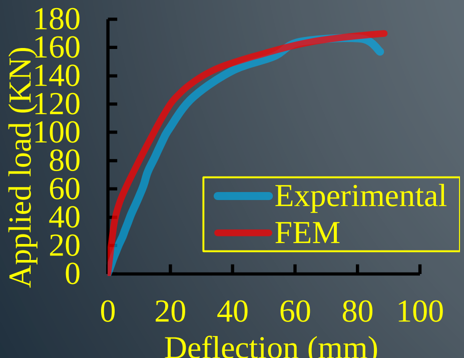
EG-F



EGS-F



EGSW-F



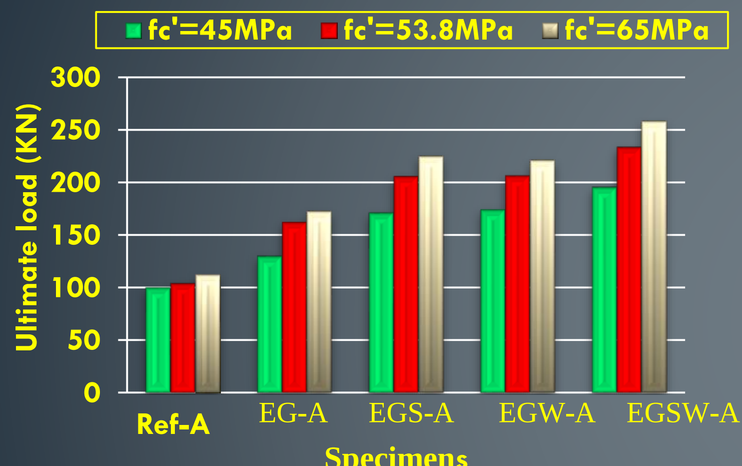
EGSW-F

Beam No.	Exp. Results		FEM Results		Change (%)	
	Ultimate load P_u (KN)	Max. Disp. (mm)	Ultimate load P_u (KN)	Max. Disp. (mm)	Ultimate load	Max. Disp.
Ref-F	80.62	56	81.85	58	1.53	3.57
EG-F	122.15	77	124.14	80	1.63	3.90
EGS-F	149.64	116	156.41	118	4.52	1.72
EGW-F	130.12	98	132.64	102	1.94	4.08
EGSW-F	166.24	87	169.75	89	2.11	2.30

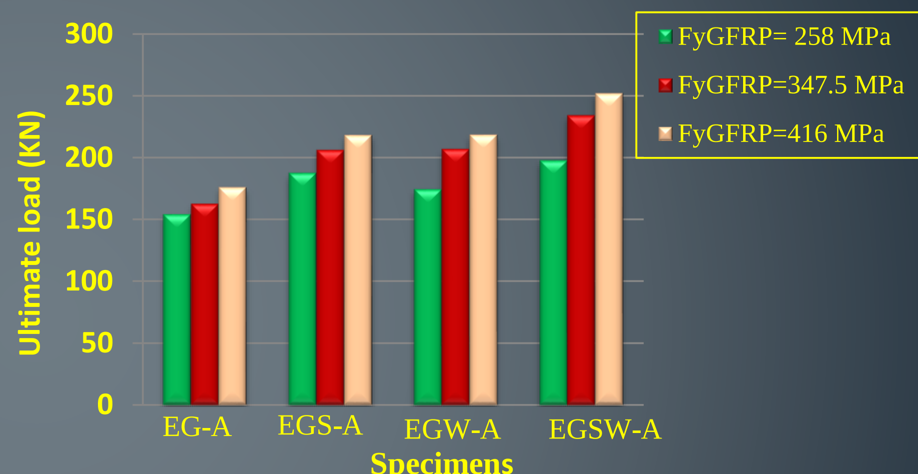
Numerical analysis

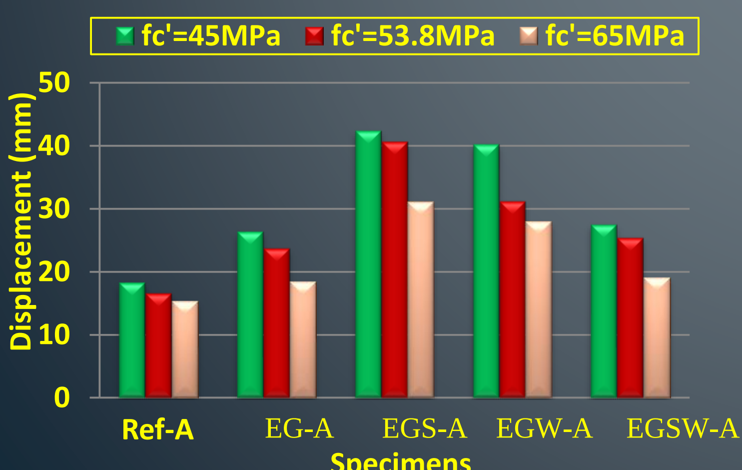
Static Paramatric study:

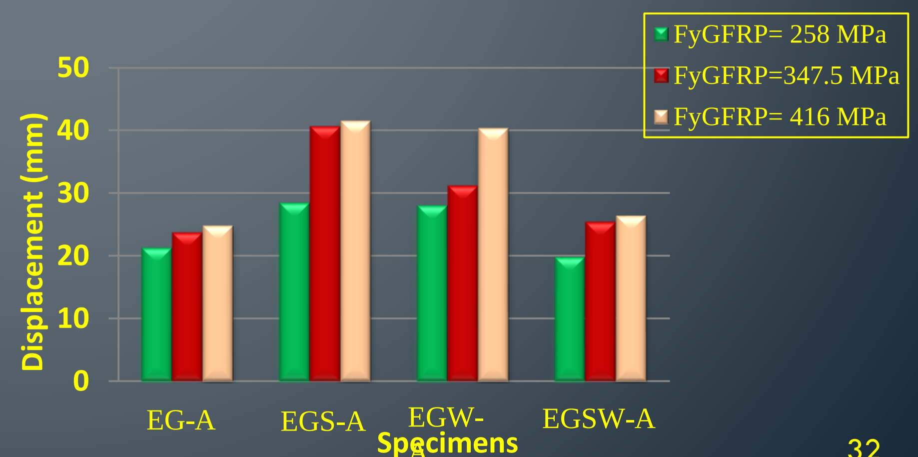
Compressive strength of concrete



Tensile strength of GFRP



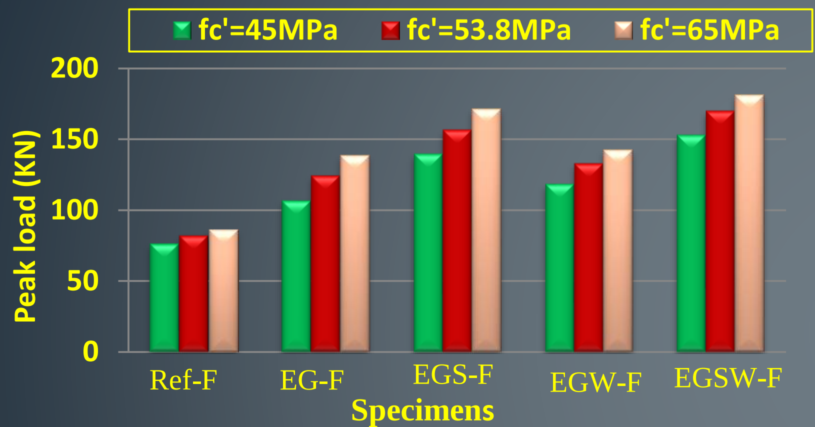




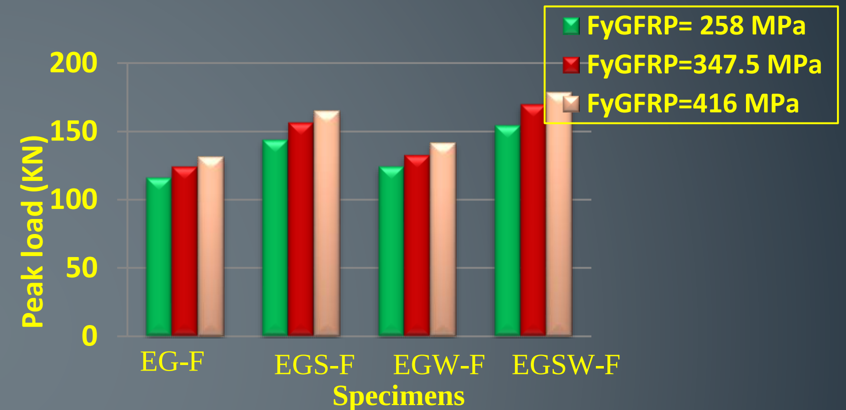
Numerical analysis

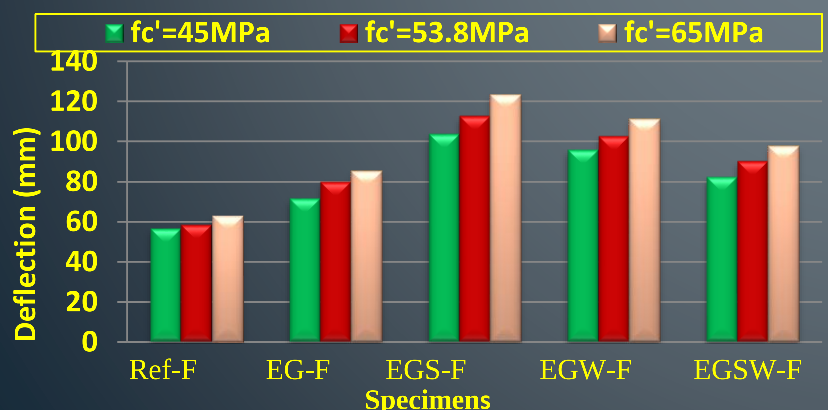
Residual Static Results:

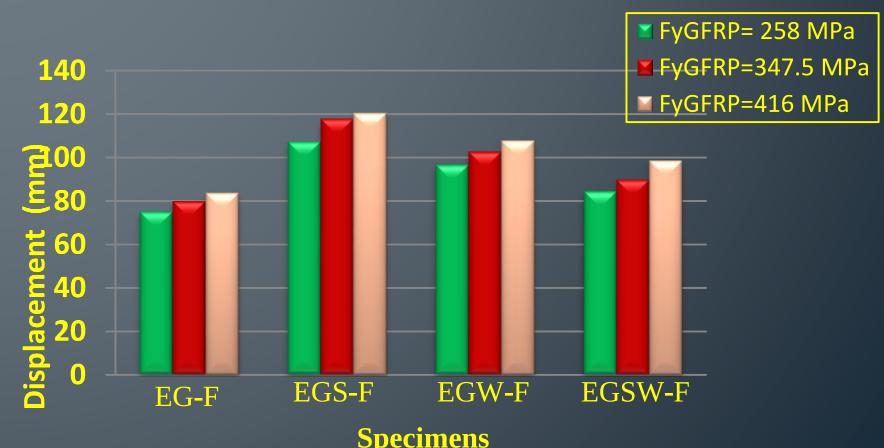
Compressive strength of concrete



Tensile strength of GFRP







Conclusion

Conclusion of expermental work

1. Encasing the GFRP beam with concrete enhanced the peak static load by 58.3%. Using shear connectors, web stiffeners, and both improved the peak loads by 100.6%, 97.3%, and 130.8%, respectively, relative to the classical reinforced concrete.
2. The shear connectors and web stiffeners increased the beams' rigidity. In addition, the GFRP beams improved the ductility by 21.6% relative to the reference one. Moreover, the shear connectors, web stiffeners, and both improved the ductility by 185.5%, 119.8%, and 128.4%, respectively, relative to the reference beam.
3. The residual post-fire peak load of the encased beam was higher than the conventional reinforced concrete beam by 52%. The presence of shear connection, web stiffener, or both increased the residual peak loads by 86%, 61%, and 106%, respectively, relative to the reference beam .
4. The encased GFRP beams could significantly reduce the residual behavior of the fire-damaged specimens relative to the unburned reference one.

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Flexural Performance of Encased Pultruded GFRP I-Beam with High Strength Concrete under Static Loading

by Enas M. Mahmood [1], Abbas A. Allawi [1] and Ayman El-Zohairy [2,*]

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Analysis and Residual Behavior of Encased Pultruded GFRP I-Beam under Fire Loading

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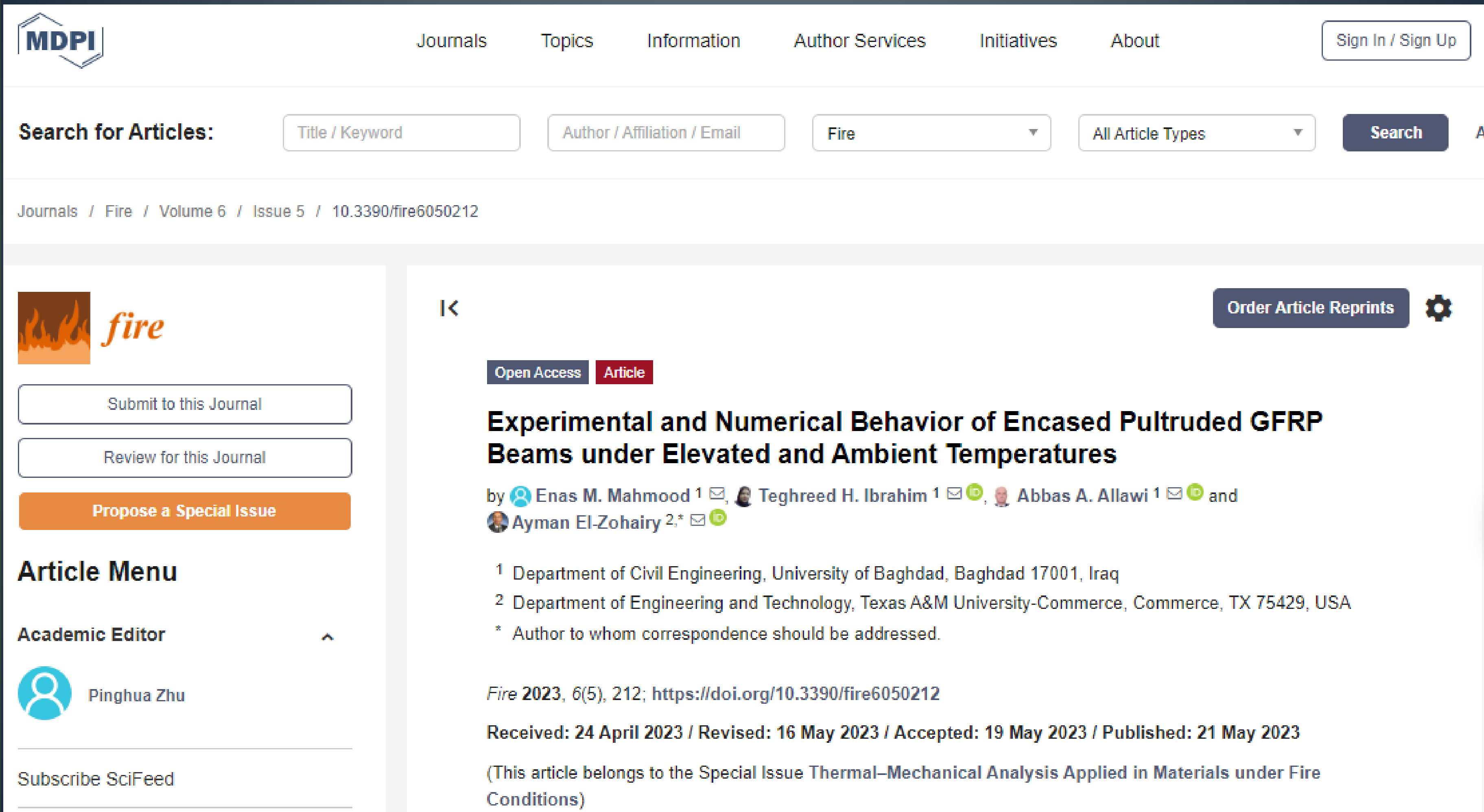

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A review in Encased Pultruded GFRP Beams with Shear connectors

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Thanks for Listening