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POLYMER CONCRETE WITH METALLIC AND NON-METALLIC REINFORCEMENT

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SUMMARY: The experimental investigation of plain and reinforced polyester concrete conducted at 23, 40 and 60 °C is described. At 23 °C the polymer concrete had a compressive strength of 128 MPa, a flexural strength of 25 MPa and a modulus of elasticity of 28200 MPa. At 40 and 60 °C the compressive strength decreased by only 8 % and the flexural strength by 24 %. The largest influence of the higher temperatures was observed for long loading periods. The creep deformation after 1000 hours bending at 50 % of the strength was nearly 4 times that at 23 °C.

Beams reinforced either with one GFRP-bar or one deformed steel bar had the same flexural strength. The GFRP-bar reinforced beams exhibited brittle failure while the steel reinforced beams exhibited ductile behaviour with yielding of the steel at ultimate load. The deflexion of the GFRP-bar reinforced beams was twice that of the beams with steel bar.

The tensile strength of the GFRP-bar was 1000 MPa and about 350 MPa higher than the of the steel. The modulus of elasticity was with 46000 MPa only 22 % of the of steel.

KEYWORDS: Polymer Concrete, Reinforcement, Glass-Fibre, Temperature**.**

INTRODUCTION

Cement concrete, a composite material consisting of a mineral based binder and mineral aggregate has been known for 2000 years, e.g. as „opus cementitum“ of the ancient Romans. In comparison, polymer concrete is a rather new material which has been in use for about 50 years [1]. Both types of concrete show a relatively low tensile strength compared with their compressive strength. Tensile reinforcement is therefore in many applications necessary [2].

Reinforced cement concrete often also with prestressed reinforcement is very well known and widely used although there is still some need for research due to new applications and innovations, e.g. high performance concrete or the application of non-metallic reinforcement. Polymer concrete is used when special requirements, which cannot be met by cement concrete, have to be fulfilled. Binders for polymer concrete are synthetic thermosetting resins such as unsaturated polyesters, vinylesters, epoxies or acrylates. These resins are generally modified – where applicable also the hardeners – and may contain additives, e.g. for shrink reduction, better adherence to mineral aggregate or fibres or to reduce the inflamability [3, 4]. The aggregate – in most cases quartz – must be dry and clean.

Plain polymer concrete is used due to its good chemical resistance and high strength for drainage systems and pipes, high quality boards or sanitary appliances. Due to the fast hardening polymer, the concrete is used as a rapid repair material for cement concrete e.g. on highways or runways [5, 6].

Polymer concrete does not give corrosion protection to steel reinforcement like cement concrete on account of its high alkalinity as long as the concrete is not carbonated. Steel reinforcement in polymer concrete should be - if cracks can occur - provided with corrosion protection.

POLYMER CONCRETE

The polymer concrete used in the present investigation had an orthophtalic polyester resin binder with shrinkage reducing additives. The aggregate was crushed quartz with maximum grain size of 5 mm. The compressive strength at 23 °C was with 128 N/mm² very high. The flexural strength was 25 N/mm². As the mechanical properties of polymers depend on temperature, the materials properties were determined at 23, 40 and 60 °C (see Table 1). On warming from 23 to 60 °C the compressive strength decreased only about 8 % while the loss in flexural strength was 24 %. The modulus of elasticity, determined at compression stress between 5 and 25 N/mm², exhibited a decrease of 13 % on warming (see Figure 1).

Table 1: Compressive and flexural strength and modulus of elasticity of polyester concrete

Temperature [°C]	Compressive Strength [MPa]	Flexural Strength [MPa]	Modulus of Elasticity in Compression [MPa]
23	128	25	28200
40	120	24	25200
60	118	19	24400

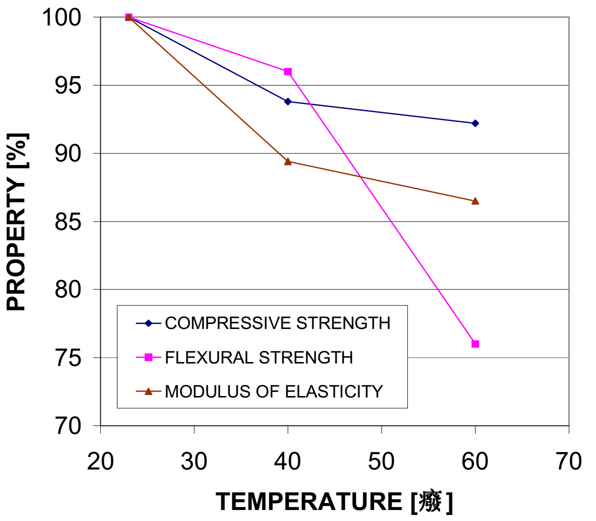


Figure 1: Normalised compressive and flexural strength and modulus of elasticity in relation to temperature

Polymers and therefore also polymer concrete are viscoelastic materials with long-term deformation depending on stress and temperature [7, 8]. Bending creep tests performed at 23, 40 and 60 °C with a stress equal to 50 % of the corresponding short-term strength show a considerable increase in deformation of 272 % on warming (see Table 2).

Table 2: Bending creep at 23, 40 and 60 °C after 1000 hours loading time
prisms 40x40x160 mm^3

Temperature [°C]	Flexural Stress [MPa]	Creep Deformation [µm]	Deformation Increase [%]
23	12.5	33	0
40	12.0	73	121
60	9.5	123	272

REINFORCEMENT

The steel reinforcement used for the tests in the present program was ribbed steel with 8 mm diameter. The yield strength was about 600 MPa, the modulus of elasticity about 210000MPa. The non-metallic reinforcing bars had a square cross-section of 8 mm and a textured surface for better adherence to both cement and polymer concrete. The bars were made from E glass fibres bonded with polyester resin. The glass fibre content was about 60 % by weight. The ultimate strength of the GFRP (glass fibre reinforced plastic) bars was about 1000 MPa, the modulus of elasticity 46000 MPa. The stress-strain relationship was linear up to failure. The GFRP had at least the strength of the steel but only 22 % of the steel- stiffness. The steel bars used for the tests were not equipped with corrosion protection. The steel reinforcement used for polymer concrete slabs at level railway crossings were welded to cages and galvanized for corrosion protection. These slabs have to carry high static and dynamic loads and may crack during their service life.

The adhesion of polymer concrete to steel is very high, as the yield strength of about 600 MPa was reached with a bond length of 28 mm in pull-out tests (see Figure 2). Galvanization did not cause any reduction in the adherence. For transferring the ultimate load of the GFRP-bar to the polymer concrete an embedded length of about 80 mm was needed. As the GFRP is not an homogeneous material like steel, for the stress transfer between the fibres and the matrix of polyester resin a bond length as given above is necessary.

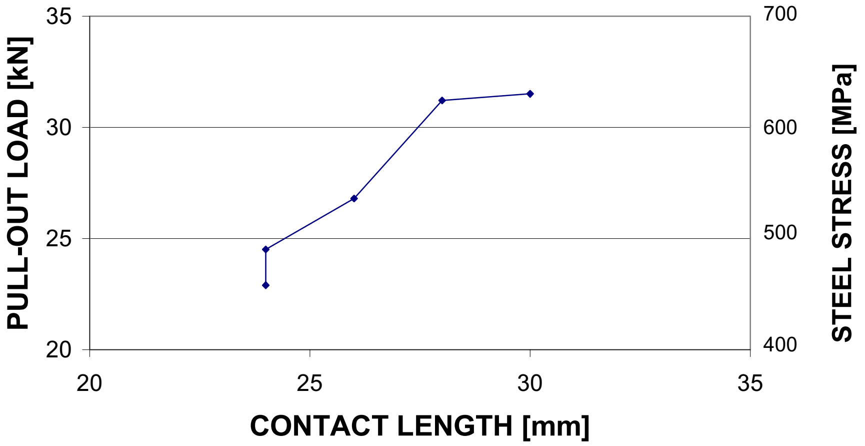


Figure 2: Pull-out load versus contact length of 8 mm diameter steel reinforcing bar

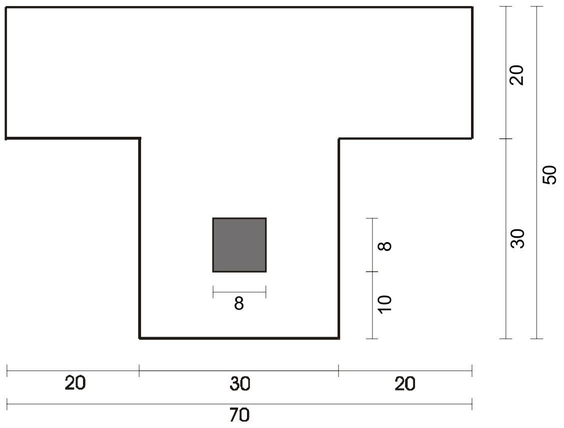
REINFORCED POLYMER CONCRETE

Bending tests were conducted with T-beams as shown in Figure 3. The beams with a length of 500 mm were reinforced either with one deformed steel bar (diameter 8 mm) or one GFRP-bar (8 mm square). The concrete cover of the reinforcing bars was for all specimens 10 mm.

Additional bending tests were performed with polymer concrete beams - 150 mm high and 75 mm wide, reinforced with two GFRP bars – at 23, 40 and 60 °C. The results given in Table 3 show that the influence of temperature on the flexural strength was significantly smaller than for the plain polymer concrete.

Table 3: Cracking load and ultimate load for polyester concrete beams reinforced with two GFRP bars of 8 mm square cross-section

Temperature [°C]	Cracking Load [kN]	Ultimate Load [kN]
23	60.0	115.1
40	66.6	116.7
60	63.3	114.2



Dimension: mm

Figure 3: Cross-section of test beams

The distance between the supports in the 3-point bending tests was 440 mm . The loads were applied to the centre of the span at a deformation rate of 2 mm/min up to about 5 kN on the first loading and to the same or higher loads at a second loading. The failure load of the polymer concrete beams with GFRP or steel reinforcement was about 10 kN. Brittle failure of the GFRP reinforced beams occurred, while for the beams with steel bar the yielding of the steel caused increased deformation and loss of load. For some additional beams with isophtalic polyester resin concrete no ultimate loads were determined as these beams were used for long-term exposures tests after being loaded to 5 kN.

The following parameters were studied:

- tensile strain in the polymer concrete before cracking
- load-deflection relation on first and second loading
- strain and stress of GFRP-bars

The results obtained are given below.

The tensile strain in the centre of the span of a GFRP-bar increased almost linearly prior to the opening of the first crack at a load of 2.3 kN. The strain development of the polymer concrete was slightly slower, but became identically to the strain of the bar before the crack opened as it would be when fully bonded (see Figure 4).

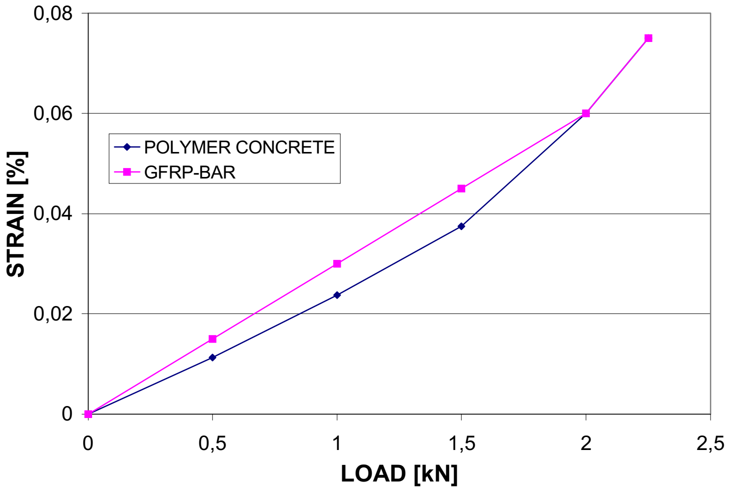


Figure 4: Strain in GFRP-bar and polymer concrete before first cracking

During the first loading a drop in load was observed at the opening of each of the cracks (see Figure 5 and 6). Independent of the type of reinforcement (GFRP or steel), the first crack opened at a load between 2 and 3 kN with a very small decrease of the load. The opening of the cracks at higher loads, further from the centre of the span caused increasing drops in the loads up to 0.4 kN. Figure 7 gives the load-deflection curves for the beams with steel or GFRP reinforcement on second loading for both polymer concretes. The load deflection relation was almost linear with the deflection decreasing with increasing stiffness of the reinforcement and the polymer concrete.

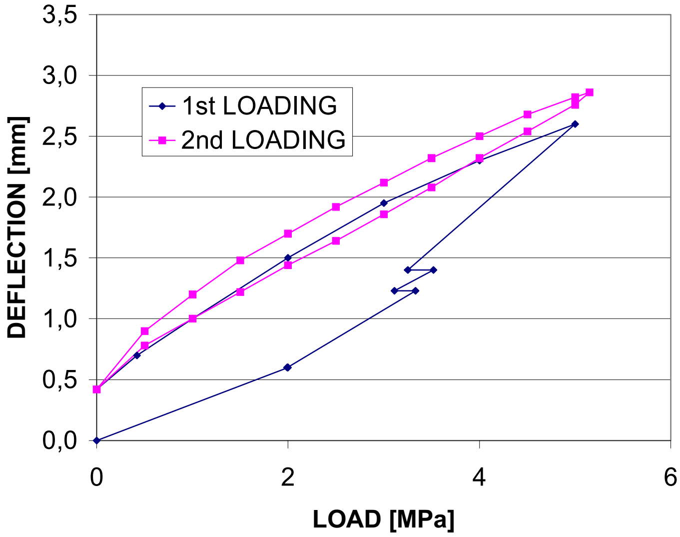


Figure 5: Load-deflection curves for polymer concrete beams with one GFRP-bar on first and second loading

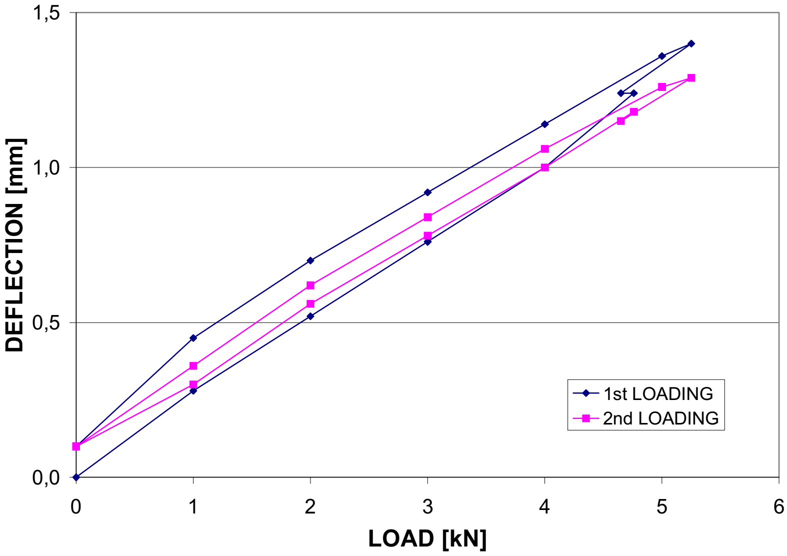


Figure 6: Load-deflection curves for polymer concrete beams with one deformed steel-bar on first and second loading

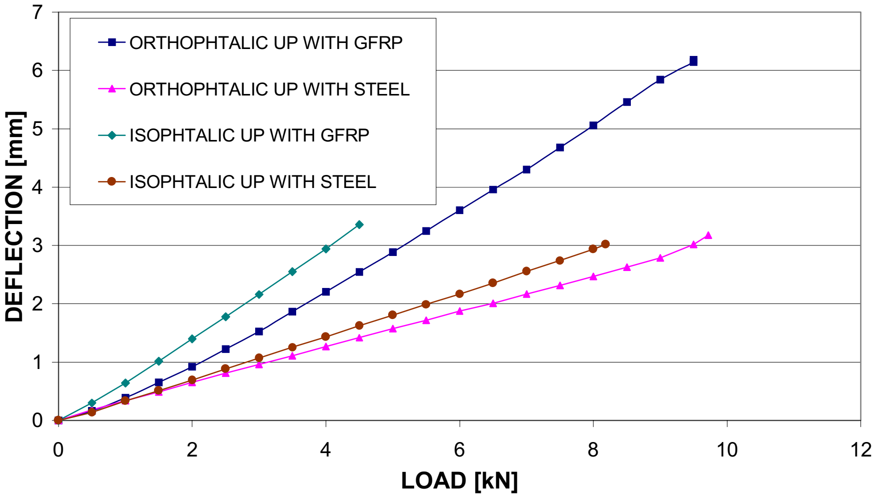


Figure 7: Load-deflection curves for beams with orthophtalic and isophtalic unsaturated polyester concrete on second loading

The stress in the GFRP-bars was measured with strain gauges at the centre of the span and at 100 mm and 200 mm from the centre. During the first loading rapid or even sudden increases in stress occurred when the cracks opened (see Figure 8). During the second loading the stress increased almost in proportion to the load applied. The tests were stopped at a load of 8 kN (80 % of the ultimate load) with a stress in the GFRP-bar at the centre of the span of 31.3 MPa and 20 mm before the support of 4 MPa (see Figure 9).

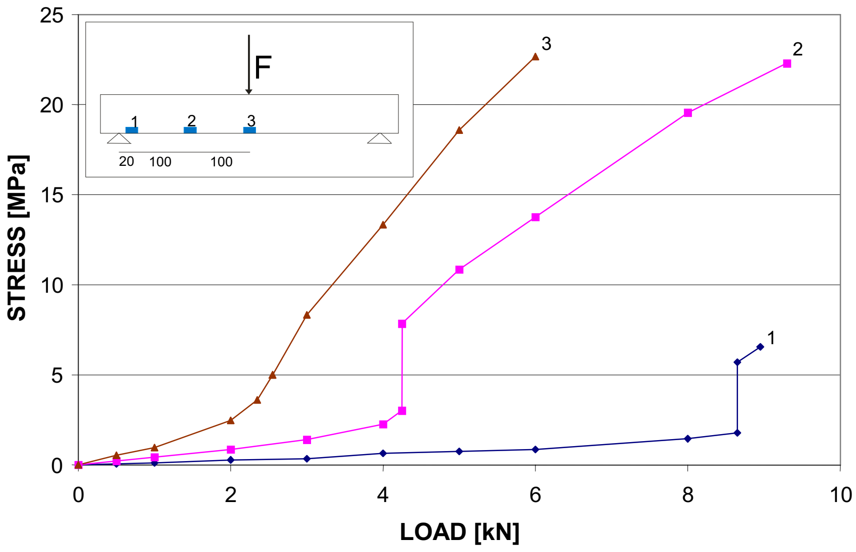


Figure 8: Stress in GFRP-bar during first loading

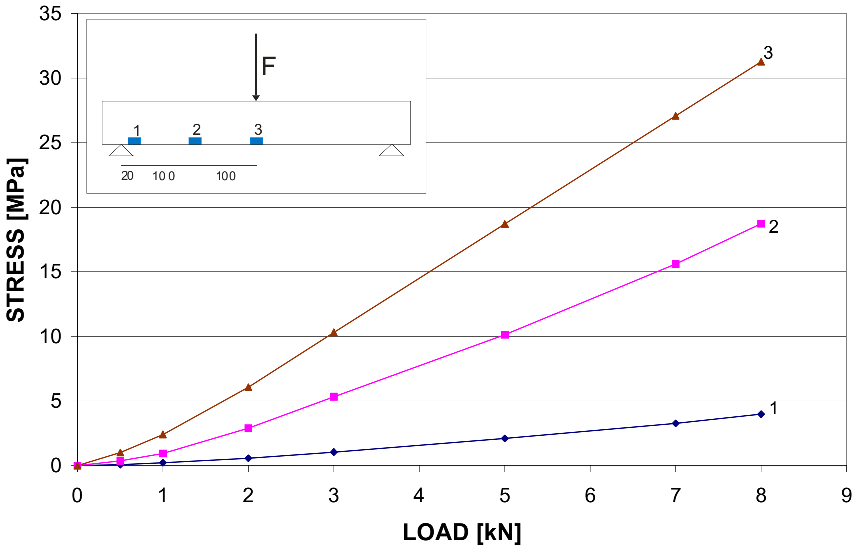


Figure 9: Stress in GFRP-bar during second loading

CONCLUSIONS

The investigations conducted with polymer concrete (binder: orthophtalic polyester resin) at temperatures of 23, 40 and 60 °C showed that higher temperatures resulted only in a small decrease in compressive strength, but a relatively large decrease in flexural strength and a very large increase in creep deformation. No change in the bending strength of GFRP-bars reinforced beams due to higher temperatures was observed.

Bending tests with beams reinforced either with an 8 mm square cross-section GFRP-bar or an 8 mm diameter deformed steel bar resulted in the same ultimate loads. However, the deflection for the GFRP reinforced beams was about double that of the steel reinforced beams. The failure mode of the steel reinforced beams was ductile with yielding of the steel. The failure of the GFRP reinforced beams was brittle with partial destruction of the beams.

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REFERENCES

1. Klöker,W.: 30 Jahre Reaktionsharzmörtel, -beton und –kunststein auf Basis ungesättigter Polyesterharze. Polymers in Concrete. Forth International Congress, Darmstadt, 19. – 21. Sept. 1984, pp 11 – 19. Institut für Spanende Technologie und Werkzeugmaschinen, Technische Hochschule Darmstadt. Ed.: H. Schulz
2. Yeon, K-S.;Kim, K-H.;Kim, K-S.;Shin, Y-S.: Flexural performance of singly/doubly reinforced polymer concrete beams. Polymers in Concrete. Third South African Conference, Johannesburg, 15. – 17. July 1997, pp 352 – 361. Rand Africaans University. Ed.: D. Kruger
3. Martinez, A.;Salla, J.;Aros, M.;Saura, P.;Aguado de Cea, A.: Influence of coupling agents on mechanical properties of polymer concrete. Polymers in Concrete, Forth International Congress, Darmstadt 19.-21. Sept. 1984, pp 219 – 221. Ed. H. Schulz, Institut für Spanende Technologie und Werkzeugmaschinen, TH Darmstadt 1984

4. Stawowy, J.: Schwindungsarm eingestellter Polymerbeton auf Polyesterbasis und die sich daraus ergebenden Möglichkeiten der Bewehrung. Polymers in Concrete, Forth International Congress, Darmstadt 19.-21. Sept. 1984, pp 257 – 262. Ed. H. Schulz, Institut für Spanende Technologie und Werkzeugmaschinen, TH Darmstadt 1984
5. Laliberte, B.: Application of polymer concrete in Canada. . Polymers in Concrete. Forth International Congress, Darmstadt, 19. – 21. Sept. 1984, pp 45 – 52. Institut für Spanende Technologie und Werkzeugmaschinen, Technische Hochschule Darmstadt. Ed.: H. Schulz
6. Matthews, D.: Precast polymer concrete in the construction industry. Polymers in Concrete, VIIth International Congress, Moscow 22. – 25. Sept. 1992, pp 43 – 57. Ed.: V. Paturoev and R. Serykh; BETECOM Moscow 1992
7. Letsch, R.: Behavior of Plastics and Plastic Mortars at Constant and Changing Temperatures. First International RILEM Congress: From Materials Science to Construction Materials Engineering, Versailles 7. – 11. Sept. 1987, pp 1107 – 1114, Chapman and Hall, London 1987
8. Letsch, R.: Verhalten von Reaktionsharzen und –mörteln bei stationären und instationären Temperaturen. Thermische Einsatzgrenzen von Technischen Kunststoffbauteilen, Lehrstuhl für Kunststofftechnik, University Erlangen .- Nürnberg, 26. Feb. 1998; pp 146 – 154, ED.: G. W. Ehrenstein – S. Pongratz, Springer-VDI-Verlag Düsseldorf 1998.