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EXPERIMENTAL STUDY ON CRACKING BEHAVIOR OF GLASS-FRP REINFORCED PRECAST CONCRETE SANDWICH PANELS

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1. INTRODUCTION

Precast concrete sandwich panels (PCSP) consist usually of two reinforced concrete wythes and a core layer composed of insulating material and mechanical connectors. The innovative solutions with integrated thermally insulating layer and non-metallic connectors can meet severe energy efficiency requirements and provide space for application of another high performance system. Application of glass fibre reinforced polymer (GFRP) rebars in concrete wythes of PCSP enables reduction of their thickness as a result of the reduced concrete cover of the rebars due to their excellent chemical properties and high durability. In this way, by application of GFRP materials as connectors and reinforcement of concrete wythes, thin and energy efficient sandwich panels can be constructed (see Fig.1). Such wall panels are competitive against known steel-reinforced panels, due to their high durability, good thermal properties and lower concrete consumption.

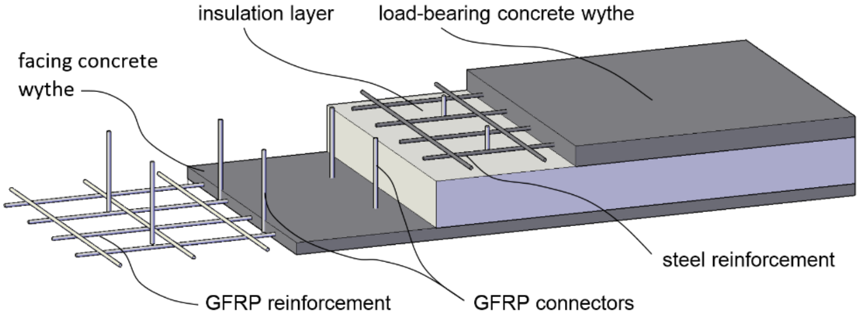

Fig. 1: Precast concrete sandwich panels (PCSP) with GFRP-reinforcement and connectors (specimens CS1 and CS2).

However, due to significantly different mechanical properties of GFRP from steel, their performance in thin concrete wythes needs to be investigated, so guidelines for optimal application can be developed. Furthermore it has been recognized that constructing panels with reduced thickness of wythes, contribution of the face wythe and the shear stiffness of insulation can provide significant reserves to the load-bearing capacity and overall flexural stiffness of the panel [1,2]. Use of GFRP reinforcement in prefabricated concrete panels allows to utilize their special properties. Due to the different bond characteristics and lower modulus of elasticity of GFRP bars the cracking behavior of GFRP reinforced structures remains one of the biggest limitation of its application. Since cracking of facing wythes of precast sandwich panels is of a great concern, investigation of the impact of the degree of composite action on the flexural cracking behavior of GFRP-reinforced panels is essential for an safe and economic design.

As it was reported in previous research [1,2] the contribution of the shear stiffness of insulation activated by bond to concrete can increase the overall flexural stiffness of panels even by 100% in the service load range in comparison to the panels with composite action provided only by connectors. However, since it is difficult to provide uniform quality of bond of insulation pressed into fresh concrete and insulation layer fails in shear cracking and subsequent debonding from concrete [3] the two crucial conditions were investigated. For specimen CS1 and CS3 good bond was provided by placing the EPS insulation plates in fresh concrete and compacting of the mixture. In case of specimen CS2 and CS4 PVC foil was placed during casting on both sides of the EPS insulation plates to prevent its bond to concrete. Created in this way two different conditions of actively shear-bearing and deactivated insulation influenced significantly cracks development in the facing wythes and overall flexural stiffness. The shear stiffness and composite action provided by GFRP connectors have constant values until their ultimate shear failure which occurs under much higher load than the shear failure of insulation and therefore constitute the majority of the panel's composite action after the shear failure of insulation. Although relatively a lot of research has been done on cracking behavior of GFRP-reinforced concrete members, the influence of the degree of composite action defined by the bond conditions of insulation to concrete on the cracking of facing wythe of sandwich panels has never been investigated.

2. EXPERIMENTAL INVESTIGATION

Aiming to investigate the cracks development and propagation a test series consisting of four test panels (width x length = 400 x 1700 mm) was conducted. Longitudinal reinforcement ratio of facing (bottom) wythe with reduced, efficient thickness of 40 mm (investigated in previous research [2]), was equal for each panel (ρ=0,031). The longitudinal rebars where positioned with spacing 85 mm. In addition, transverse rebars where used, with spacing ~ 280 mm. Concrete cover of 10 mm was applied for longitudinal reinforcement in each specimen. In case of panels CS1 and CS2 facing wythes were reinforced with Schoeck Combar® GFRP rebars of nominal diameter 8 mm, while facing wythes of panels CS3 and CS4 were reinforced with conventional steel reinforcement of nominal diameter 8 mm. The load-bearing (top) wythe (70 mm thick in each specimen) were reinforced with conventional steel reinforcement of nominal diameter 8 mm. Connectors of diameter 12 mm (16 pcs per specimen, every 20 cm), with length equal to the thickness of the panel, were anchored by bond to the concrete along the length embedded in the concrete wythes (see Fig. 1). Tested mean cubic compressive strength of concrete used was 54,7 MPa, while maximum aggregate size was 8 mm, in order to ensure proper compaction of the mixture around the rebars. The middle-density (18 kg/m^3) expanded polystyrene (EPS) with thickness of 140 mm was used as a core material of the panels. The longitudinal E-modulus of the Schoeck Combar® rebars and connectors given by the manufacturer is equal to 60 GPa [4]. Their good bond characteristics are provided by grooves cut into the surface after curing. The steel-reinforced panels (CS3 and CS4) where tested as a reference in terms of stiffness as well as cracking and damage development. Simply supported panels with roller and pin, four point bending test configurations, were loaded in flexure, displacement controlled with servo hydraulic cylinders up to the ultimate failure of the concrete wythes. The extensive instrumentation, including measurement of the deflection along the panel (with linear variable displacement transducers), relative displacement of wythes and strains in reinforcement (strain gauges), were implemented. Load was applied in displacement controlled manner at the rate of 2 mm/min in order to investigate development of the crack pattern.

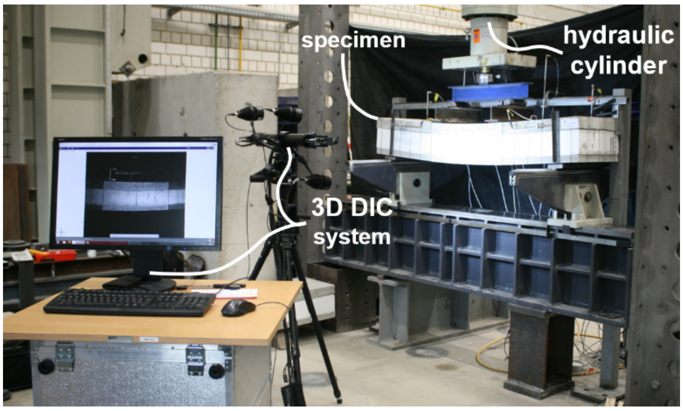

Fig. 2: Test set-up for measurement with Digital Image Correlation System.

The 3D Digital Image Correlation (DIC) technique was used for continuous measuring of crack widths of the facing wythe. The DIC system allows contactless determination of deformations and displacements of the surface of a specimen under loading. The system uses two high-resolution cameras and Aramis software [5]. The calculation of the surface deformation is based on comparison of two consecutive images taken at two different stages during the test. The captured field of the used 3D DIC system covered the middle area of the panel (see Fig. 3). The data were captured with two digital cameras acquiring frames at frequency of 0,5 Hz with a resolution of 2448 x 2050 pixels. The post-processing of images allowed the measurement of the 3D full field displacement on the front side of the facing wythe. For this purpose, that side of the specimen was painted white and randomly speckled with black acrylic paint.

3. RELATION OF CRACKING BEHAVIOUR OF FACING WYTHES AND DEGREE OF COMPOSITE ACTION

Conducted tests allowed continuous observation of crack pattern development of the thin GFRP-reinforced sandwich panels with comparison to the steel-reinforced reference specimens. It is important to mention that throughout the loading of the panels up to the ultimate failure, the cracks in facing wythes were growing slowly through these layers, never protruding the full depth of the wythes.

The analysis of crack development is done on a basis of mean crack width (MCW), calculated as a mean value of crack widths measured continuously during loading in the middle area of the panel between the loading points. Crack widths were calculated from the relative displacement of two points localized on both sides of the crack at the depth of the reinforcement axis. Figure 3 shows the fully developed crack pattern of the facing wythe (CS1) displayed as the strain map in the X direction and the middle area of the panel where the DIC technique was applied.

Since the degree of composite action is governed by the active shear contribution of the insulation to the flexural stiffness of sandwich panels, the quality of insulation to concrete bond is of a particular importance for cracking behavior. Figure 4(a) shows the difference in the flexural behavior of panels with actively contributing insulation - CS1, and reference panels with passive insulation - CS2.

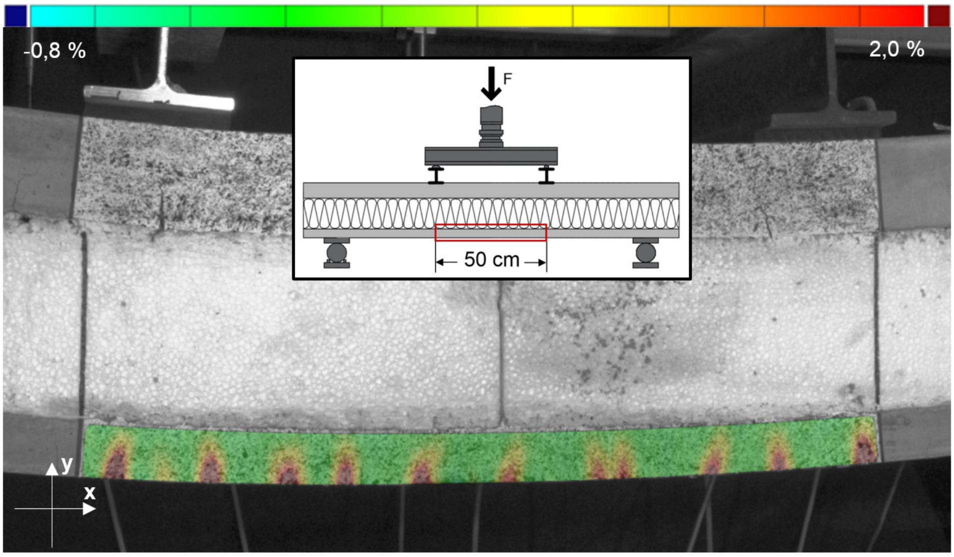

Fig. 3: Distribution of cracks in the facing wythe of CS1 specimen (stains in X-direction) under load of 46,6 kN and middle area.

The mean crack width measured with DIC system showed significantly different cracking behavior of GFRP and steel-reinforced facing wythes.

Although the cracking initiation starts at comparable load level for all specimens the MCW at the higher load is much larger for GFRP-reinforced specimens. The reducing influence of the active insulation on MCW can be observed as the shear cracking of insulation (for CS1 and CS3) results in its deactivation in terms of its contribution to the flexural stiffness and sudden increase of MCW and increase of its growing rate. This phenomenon is particularly clear for GFRP-reinforced panels, where MCW of the panel with active insulation (CS1) after shear failure and deactivation of insulation, exceeds the MCW of CS2 (see Fig. 4(b)). This indicates strong dependence of the crack width and crack pattern on the degree of the composite action. However in each test, the MCW was not exceeding 0,08 mm and maximum crack width 0,15 mm, values much below the recommended allowable crack widths in concrete structures reinforced with GFRP rebars. The presented test results confirm the positive impact of an actively shear-bearing insulation on the flexural stiffness as well as on the reduction of crack widths in sandwich panels.

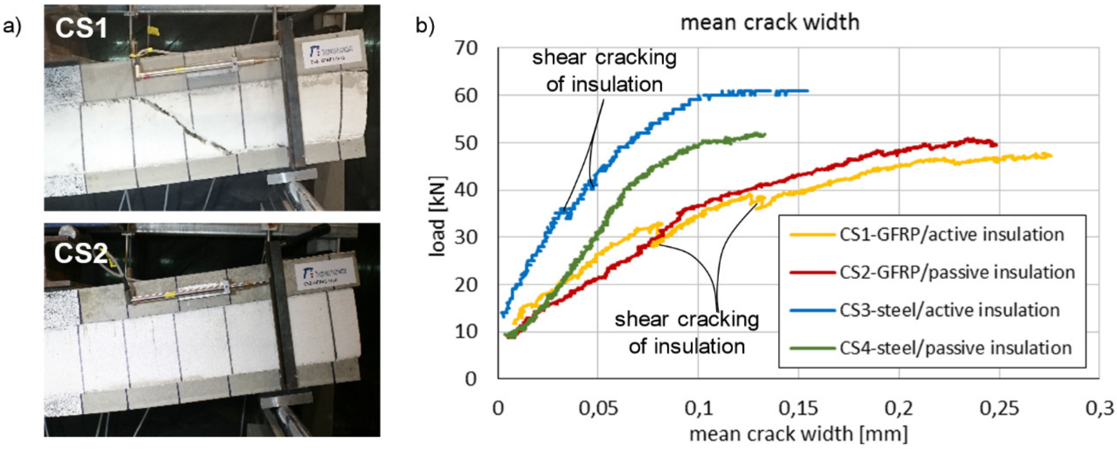

Fig. 4: Experimental mean crack width depending on the load.

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