Mechanical Properties of Functionally Double Layered Thin Slabs

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***Abstract*—The contribution deals with mechanical properties of functionally double layered thin slabs (totally thickness 25 mm) made from two cement-based composite materials with different properties and rupture behavior. The load bearing part of the slab was done from Ultra-High Performance Steel Fibere Reinforcement Concrete (here and after noted as UHPSFRC) with short brass coated steel fibres BASF MASTERFIBER® 482 0.2/13. The second layer of fine-grained Engineered cementitious composite (here and after noted as ECC) material with thickness about 10 mm reinforced by short PVA fibres Kuraray REC15/8 was spread on so prepared samples after 15 minutes. Total thickness of slabs was 25 mm. The performed functionally layered thin slabs were tested in a four-point bending test. The layered samples take advantage of the potential of the hi-tech UHPSFRC material and properties of the ECC matrix that thanks to the reinforcement by PVA fibres prevents a developing and spreading of micro-cracks and a getting out of steel fibres on to the surface of a structure.**

***Index Terms*—UHPSFRC; Thin Slabs; ECC; Layered Materials; Bending Tests; Corrosion; Durability.**

I. INTRODUCTION

Ultra-High Performance Concrete UHPC is a fine-grained cement-based composite material that exceeds mechanical and physical properties of Normal Strength Concrete (NSC). The uniform classification characterizing UHPC materials does not exist worldwide but some national recommendations characterizing UHPC materials could be noted [1]-[4]. UHPC materials are primary characterized by compressive strength exceeding 150 MPa and by direct tensile strength exceeding 8 MPa in these national recommendations. The compressive strength, type of reference elements and other border conditions are not unified, too. Cylindrical specimens with diameter 110 mm and high of 220 mm are noted at French recommendations AFGC/SETRA [1], cylindrical specimens with diameter 100 mm and high of 300 mm are noted at the German recommendation [3].

High compressive strength exceeding 120 MPa could be reached by suitable mixture properties and also by conditions during curing elements. The tensile strength of cement-based composites is increased by the fiber reinforcing. As normal concrete strength, UHPSFRC exhibits elastic linear tensile behavior up to the maximum tensile strength of a plain matrix. After reaching the maximum of tensile strength, the fibers take over from the cement matrix after cracking occurs. The tensile strength after cracking occurs is conventionally translated by the fibers that are pulled out. The quantity of fibers, their length and slenderness ratio lead to three different constitutive law (strengths softening, low strength hardening and strength hardening). The constitutive law is determined by the difference between maximum tensile strength of a plain matrix and postcracking resistance.

II. EXPERIMENTAL PROJECT

Fine grained cement based composite materials that could be defined as UHPC have been developed in the Klokner Institute of the Czech Technical University in Prague. This material is developed by local materials. The basic mechanical properties of the developed mixtures are: compressive strength at the range from 110 to 170 MPa and bending tensile strength at the range from 12.5 to 26.0 MPa. The strengths were set on small beams with size of 160/40/40 mm. Compressive strength on the cube 100 mm is 150 MPa. Bending tensile strength tested on prism beams 300/70/70 is at the range from 8.8 MPa (without fibers) to 26.6 MPa (with 300 kg/m^3 fibers). These strengths were tested at elements that were not heated during the curing. Short brass coated steel fibers BASF MASTERFIBER® 482 were used for reinforcing. The optimum volume fraction of short steel fibers V_f = 1.5 – 2.3% (120 – 180 kg/m^3) according to our experience seems to be an optimal from the point of view of workability, flow desk test, compressive strength, tensile strength in bending and price costs for unit of strengths [5]-[7]. The mixture proportion with fibers amount 120 kg/m3 is presented in this paper.

Whereas steel fibers primary increase tensile strength of fine-grained cement based composite materials and their efficiency is described also after the cracking occurrence, glass and polymer fibres increase material resistance before the cracking occurrence and their

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efficiency after the crack is almost negligible. High-modulus PVA fibers used for fine-grained ECC composite materials (Engineered Cementitious Composites) are developed especially in Japan and in the USA. High relative deformation under tensile stress of these composite materials is enabled by PVA fibers. Experimentally achieved elongation at rupture is around 6% for ECC [8]-[11], [12]-[15], [16]-[19] and from 0.01% to 0.02% for common used concrete.

Functionally layered thin slabs made from UHPC and ECC were produced and tested due to the potential of UHPC materials and properties of ECC. The bearing part was done from UHPSFRC in thickness of 15 mm, on this part is layered ECC in thickness of 10 mm [12]. Due to properties of ECC reinforced by PVA fibers are the steel fibers protected against moisture, air and also against corrosion. The steel fibres at the surface area are exposed to the corrosion effect as you can see at Fig. 1 [13], [16]. The mixture composition and basic mechanical properties tested at the age of 28 days after casting are shown at Table I, the mechanical properties of the fibers are shown at Table II.

Figure 1. Surface area of UHPSFRC elements explosured to the climatic load after 1 year of exposuring.

TABLE I. MIXTURE PROPORTION AND PROPERTIES OF UHPSFRC AND ECC MIXTURES

Component		UHPSFRC	ECC
CEM II 42.5R A+S	kg/m^3	700	448
silica fume	kg/m^3	100	56
slag	kg/m^3	80	-
ground quartz	kg/m^3	50	-
fly ash	kg/m^3	-	784
sand I 0/2 mm	kg/m^3	785	-
sand II 0/1 mm	kg/m^3	395	-
fine aggregates (max grain size 0.312)	kg/m^3	-	456
steel fibers	kg/m^3	120	-
PVA fibers	kg/m^3	-	16.3*
superplasticizes	kg/m^3	50	25.2
water	kg/m^3	170	288
tensile strength in bending $f_{t,b}$	MPa	19.4	9.3*
compressive strength $f_{c,cube\ 100}$	MPa	170.7	99.7*
bulk density	kg/m^3	2400	2000

Note: * ECC1 – with V_f = 1.5% (16.3 kg/m^3), $f_{t,b}$ = 9.3 MPa, f_c = 99.7 MPa
ECC2 – with V_f = 2.0% (21.7 kg/m^3), $f_{t,b}$ = 12.0 MPa, f_c = 100 MPa

TABLE II. MECHANICAL PROPERTIES OF USED FIBERS FOR UHPSFRC AND ECC

Type	Material	L_f [mm]	D_f [mm]	E_f [GPa]	f_t [MPa]
BASF Masterfiber® 482	brass coated steel	13	0.2	200	≥ 2200
REC fiber Kurary	dry bundled PVA	8	0.04	41	1600

Mixing, casting and curing The mixing was done at the mixer with capacity of 60 liters. The tested elements including slabs and basic elements for determination of basic mechanical parameters were done from volume of 21 liters of fresh concrete. All specimens were cured at the water till the testing. The basic mechanical properties noted at Table I were tested at the age of 28 days after mixing and the slabs were tested at the age of 190 days. For each mixture were tested small beams size 160/40/40 mm at the age of 190 days.

Dry aggregates, cement, silica fume, slag and ground quartz were mixed for 120 sec, then 75% of water was added, remaining 25% of water was added together with a PCE superplasticizer. All components were mixed next 300 sec. After this time the fibers, brass coated fibers or dry bundled PVA fibers were added and mixed next 420 sec for UHPSFRC and 300 sec for ECC.

Homogeneous thin slabs The series of specimens were manufactured at the base of the experimental program for determination of the basic mechanical properties of both type materials. UHPSFRC was reinforced by short brass coated steel fibers MASTERFIBER® 482 0.2/13, the volume fraction of fibers V_f = 1.5%. More than 50 mixtures of ECC was performed and tested. In this paper are shown only the results of two type of ECC with different volume fraction of fibers: ECC1 with volume fraction V_f = 1.5% and ECC-2 with volume fraction V_f = 2.0%. The homogeneous thin slabs 700/300/25 mm were made from each mixture.

The slabs were tested at the four-point bending test with span L0 = 600 mm, the load was applied at the third of the span. The loading speed rate was 0.015 mm/sec. The results of the load bearing tests are shown at Fig. 2.

There are no marked load bearing capacity differences and the mid-span between ECC mixtures with a different volume fraction of PVA fibers. The load bearing capacity of slabs made from ECC1 was 2.0 kN and for slabs made from ECC2 the capacity was 2.4 kN. The market differences between slabs made from UHPSFRC and ECC were noted. The load bearing capacity oc UHPSFRC slabs was 4.6 kN that is more than twice capacity at ECC slabs.

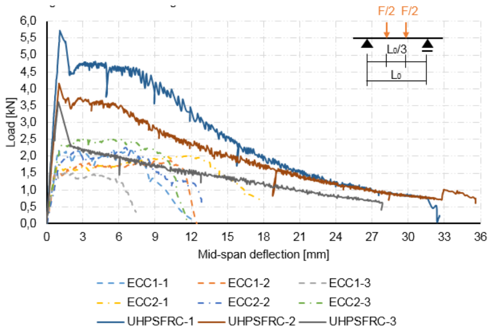

Figure 2. Load-deflection relationship for basic mixtures

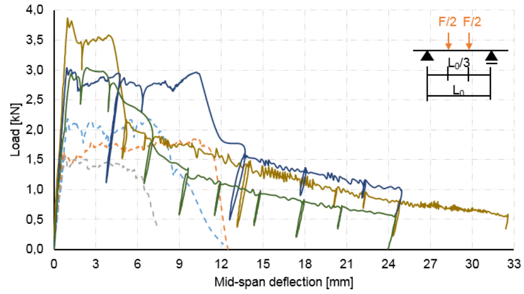

Figure 3. Load-deflection relationship for functionally graded slabs made from UHPSFRC and ECC with volume fraction V_f = 1.5%.

Functionally layered slabs Functionally layered slabs size of 700/300/25 mm were produced by a combination of UHPSFRC and ECC at the second part of the experimental program. These slabs take advantages of the both materials. The load bearing part is made from 15 mm thick UHPSFRC slab, the rest 10 mm is made from ECC. The layered slabs were made by a gradual casting of individual mixtures. It was made in following order: 15 mm of UHPSFRC and 10 mm of ECC. The interval of the casting of each individual mixture was 20 minutes that is the time corresponds with possibilities of a concrete plant for the preparing and transporting another mixture. This time is the same time guaranteeing a connection of the neighboring layers because the casting was performed in to the fresh previous mixture. The slabs were also tested at four-point bending tests as homogeneous slabs. The ECC layers during tests were oriented at the tension area. The results of the four-point bending tests are shown at Fig. 3 and Fig. 4. According to the results of the load bearing tests the functionally layered slabs made from ECC (40% of total thickness) and UHPSFRC (60% of total thickness) have higher load bearing capacity than slabs made from ECC. The load bearing capacity of the functionally layered slabs is lower than the slabs made only from UHPSFRC. The behavior after the cracking of the slabs made with the volume fraction of PVA fibers V_f = 1.5% could be characterized as strain-softening, strain-hardening could be characterized for slabs made with the volume fraction of the PVA fibers V_f = 2.0%.

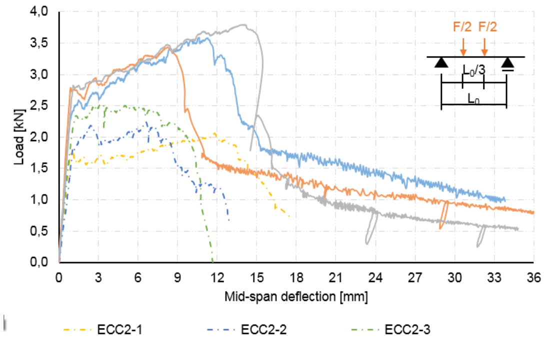

Figure 4. Load-deflection relationship for functionally graded slabs made from UHPSFRC and ECC with volume fraction V_f = 2.0%.

III. CONCLUSION

Ultra-High Performance Concrete (UHPC) is a fine-grained cement-based composite material that exceeds mechanical and physical properties of Normal Strength Concrete (NSC). The uniform classification characterizing UHPC materials does not exist worldwide but some national recommendations characterizing UHPC materials could be noted [1]-[3]. UHPC materials are primary characterized by compressive strength exceeding 150 MPa and by direct tensile strength exceeding 8 MPa in these national recommendations. The compressive strength, type of reference elements and other border conditions are not unified, too. Cylindrical specimens with diameter 110 mm and high of 220 mm are noted at French recommendations AFGC/SETRA [1], cylindrical specimens with diameter 100 mm and high of 300 mm are noted at the German recommendation. [3]

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There are no mark differences between 25 mm thick slabs made from ECC with 1.5% of fibers and 2.0% fibers. The differences between UHPSFRC and ECC are more than twice at the load bearing capacity. PVA fibers are cracked but steel fibers are pulled out from the matrix. According to the results of load bearing tests the functionally layered slabs made from ECC (40% of total thickness) and UHPSFRC (60% of total thickness) have higher load bearing capacity than the slabs made from ECC. The load bearing capacity of the functionally layered slabs is lower than of the slabs made only from UHPSFRC. The behavior after the cracking of the slabs made with the volume fraction of PVA fibers $V_f = 1.5\%$ could be characterized as strain-softening, strain-hardening could be characterized for slabs made with the volume fraction of the PVA fibers $V_f = 2.0\%$.

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