Computers and Concrete, *Vol. 16, No. 6 (2015) 909-918*
DOI: http://dx.doi.org/10.12989/cac.2015.16.6.909

Bond behavior of lightweight concretes containing coated pumice aggregate: hinged beam approach

Ahmet Beycioğlu[1], Mehmet E. Arslan*[1], Özlem S. Bideci[2], Alper Bideci[2] and Mehmet Emiroğlu[1]

[1]*Department of Civil Engineering, Technology Faculty Düzce University, 81620, Turkey*
[2]*Department of Architecture, Art-Design and Architecture Faculty, 81620, Turkey*

(Received October 26, 2015, Revised December 10, 2015, Accepted December 11, 2015)

Abstract. This paper presents an experimental study for determining the bond performance of lightweight concretes produced using pumice aggregate coated with colemanite-cement paste. For this purpose, eight hinged beam specimens were produced with four different concrete mixtures. 14 mm deformed bars with 10Φ development lengths were selected constant for all test specimens. All the specimens were tested in bending and load-slip values were measured experimentally to determine the effect of colemanite-cement coated pumice aggregate on bond performances of lightweight concretes. Test results showed that, colemanite-cement coated pumice aggregate increases compressive strength and bond performance of the lightweight concretes, considerably.

Keywords: colemanite; coated pumice aggregate; lightweight concrete; bond strength; hinged beam test

1. Introduction

Many researchers in concrete technology have been working on manufacturing mortar and concrete by using natural (such as diatomite, pumice, scoria, sawdust, oil palm shells, and bottom ash) or artificial (such as expanded shale, slag, slate, perlite, and vermiculite) lightweight aggregates (Hosain *et al*. 2011). As it is well known, pumice is one of the natural lightweight aggregate used producing lightweight concrete. Considering the construction industry, pumice has large application areas both in structural and non-structural building elements. It is found abundantly in volcanic area e.g. countries like Chile, Ethiopia, Greece, Spain, Turkey, the United States and Iran (Libre *et al*. 2011). Pumice reserve of Turkey is approximately 3 billion m^3 (Bideci *et al*. 2014).

Lightweight Aggregate Concretes (LWACs) have been used in construction industry for more than 30 years and these materials have been preferred since their better properties than those of ordinary concrete such as porous structure, lower unit weight and strength values, better heat insulation(Arslan 2007, Güneyisi *et al*. 2013, Bideci *et al*. 2013, Arslan and Durmuş 2014). However, knowledge about the LWAC is less than that of ordinary concrete (OC).

*Corresponding author, Assistant Professor, E-mail: mehmeteminarslan@duzce.edu.tr

http://www.techno-press.org/?journal=cac&subpage=8 ISSN: 1598-8198 (Print), 1598-818X (Online)

National and international codes of reinforced concrete are constituted using the behavior of OC (with lower compressive strength than 50 MPa and unit weight higher than 20 kN/m^3) (Arslan 2011). Thus, it can be said that the equations in these codes are not valid for LWACs (Babu and Babu 2003).

One of the most important properties of reinforced concrete construction is bond strength (Campione and Mendola 2004). Bond between concrete and rebar allows redistribution of loads and moment. This event leads to existence of reinforced concrete. Many experimental methods have been conducted to determine the bond mechanisms between concrete and rebar. The simplest and mostly used bond test is pull-out method. Deficiencies of pull-out test are local compressive stresses at supports, thick concrete cover and absence of shear force vertical to the rebar. For these reasons, it does not represent entirely the bond behavior of flexural members. Thus, beam tests have been developed to determine more correctly bond behavior of flexural members. Hinged Beam Test (HBT) is one of the bending tests (Yeih *et al*. 2004, Ichinose *et al*. 2004, Arslan and Durmuş 2011, Mounir *et al*. 2013).

Although pumice has superior physical properties such as pore structure and lower unit weight, these properties induce deterioration in compressive strength and diffusion of chloride ions. To eliminate these unwanted situations a set of coating techniques have been performed. In this study, bond performances of lightweight concretes containing colemanite coated pumice aggregate were investigated experimentally in bending using hinged beam test.

2. Materials and methods

2.1 Materials

In this study, pumice aggregate of Nevşehir City was used. The ground Colemanite was used as surface coating material to produce coated pumice aggregate. The chemical properties of pumice aggregate and ground colemanite used in this study are given in Table 1 (LTC Factory 2012,

Table 1 Chemical analysis of the pumice aggregate and colemanite

Chemical Composition	Pumice	Colemanite
B_2O_3	-	40.09
SiO_2	74.1	4.98
Al_2O_3	13.45	0.15
Fe_2O_3	1.4	0.029
CaO	1.17	26.95
MgO	0.35	2.37
K_2O	4.1	-
Na_2O	3.7	0.09
SO_3	-	0.26
SO_4	-	0.31
As_2O_3 (ppm)	-	15
As (ppm)	-	11.36
Loss on Ignition	1.54	0.27

EMBBWG 2011). Portland cement (CEM I 42.5 R) was used as binder.

2.2 Method

This study consists of three stages. In the first stage, pumice aggregate was coated with CEM I 42.5R cement containing 0%, 7.5%, 12.5% and 17.5% colemanite substitution by weight. In the second stage, mixture designs of concretes produced with colemanite substituted cement coated aggregates were calculated. Also 7 and 28 day compressive strengths of produced mixtures were determined. In the third and final stage, hinged beam specimens were produced and tested in bending to evaluate the bond performance of concretes. Afterwards, performances of all the specimens were compared. In all experimental stages of this study, some abbreviations were used to code hinged beam specimens. In the coding, beams were coded in the form of UCP-CONTROL (produced by **U**n**C**oated**P**umice) or CLCP (**C**o**L**emanite substituted cement **C**oated **P**umice) with coating percent of pumice by colemanite substitution 7.5% (CLCP7.5), 12.5% (CLCP12.5) and 17.5% (CLCP17.5).

2.2.1 Coating process of pumice aggregates

Pumice aggregates were separated to range of grades with 4-8 mm and 8-16 mm for coating. Also pumice aggregates were kept in oven at 60°C for 24 hours before coating. Coating machine used for covering process has 800mm diameter, 1700 mm width and 1550 mm height with 1.85 kW-2.25 kW electric power. Surface is provided to be covered completely by spilling the cement and cement-colemanite grout on the aggregates put into the machines in two layers. In order to separate each layer, ground colemanite powder was spilled onto the aggregates. Aggregates were tried to coat for having the same cover thickness (Bideci 2013).

2.2.2 Mixture design of concretes containing coated/uncoated pumice aggregates

Uncoated and coated pumice aggregates (including 0%, 7.5%, 12.5% and 17.5% colemanite by weight of cement) were used in two-sieve opening as 4-8 mm and 8-16 mm for producing of structural lightweight concretes. Mixture designs of structural lightweight concretes were carried out in accordance with TS 2511-Mix Design for Structural Lightweight Aggregate Concrete (1977). Mixture proportions of concrete for each series are given in Table 2.

2.2.3 Hinged beam test set-up and application

There are many tests in technical literature for determining bond behavior of concrete and steel

Table 2 Mixture proportions

Mixing materials	Amount of concrete mixing materials (kg/m3)			
	UCP-CONTROL	CLCP7.5	CLCP12.5	CLCP17.5
8-16 mm aggregate	118.88	163.99	175.10	167.16
4-8 mm aggregate	173.93	275.75	281.69	268.63
0-4 mm aggregate	914.25	914.25	914.25	914.25
Water	254.53	205.00	204.00	208.00
Cement	400.00	400.00	400.00	400.00

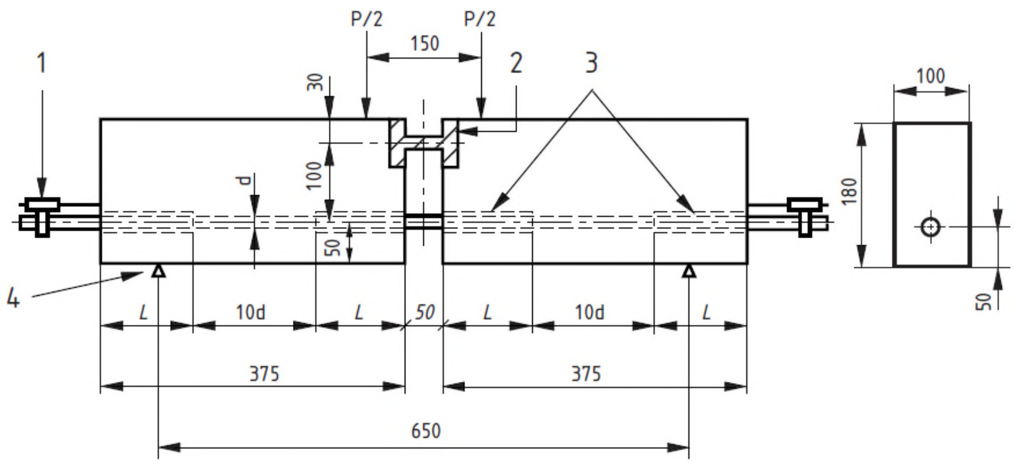


Fig. 1 Schematic illustration of hinged beam test setup

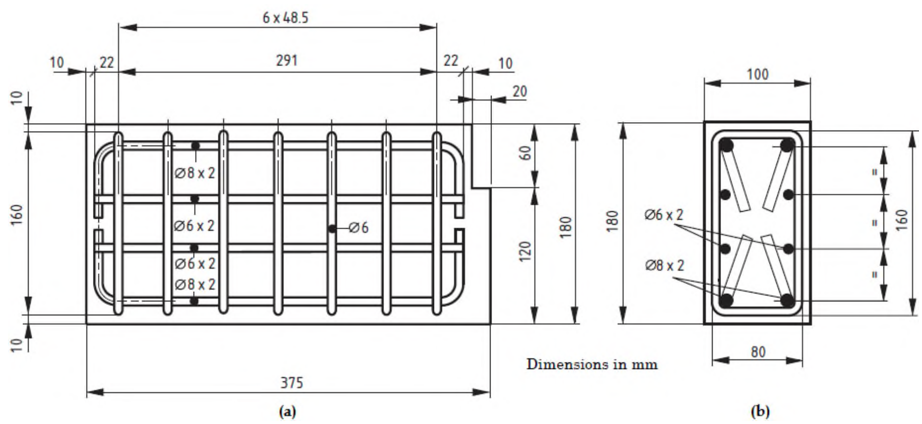


Fig. 2 Reinforcement arrangement of hinged beam blocks

rebars. As it is stated before the simplest of those is pull-out test. Although pull-out is simple, it supports, thick concrete cover and absence of shear forces vertical to the rebar. For these reasons, pull out test is not convenient in order to determine development length, but it can be used to compare bond behavior of rebars having different properties. Thus, beam tests have been developed to determine bond behavior of flexural elements more correctly. Hinged Beam Test is one of these and in this study, bond performance of lightweight concretes containing colemanite coated pumice aggregate was investigated in bending by using this test (Arslan and Durmuş 2011, Ersoy and Özcebe 2012).

The principle of the HBT is to load a test beam vertically by simple flexure until complete bond failure between concrete and rebar or ultimate tensile stress in rebar. During loading, the slippages at the end of rebars and applied loads are measured. The beam used for the test consists of two parallelepiped reinforced concrete blocks. These blocks works together by the help of a steel hinge placed in the middle of the beam. This steel hinge enables to ascertain the tensile forces more adequately (BS-4449 2015). The principle of the test is illustrated in Fig. 1.

In this test set-up; 1) Linear Potentiometric Displacement Transducer (LPDT) for measuring slips, 2) Steel hinge, 3) Plastic sleeves. Here, it should be expressed that it is important to complete the experiments without shear cracks. Stirrups were used to ensure shear resistance of beam specimens. Reinforcement arrangement of the hinged beam blocks are given in Fig. 2.

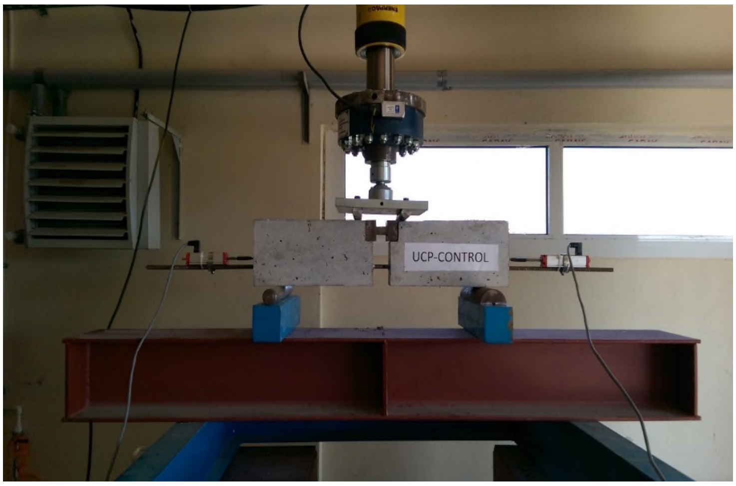
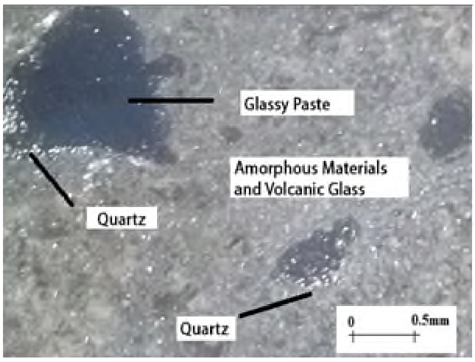
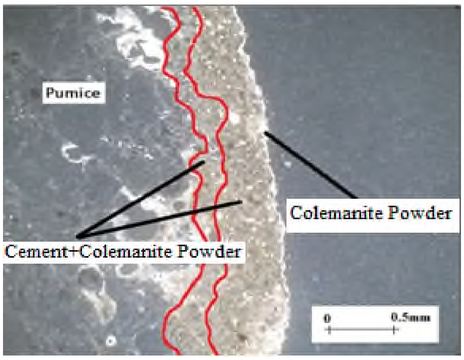


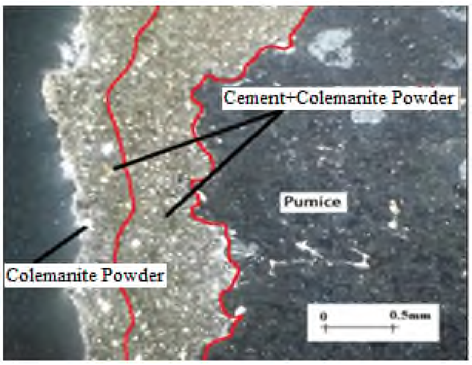
Fig. 3 The application of HBT



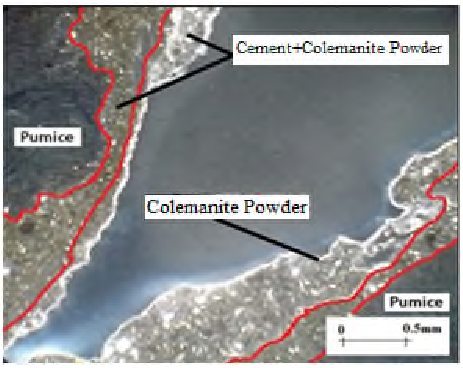
(a) UCP-CONTROL



(b) CLCP7.5



(c) CLCP12.5



(d) CLCP17.5

Fig. 4 Images of thin sections of coated and uncoated pumice aggregates

Table 3 Compressive strength of concretes

Concrete ID	Compressive strength			
	7 days		28 days	
	(MPa)	%	(MPa)	%
UCP-CONTROL	19.5	100	23.2	100
CLCP7.5	31.6	162	33.7	145
CLCP12.5	35.5	182	36.2	156
CLCP17.5	33.0	169	36.8	159

During the tests, loadcell and the LPDTs were used to measure the vertically applied loads and slips of rebars by loading the beam at mid-point as seen in Fig. 3.

In this study, bond stress which has 0.25 mm slippage was accepted as reliable bond stress (Mathey and Watstein 1961). For all beams, development lengths were kept constant as 10Φ. After bending tests, tensile stress-slippage figures were created by the help of the obtained data from bending tests to compare the bond performances of all types of concrete.

3. Results and discussions

3.1 Physical forms of colemanite coated pumice aggregates

Photomicrograph images of pumice aggregates thin sections (UCP CONTROL) (Fig. 4(a)) indicate that the majority of rock formed by volcanic glass in amorphous form is observed. Porosity of the rock is about 2%-3% and at boundary of pores some crypto crystalline quartz is available. Flow texture is also monitored in the rock. The rock is a dacitic magma product. As for thin sections of colemanite substituted cement coated pumice aggregates, it is seen that cover thicknesses of coated aggregates have not homogeneous structure. Cover thicknesses of coated pumice aggregates are approximately 0.6-1.0 mm, 0.8-1.2 mm and 0.3-1.0 mm for CLCP 7.5, CLCP 12.5 and CLCP 17.5, respectively (Fig. 4 (b)-(c)-(d)).

3.2 Properties of concretes produced by using coated/uncoated pumice aggregates

The compressive strength tests were performed according to BS EN 12390-3 (2009). 7 and 28 day characteristic compressive strengths of concretes (UCP-CONTROL, CLCP7.5, CLCP12.5 and CLCP17.5) are given in Table 3. It is clearly seen from the table that either 7 day or 28 day compressive strength of concretes produced using colemanite substituted cement coated pumice aggregates are considerably higher than that of concrete with uncoated pumice aggregate. This result shows that the most important mechanical property of concrete increases by the help of colemanite substituted cement coated pumice aggregate.

3.3 Bond performance of concretes with coated/uncoated pumice aggregates

As mentioned before, in this study, hinged beam tests have been carried out on beam specimens produced with coated uncoated pumice aggregates to determine bond performance between steel

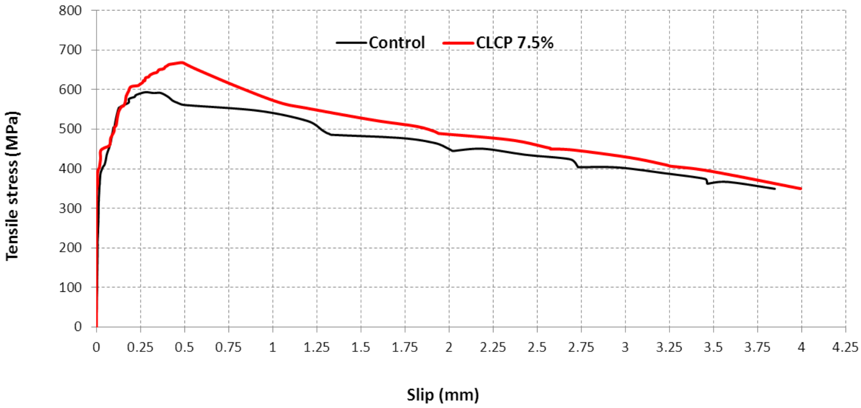


Fig. 5 Tensile stress-slip relation of CLCP 7.5 in comparison to UCP-CONTROL

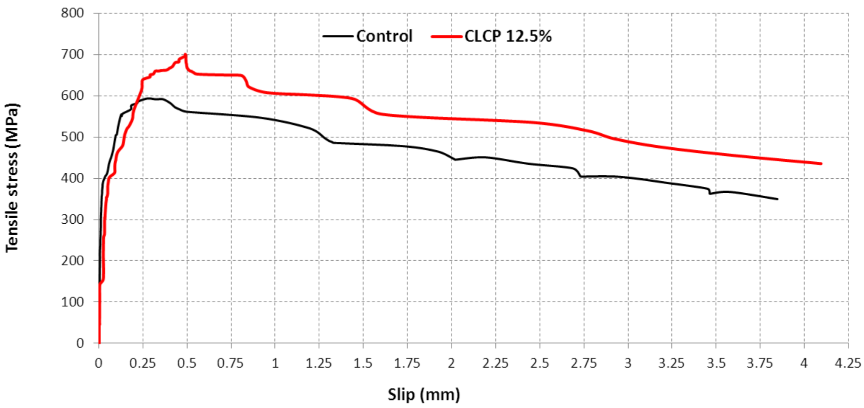


Fig. 6 Tensile stress-slip relation of CLCP12.5 in comparison to UCP-CONTROL

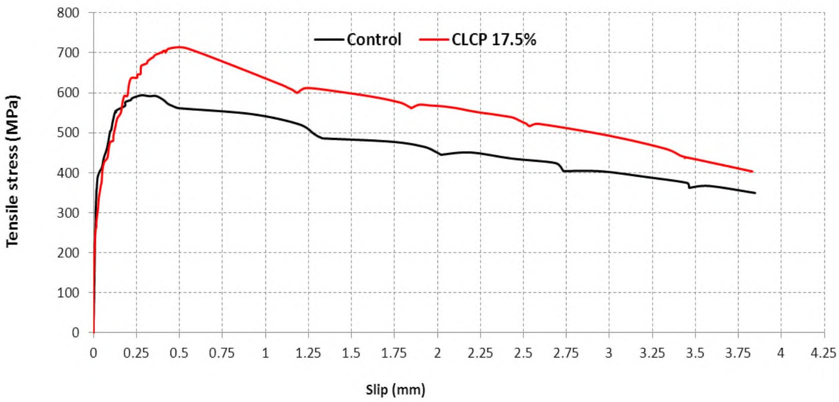


Fig. 7 Tensile stress-slip relation of CLCP17.5 in comparison to UCP-CONTROL

rebar (14Φ) and concretes in bending at constant development length (10Φ). Tensile forces at rebars and the associated stress values were calculated using equation of equilibrium with the help

Table 4 All results and parameters taken into account to evaluate bond performances

Concrete Code	f_{ck} (MPa)	$f_{0.25}$ (MPa)	f_y (MPa)	f_u/s_u	τ_u
UCP-CONTROL	23.2	590	560	593/0.281	14.83
CLCP7.5	33.7	613		668/0.485	16.70
CLCP12.5	36.2	639		700/0.490	17.50
CLCP17.5	36.8	645		711/0.443	17.78

of the recorded data by loadcell. Tensile stress-slip curves seen in Figs. 5-7 have been constituted after determining slippages (mm) measured with LPDTs corresponding to the tensile stress values.

In this study, while the test results were evaluated, bond stress at 0.25 mm slippage was considered (Mathey and Watstein 1961), whether at this slip value rebar reaches yield stress or not. Tensile stress values at 0.25 mm slippage for UCP-0, CLCP7.5, CLCP12.5 and CLCP17.5 beam specimens are 590 MPa, 613 MPa, 639 MPa and 645 MPa, respectively. Maximum tensile stresses obtained for each specimen were determined as 593 MPa, 668 MPa, 700 MPa and 711 MPa in the same order. In addition, bond stresses were calculated using maximum tensile stress values by the help of following Eq. (1).

$$\tau_u = \sigma_u f / 4l_b \tag{1}$$

Bond stress values calculated in this study are 14.83 MPa, 16.70 MPa, 17.50 MPa and 17.78 MPa for UCP-CONTROL CLCP7.5, CLCP12.5 andCLCP17.5 beam specimens, respectively. These bond stress values indicate that bond performance of concrete is enhanced by colemanite presence in varying ratio. Furthermore, as seen in Figs. 5-6 and 7 for all the beams slip values at yield stress (560 MPa) were lower than 0.25mm. Hinged beam test results and parameters used for evaluating the bond performance of the specimens are given in Table 4.

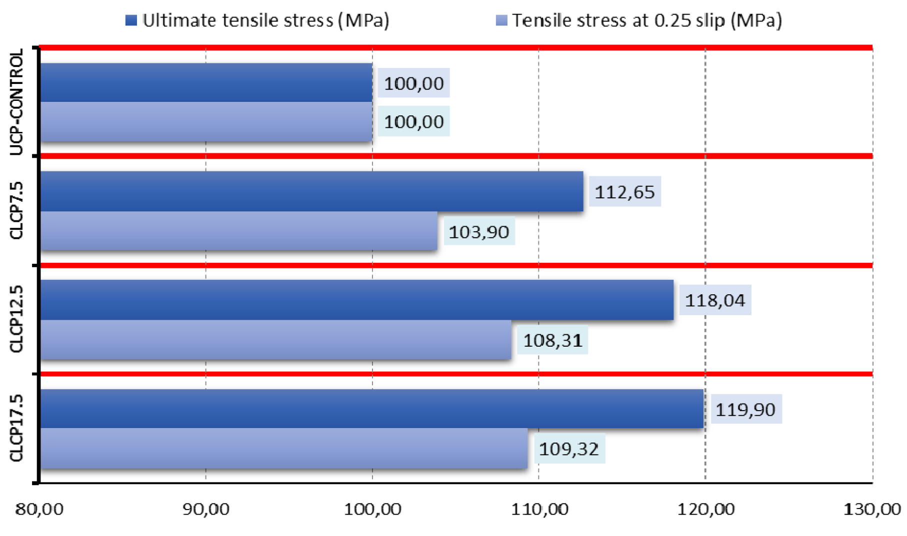


Fig. 8 Relative comparison of bond results

Fig. 8 was constituted for better understanding and to compare the test results relatively using maximum tensile stress and tensile stress at 0.25 mm slippage given in Table 4. In the figure, it is seen that, maximum tensile stresses for CLCP7.5, CLCP12.5 and CLCP17.5 increase 12.65%, 18.04% and 19.90% compared to UCP-CONTROL beam specimen. These increase percentages are 3.90%, 8.31% and 9.32% for 0.25mm slip value.

4. Conclusions

Based on the experimental results of this research, the following conclusions can be written:

• According to the thin section images, cover thicknesses could not be controlled during coating process to obtain a homogeneous cover thickness. Cover thicknesses of coated pumice aggregates are 0.6-1.0 mm, 0.8-1.2 mm and 0.3-1.0 mm for CLCP7.5, CLCP 12.5 and CLCP17.5, respectively.

• Increase in 28-day compressive strength of concrete produced using colemanite substituted cement coated pumice aggregates reached up to 59% compared to concrete with uncoated pumice aggregate. These results indicate that compressive strength of lightweight aggregate concretes can be increased by coating the aggregates by the method given in this research to provide structural lightweight concretes.

• For all the beam specimens, slip values at yield stress (560 MPa) were lower than 0.25 mm. The lowest tensile stress at 0.25 mm slip value is 590 MPa for UCP-CONTROL beam specimen and the highest is 645 MPa for CLCP17.5 beam specimen.

• The highest tensile and bond stresses are calculated for CLCP17.5 as 711 MPa and 17.78 MPa, respectively. These values are higher than 19.89% those of UCP-CONTROL specimens.

Consequently, usage of colemanite substituted cement coated pumice aggregates for producing structural lightweight aggregate concrete improves mechanical and bond performance concretes. Results of the study show that natural lightweight aggregates exist plenty in nature such as pumice can be used for producing structural lightweight concrete after coating. Here, it should be expressed that conclusions were made based on the results of the current study. Therefore, these tests should be carried out by using different materials and methods.

References

Arslan, M.E. (2007), “Investigation of bond strength of structural lightweight concrete and ordinary concrete comparatively in bending”, MSc Dissertation, Karadeniz Technical University, Trabzon.

Arslan, M.E. and Durmuş, A. (2011), “Investigation of bond behavior between lightweight aggregate concrete and steel rebar using bending test”, *Comput. Concrete*, **8**(4), 465-472.

Arslan, M.E. and Durmuş, A. (2014), “Fuzzy logic approach for estimating bond behavior of lightweight concrete”, *Comput. Concrete*, **14**(3), 109-125.

Babu, K.G. and Babu, D.S. (2003), “Behavior of lightweight expanded polystyrene concrete containing silica fume”, *Cement Concrete Res.*, **33**(5), 755-762.

Bideci, A., Gültekin, A.H., Yıldırım, H., Oymael, S. and Bideci, Ö.S. (2013), “Internal structure examination of lightweight concrete produced with polymer-coated pumice aggregate”, *Comp. Part B-Eng.*, **54**, 439-447.

Bideci, Ö.S. (2013), “Investigation of the physical and chemical properties of boron-coated lightweight aggregate concrete”, Ph.D. Dissertation, Trakya University, Edirne.

Bideci, Ö.S., Bideci, A., Gültekin, A.H., Oymael, S. snd Yıldırım, H. (2014), "Polymer coated pumice aggregates and their properties", *Comp. Part B-Eng.*, **67**, 239-243.

BS EN 12390-3 (2009), Testing hardened concrete. Compressive strength of test specimens, London.

BS 4449:2005+A2:2009 (2009), Steel for the reinforcement of concrete: Weldable reinforcing steel: Bar, coil and decoiled product, London.

Campione, G. and Mendola, L.L. (2004), "Behavior in compression of lightweight fiber reinforced concrete confined with transverse steel reinforcement", *Cement Concrete Comp.*, **26**, 645-656.

Ersoy, U. and Özcebe, G. (2015), *Reinforced concrete: Basic Principles and Designing According to TS-500-2000 and Turkey's Earthquake Resistant Design Code-1998*, 4th Edition, Seçkin Publishing, Ankara, Turkey.

Factory LTC, (2012), *Cement chemical analysis report*, Chemistry Lab Report, Kırklareli, Turkey.

Guneyisi, E., Gesoglu, M. and Ipek, S. (2013), "Effect of steel fiber addition and aspect ratio on bond strength of cold-bonded fly ash lightweight aggregate concretes", *Constr. Build. Mater.*, **47**, 358-365.

Hossain, K.M.A., Ahmed, S. and Lachemi, M. (2011), "Lightweight concrete incorporating pumice based blended cement and aggregate: Mechanical and durability characteristics", *Constr. Build. Mater.*, **25**(3), 1186-1195.

Ichinose, T., Kanayama, Y., Inoue, Y. and Bolander, J.E. (2004), "Size effect on bond strength of deformed bars", *Constr. Build. Mater.*, **18**(7), 549-558.

Libre, N.A., Shekarchi M., Mahoutian, M. and Soroushian P. (2011), "Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice", *Constr. Build. Mater.*, **25**(5), 2458-2464.

Managment EMBBWG, (2011), Colemanite Analysis Report, Balıkesir, Turkey.

Mathey, R.G. and Watstein, D. (1961), "Investigation of bond in beam and pull out specimens with high yield strength deformed bars", *ACI J.*, **57**, 1071-1089.

Mounir, M.K., Mohamed, A.S. and Mohamed, A.A. (2013), "Steel-concrete bond potentials in self-compacting concrete mixes incorporating dolomite powder", *Adv. Concrete Constr.*, **1**(4), 273-288.

TS 2511 (1977), Mix Design for Structural Lightweight Aggregate Concrete. Ankara.

Yeih, W., Chang, J.J. and Tsai, C.L. (2004), "Enhancement of the bond strength of epoxy coated steel by the addition of fly ash", *Cement Concrete Comp.*, **26**(4), 315-321.

CC