

# Bond strength between concrete layers of three-layer concrete structures

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**Abstract.** Development of the methods for the calculating reinforced concrete structures covers a wide range of issues, including the expansion of the application of new innovative materials such as concrete and reinforcement. In practice, modern construction of multilayer structures is made of concrete with different strengths and it is compulsory to conduct numerical and experimental studies of the bond strength between concrete layers with different strengths. In this study, the influence of some physical-mechanical factors and temporal manufacturing parameters on the monolithic bond of concrete layers of three-layer structures made of concrete with different densities according depending on the sample is considered. An experiment was conducted to evaluate the development of the shear bond strength between two concrete layers of three-layers sandwich concrete. Three-layer samples consist of normal concrete (NC) in the external layers and lightweight concrete (LWC) in the inner layer. The results of the study show that these factors directly affect the monolithic bond of concrete layers in three-layer structures, which are made by concrete of different strengths. The obtained scientific results allow the determination of reasonable parameters to ensure the monolithic bond of concrete layers with different strengths of the 3-layers structure in design and production.

## 1. Introduction

Nowadays multilayer reinforced concrete structures are used in the expansion of fields. One of these is the use of multilayer reinforced concrete structures with a middle layer of low thermal conductivity concrete. Three-layer construction with a heat-insulating layer of light concretes of low average density and strength relate to a special class of reinforced concrete structures. They occupy an intermediate position between conventional reinforced concrete structures and combined composite section with outer layers of reinforced concrete and the middle layer of different types of thermal insulation materials, characterized by low strength and high deformation.

In the publications [1, 2, 3, 4], the theory and experimentation, calculating the three-layer structure with the middle layer from low thermal conductivity material polystyrene concrete, are presented. These calculation methods are mainly based on the assumption that these layers of different intensity materials are absolutely bound. The fact has shown that the adhesion force between different material bonding layers in many cases will no longer be absolute.

In composite structures, three basic factors contribute to the bond strength: the natural adhesion, friction between concrete layers and the use of reinforcements [5, 6, 7, 8]. Natural adhesion is the result of physical-chemical phenomena occurring at the interface of two materials. Natural adhesion



can be further classified as mechanical or specific. Mechanical adhesion occurs when glue penetrates into the irregularities of the surface which creates a bond.

The transfer mechanism of the shear stress developed in members made of concrete layers with different strengths is extremely complex since it is influenced by diverse factors including the reinforcement crossing the interface, the resistance to compression of concrete with low strength, the roughness level of the interface and the stresses generated by the loads normal to the interface. Research on this mechanism was pursued by Santos and Júlio [9], Birkeland and Birkeland [10], Mattock and Hawkins [11], Walraven and Reinhardt [12], and Loov and Patnaik [13] who conducted various studies on the shear friction behaviour.

One issue that needs to be considered is that when pouring concrete between layers, with a long rest period, it may cause to set the precast concrete in progress. At the interface between the composite concrete an inter-phase transition zone is formed. In this study, the authors investigated the influence of some physical-mechanical factors and temporal manufacturing parameters on the monolithic bond of concrete layers of three- layers concrete structure

## 2. Experimental procedure

### 2.1. Concrete mixtures

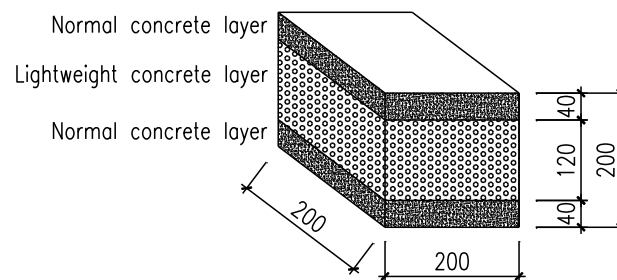
In the study two different types of concrete were used, normal concrete (NC) and lightweight concrete (LWC) – polystyrene concrete. For the manufacture of normal concrete of strength class B25 and polystyrene concrete D350, raw materials are used in the following composition [15, 16], show in table 1 and 2:

**Table 1.** Composition by mass of mixes

	Density, (kg/m <sup>3</sup> )	Cement (M400), kg	Water, (l)	Limestone 0,5-1cm, (m <sup>3</sup> )	Sand 0/2mm, (m <sup>3</sup> )	EPS 2/5mm ( $\rho=20$ kg/m <sup>3</sup> ), (kg/m <sup>3</sup> )	Chemical additives SilkRoad SR-5000F, (g)
D350	338	330	105	-	-	6.9	710
B25	2400	358	205	0.783	0.483	-	-

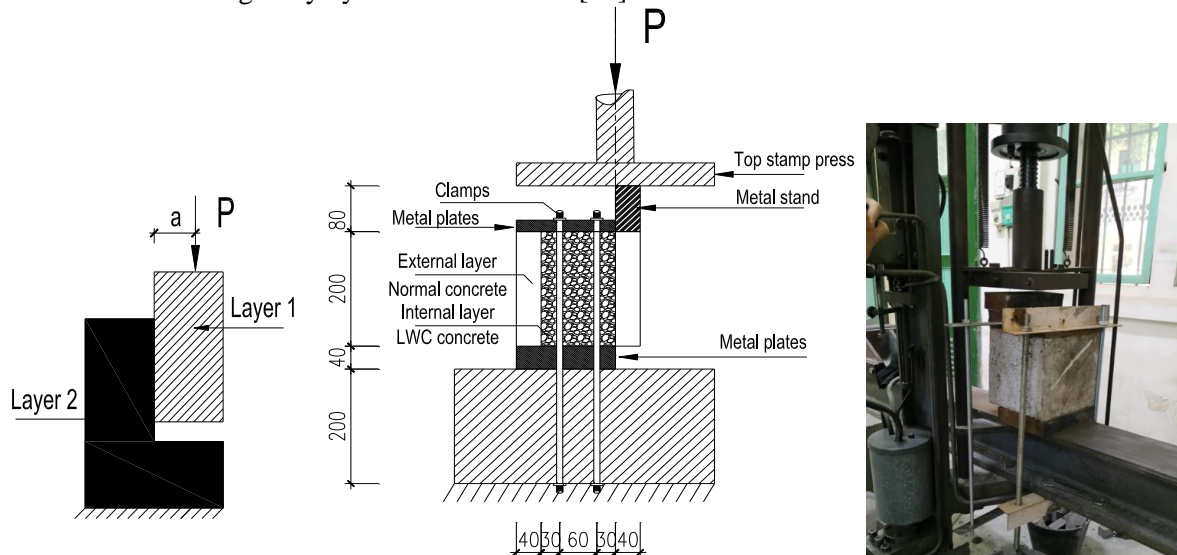
### 2.2. Testing methods

The experiments were performed on composite cubic samples of dimensions 200x200x200 mm. At first, concrete B25 was placed in the forms with thickness 40mm, then was placed lightweight concrete D350 with thickness 120mm. Finally, proceed to the construction of the external layer of B25 concrete with thickness 40mm. Samples were made in inventory forms by layer-by-layer laying of concrete mixtures with varying time intervals between laying layers of concrete of different densities from 30 minutes to 4 hours in steps of 30 minutes. After 28 days of curing in laboratory conditions at a temperature of 20°C and a relative humidity of 95%, the contact surfaces were prepared.



**Figure 1.** Sample three-layers concrete for shear test.

There have been many different test methods used to test Interface Shear Transfer (IST). The slant shear and splitting tests were used by Santos and Julio [5, 6]; the pull-off test was used originally by Mattock and Hawkins [11]; the corbel with moment test was applied by Johal [14]; and the beam test was conducted originally by Loov and Patnaik [13].



**Figure 2.** Scheme of three-layer blocks for shear test

With the specific geometric shape and size of the 3-layer block as shown in figure 1, the determination of cross-cutting on the surface between concrete layers is relatively complicated. The plasticity of ordinary concrete mixture and the plasticity of polystyrene concrete (lightweight concrete) mixture are different. When pouring and compacting a concrete mixture, the cement water from the upper mixture tends to flow and penetrate into the lower layer. Therefore, in two locations of the interface surface between normal concrete and lightweight concrete in a 3-layers block, there will be different binding forces at the contact surface. Pugach E M presents a solution to determine the shear strength between concrete layers in multilayer structures with other materials [17]. However, this method is difficult to implement on conventional equipment in the laboratory. In this study authors use test method the corbel of Johal [14] to determine interfacial shear bond strength between concrete layers (show in figure 2). Moments in the shear plane less than or equal to the flexural ultimate moment of the shear plane do not reduce the shear transfer strength.

The loading of the samples was performed on a laboratory press with the method of fixing the sample proposed in figure 2: each sample, located between two steel plates with a thickness of 20 mm, was fixed on the upper stationary stamp of the press using clamps with a slight pressure or twitching, its displacement would not occur. In this case, the sample was located between the plates, the edges of the plates were on the tested interface between the layers of polystyrene concrete and expanded clay concrete, and the border itself was located in the centre of the press die. The load on the block was applied using a table made of steel prism, that is mounted on the lower movable die of the press. The loading was carried out continuously at a speed that provided an increase in the calculated stress in the sample to its complete destruction within 0.05 ... 0.02 MPa/s. The destroyed sample was subjected to visual inspection, while the nature and place of destruction was noted in the test log.

The shear strength at the junction of the layers for each sample is determined by the formula:

$$f_v = \frac{P}{A}$$

P - maximum load, [N] and A- the working cross-sectional area of the test piece, mm<sup>2</sup>;

### 3. Results and Discussion

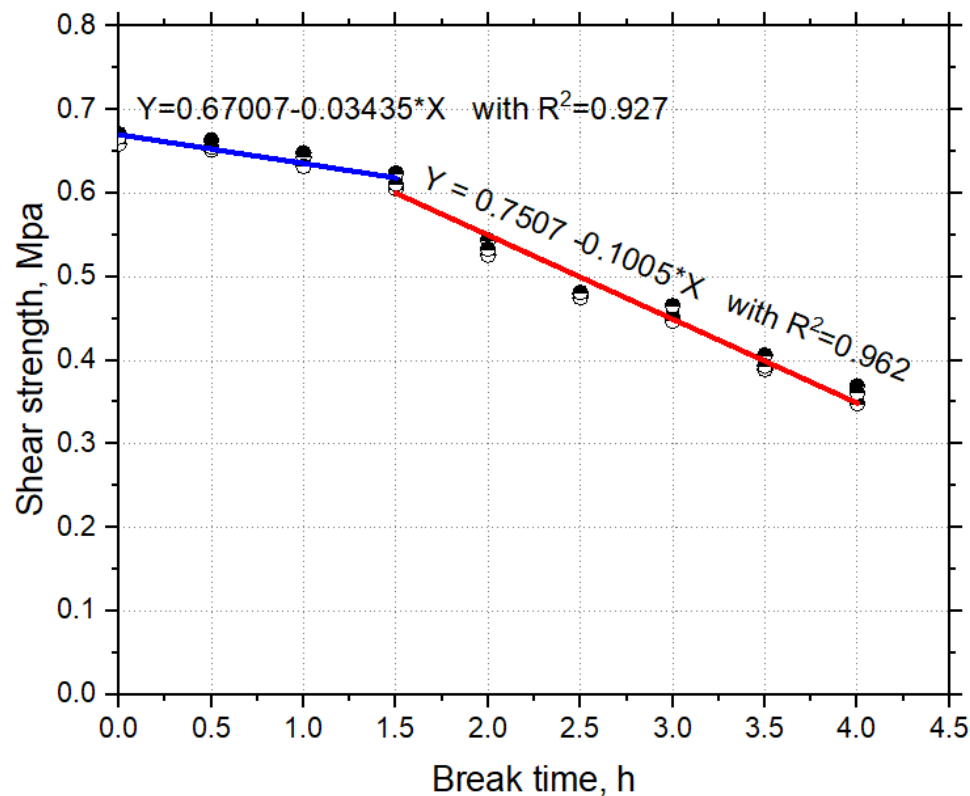
A total of 27 samples were tested to determine the shear bond strength and 27 values of the breaking load were obtained. Depending on the time elapsed between concreting two adjacent layers, all tests can be divided into 9 groups by time, from 0 hour to 4 hours. The results of the experiments are shown in Table 2 and Figures 3.

**Table 2.** Three-layer shear tests

	№ Sample	Break time, h	Ultimate load, kg	Shear strength, $f_v$ , MPa	Average shear strength, MPa	The nature and location of destruction
1	0-1	0	2695	0.672	0.665	Destruction of polystyrene concrete with a break in part of the granules and a break in part of the middle layer
2	0-2	0	2685	0.656		
3	0-3	0	2705	0.667		
4	1-1	0.5	2720	0.663	0.657	Destruction of polystyrene concrete with a break in part of the granules and a break in part of the middle layer
5	1-2	0.5	2635	0.652		
6	1-3	0.5	2720	0.655		
7	2-1	1.0	2725	0.648	0.640	Destruction of polystyrene concrete with a break in part of the granules and a break in part of the middle layer
8	2-2	1.0	2600	0.641		
9	2-3	1.0	2615	0.632		
10	3-1	1.5	2495	0.624	0.613	Destruction of polystyrene concrete with a break in part of the granules and a break in part of the middle layer
11	3-2	1.5	2480	0.605		
12	3-3	1.5	2480	0.611		
13	4-1	2.0	2160	0.544	0.534	Destruction along the shear plane without destruction of the polystyrene concrete layer
14	4-2	2.0	2120	0.526		
15	4-3	2.0	2145	0.533		
16	5-1	2.5	1915	0.479	0.478	Destruction along the shear plane without destruction of the polystyrene concrete layer
17	5-2	2.5	1900	0.475		
18	5-3	2.5	1925	0.481		
19	6-1	3.0	1720	0.452	0.433	Destruction along the shear plane without destruction of the polystyrene concrete layer
20	6-2	3.0	1740	0.447		
21	6-3	3.0	1735	0.465		
22	7-1	3.5	1585	0.406	0.394	Destruction along the shear plane without destruction of the polystyrene concrete layer
23	7-2	3.5	1555	0.389		
24	7-3	3.5	1570	0.393		
25	8-1	4.0	1475	0.369	0.361	Destruction along the shear plane without destruction of the polystyrene concrete layer
26	8-2	4.0	1430	0.348		
27	8-3	4.0	1460	0.361		

According to the test results (table 2), the dependence of the strength of the contact zone of the layers on the slice on the holding time of the previous layer before laying the next one was established (Figure 3).

When the value of the time intervals between the laying of the layers is less than 1.5h, the destruction during shearing occurred as in the least durable material, i.e. polystyrene concrete, and in the contact area. For values of the time interval exceeding 1.5h, the fraction of samples destroyed directly in the contact zone increased significantly, i.e. the formation of a monolithic bond between the layers did not occur. For samples whose production intervals were more than 2.5 hours, failure occurred only along the adhesion plane. So, with a break of 4.0 hours, the adhesion strength of the layers decreases to 50% of the original value.



**Figure 3.** Results of tests of three-layer samples for shear along the contact zone for various values of technological breaks between laying layers  $t$  (h)

The calculated dependences for assessing the adhesion strength of the layers are differentiated depending on the time interval between laying layers:

$$\text{Break time } t < 1.5h: f_v = 0.67007 - 0.03435t$$

$$\text{Break time } t > 1.5h: f_v = 0.7507 - 0.1005t$$

#### 4. Conclusions

Based on the experiments pertaining to the development of bond strength in composite components of three-layer concrete with different strengths, the following conclusions are drawn:

- Practical shear bond strength methods were introduced. The characterization of interface bond strength should consider the predominant stress at the interface, which in many cases is shear.
- The influence of some factors and manufacturing time parameters on the physical-mechanical characteristics of the monolithic bond of concrete layers in three-layer structures made of concrete of various densities is considered and investigated.
- According to the results of experiments, the dependences of the strength of the monolithic bond of the layers on the temporal parameters of the manufacture of structural elements after

manufacture are established. The optimal value of aging duration of layers of the three-layer structure is from 0.5 to 1.5 hour.

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