Development of New Materials for Prefabricated Concrete Elements for Building Construction in Tropical Climatic Conditions

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Abstract. This paper presents the development of new concrete mixtures, which constitutes prefabricated elements for building constructions in tropical conditions in Gabon (Africa). The Client from Gabon required prefabricated buildings fabricated overseas (in Serbia) and assembled at the site (Okolassi, Gabon). The main problem was to achieve sufficient strength and resistance of finishing material, with small weight. New material was developed in order to satisfy the following conditions: low unit weight, high compressive/tensile strength, low shrinkage, reduced spalling, resistance to high temperatures and moisture. The main need for development of these new concrete mixtures lies in characteristics of designed prefabricated concrete elements, with the following main properties: a) concrete panels, with dimensions 240-360 cm (length), 110 cm (height), and 20 cm (width); b) panels should weigh up to 100 kg/pc, but sound and robust, so surface must be casted of ultra-high-performance concrete, while the inner part of the element should have smaller unit weight. New concrete mixtures with the required properties were designed on the basis of the extensive laboratory analysis. Concrete specimens were prepared using the materials available at the market and tested. Testing results were further analysed in order to derive convenient mathematical models for the target concrete properties. The results of this analysis were new concrete mixtures, prepared according to the derived models, to be used for construction of prefabricated concrete panels.

1. Introduction
This paper presents the results of developing new cementitious material for prefabricated concrete panels, that should provide prefabricated buildings fabricated overseas (in Serbia, Europe) and assembled at site (Okolassi, Gabon, Equatorial Africa). The Employer provided the architectural design for the “growing house”, single family house with the expandable floor plan for the growing family needs (Figure 1). As the smallest (92 m²) building required up to 180 m² of concrete panels, the main challenge was to produce light façade and internal panel, suitable for the manual manipulation on the construction site.
Because of the panel’s dimension (L/H/W = 240-360/110/20 cm), after several trials, composite panel with light insulated core and concrete surface was chosen (Figure 2).

The required properties of concrete were tried to be achieved by adding various additives, including: light micro-granules for the reduction of unit weight, special types of nano-cements, special admixtures for entrapping air, special admixtures for reduction of moisture loss (lime, retarders) [1, 2]. The limited weight of the panel required thin surface layers, so the concrete had to be fine-grained, with a maximum aggregate size of 2 mm [3, 4].

Numerous ways to prepare lightweight concrete mixtures with ordinary potland cement (OPC) have been described in the literature [5-7]. However, the dimensions of the elements made of these lightweight concretes were significantly larger than the linings of these panels (5-10 mm). Another requirement that had to be investigated is that such a lightweight concrete mix must interconnect with thermal insulation (EPS or mineral wool) and therefore must have good adhesion to this material. These were the main tasks set before this research.

In order to optimize number of trials, program for laboratory analyses was developed based on the experimental design with the set goals (higher compressive and tensile strength, lower unit weight, higher resistance to the environmental impact and lower price of the new material). Purpose of the application of the experimental design is that maximum number of data on the material properties could be obtained with the smallest number of well-planned experiments. During this phase of the research, a diverse field of values for individual parameters was obtained (Figure 3), and overall evaluation highlights the most influential ones.
As a result of the performed analysis, second phase of the research went in two directions, depending of the thickness of the panel surface layer: one was the development of heavy but hard materials for a thinner layer, and the other was the development of lighter, weaker ones for a thicker layer. Developing the lighter materials, the main challenges were to achieve sufficient strength and resistance of finishing material, with small weight. On the other hand, heavier materials have been developed with increased bond and flexural strength, as well as increased durability [8-11].

2. Material
Numerous test batches with different mixture proportions were performed according and EN 206-1. Previous research has shown that the use of special types of cement does not improve the properties to such an extent as to justify a higher price.
In this research, cement type CEM I 42.5 R (Lafarge BFC, Serbia, according EN 197-1:2000) was used. In order to test the influence of aggregate type on concrete properties, two different types of aggregate were used: crushed marble (M) aggregate 0 – 2 mm from “Venčac” quarry in Arandželovac, Serbia, and quartz (Q) aggregate 0 – 2 mm from “Kopovi Ub” quarry in Ub, Serbia. Polycarboxylate superplasticising admixture (PCA) was added to normal weight mixture in order to achieve higher strength and designed Abrams’ cone slump of 18 – 20 cm (self-compacting concrete). Steel fibres (SA/M 0.22x6; L = 6 mm, d = 0.22 mm, L/d = 27, round, ft ≥ 2100 N/mm²) were added in the mixture to increase bending and ductile strength.
For the light concrete mixtures, expanded polystyrene granules (EPS) size 1 – 3 mm, were used, and combined with special admixture for the segregation prevention.

3. Mixtures and testing

3.1. Normal weight surface material
Previous research on concrete panels has shown that composite panels with a light core (mineral wool or foam insulation) can have the required weight and sufficient strength in all phases of manufacture, transport and installation, if they are finished with concrete of normal weight, which meets the conditions for the class at least C 30/37 (Eurocode 2).
Normal weight fine-grade concrete mixture were developed in two types: normal strength for the panels up to 2.5 m, and high strength concrete mixture for the panels up to 4 m.
Table 1 shows mixture proportions of different concrete batches for two selected normal weight concrete mixtures.
Preliminary tests of concrete have shown that concrete has a rapid increase in strength. Based on that, it was decided that the selected mixtures should be tested after 2 days in order to enable data for fast manipulation with the panels, and after 28 days in order to obtain information on the class of concrete. Concrete was casted in 40/40/160 mm prismatic moulds. All the mixtures were casted in series of 4 samples: 2 were tested for three point bending and compressive strength (EN 12390-2, EN 12390-5) after 2 and 28 days, respectively. Testing was performed in the Concrete laboratory of the Highway Institute of the Republic of Serbia. Testing equipment used for this experiment is CONTROLS hydraulic load frame, max. capacity of 600 kN. Load frame provide automatic acquisition of data with capacity of 20 to 40 data points per second. The results of the concrete samples are shown in Table 2.

### Table 2. Compressive and Bending Strength

| Mix No | days | Average weight (kg/m³) | Average bending (MPa) | Average compression (MPa) |
|--------|------|------------------------|-----------------------|---------------------------|
| 1      | 2    | 2153                   | 5.65                  | 23.22                     |
| 1      | 28   | 2189                   | 7.15                  | 44.85                     |
| 2      | 2    | 2335                   | 11.87                 | 66.70                     |
| 2      | 28   | 2355                   | 13.50                 | 95.03                     |

### 3.2. Normal weight surface material

Experiments on panels have shown that composite panels can meet the required conditions with a coating of lightweight concrete, but of greater thickness. Light weight fine-grade concrete mixture were developed in two types, depending on weight (Table 3).

### Table 3. Selected Mixture Proportions for Light Weight Concrete (kg/m³)

| Mix No | CEM I 42.5 | Q 0 - 2 mm | M 2 - 4 mm | EPS admix. | EPS 1 – 3 mm | Latex | Water |
|--------|-------------|------------|------------|------------|--------------|-------|-------|
| 5      | 565         | 425        | 0          | 9          | 15           | 0     | 255   |
| 6      | 390         | 300        | 700        | 6          | 10           | 40    | 100   |

The condition for both mixtures was that the concrete must meet the requirements for class C 8/12 or C 10/15 as the lower limit for the application of panels in residential construction. This value is determined according to the highest quality class of masonry walls made of concrete blocks. As in the previous case, the testing was performed at the Institute for Roads of the Republic of Serbia, on the same equipment and in the same conditions. The results of the concrete samples are shown in Table 4.

### Table 4. Compressive and Bending Strength

| Mix No | days | Average weight (kg/m³) | Average bending (MPa) | Average compr. (MPa) |
|--------|------|------------------------|-----------------------|----------------------|
| 5      | 2    | 1237                   | 2.64                  | 7.19                 |
| 5      | 28   | 1352                   | 4.59                  | 15.83                |
| 6      | 2    | 1547                   | 3.63                  | 10.32                |
| 6      | 28   | 1569                   | 4.70                  | 15.86                |
4. Results and discussion
During the project, two mixtures for normal weight concrete and lightweight concrete were selected. One mixture of each type has better mechanical characteristics, and the other a better possibility of application from the architectural point of view [12, 13].

Panels with marble aggregate can be grinded and in that way the finishing of the panels can look like an artificial stone - terrazzo. Abrasion resistance of the material is equal to the abrasion resistance of marble. The material was also tested for abrasion. Panels with quartz aggregate have 2-3 times less abrasion than panels with marble aggregate and can be used in a severe conditions environment.

Although the cement industry has made a big step forward in the technology of producing new, finer types of cement (nano-cements), their relatively high price discourages their application in simple, affordable and mass-produced elements This research also showed that high classes of concrete (up to 100 MPa, i.e. C 80/95) can be achieved with ordinary cement (CEM I 42.5 R).

Numerous examples in the literature emphasize the importance of the water-cement (W/C) factor for the properties of concrete, primarily strength and durability. The W/C factor below 0.45 enables the production of concrete without capillary pores, and thus the required durability of concrete. During this research, it was shown that low W/C factor remains the key parameter for concrete quality.

The latest generation of polycarboxylate superplasticizers enable a significant reduction of the W/C factor while maintaining a self-compacting consistency. Their application results in fine-grained concretes of high strength and performance that are ideal for use in thin layers. This type of concrete can be applied on the surface of the light core in a thin layer without the risk of penetration, impact or damage.

The use of steel fibres significantly increases the tensile strength and allows the production of thin layers of concrete on the surface of the light core, thus reducing the overall weight of the panel.

Weight loss was most effectively achieved by the use of expanded polystyrene (EPS) granules. The use of air entraining admixtures - aerants and foaming agents, reduced the weight, but did not allow simultaneous control of the mechanical properties of the material. However, when applying EPS granules, an additive should be applied to prevent floating out and segregation in order for the mixture to be workable.

Polymer additive - latex, was used to increase the bending strength of light mixtures. However, as can be seen in the results, the same final strength can be achieved by increasing the amount of cement instead of adding latex, but with a slower early strength development.

5. Conclusions
During the project, two mixtures for normal weight concrete and lightweight concrete were selected. One mixture of each type has better mechanical characteristics, and the other a better possibility of application from the architectural point of view.

In order for concrete panels to meet the required requirements, they must have a light core made of mineral wool or foam.

Having in mind all the phases in the production and installation of the concrete panel (transport, installation), although heavier, the concrete of normal weight showed significantly better characteristics than the lightweight one. Mixture 1 is 10% lighter, but its mechanical characteristics are only 50% of mixture 2. Still, mixture 1 can be economically finished by grinding and become similar to artificial marble - terrazzo, and thus provide additional value to the panel.

For the final surface of the panel, the best characteristics were shown by mixture number 2, high-performance concrete that has high mechanical characteristics (bending, compression) and high resistance to impact and wear. In the thickness of 6 mm this material met all the conditions set for the panel.

Lightweight concrete mixtures (5 and 6) can be used for interior partition panels. Mixture 5 is more than 40% lighter than high-strength concrete (mixture 2), but its mechanical characteristics are much weaker (compressive strength is 6 times lower, and bending strength 3 times).

Thanks to the larger amount of marble aggregate, the mixture 6 can be grinded and thus a quality finish can be achieved. Thus grinded and impregnated panels can also be used as facade, without additional processing.
The selected mixtures are currently being tested in real conditions and the obtained results will be used for further development of the material (Figure 4). The real condition testing showed some of the issues to be addressed in the future, which consider the panel as a whole: soundproofing of the walls, long-term durability and the impact resistance of the building structure.

6. References

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