Analysis of concrete deformation diagram, received by different ways of formation, and their separate layers

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Abstract. The article covers the processes that occur during centrifugation and vibration centrifugation of ready-mix concrete. It dwells upon the conditions of specific (variational) structure formation of as-formed centrifuged concrete, the outer layer of which is formed mostly by coarse aggregate with an interlayer of cement-water paste; the closer to its inner surface, the higher the content of small particles of dense aggregate and cement-water paste. Having conducted the research, the authors plotted and analyzed stress-deformation diagrams of concrete samples and their separate layers acquired through various molding processes. They studied different concrete mixes with varied combinations of aggregate and dispersed fiber. A mix of vibration centrifuged concrete with combined aggregate (granite + lightweight expanded clay aggregate) and combined fiber (steel + basalt) was chosen for further research. One diagram was plotted for vibrated concrete, which has an even distribution of properties over the cross sections; three diagrams were plotted for centrifuged and three – for vibration centrifuged concrete (one for each layer: outer, middle, and inner). The experimental data was analyzed.

1. Introduction
Vibration centrifuged fiber-concrete structures have a number of advantages compared with substitutes, and their research is scientifically and practically significant for the present-day construction industry [1-30].

When consolidated by centrifuging, the concrete mixture is separated into zones based on the grain size (Figure 1). A heavier weight coarse-grained conglomerate shifts to the outer surface of a product, and a lighter weight conglomerate shifts closer to the inner surface, respectively. Particles are separated faster when an aggregate is denser and bigger, and the speed of a form spin is higher. In fact, a large dense aggregate reaches the outer surface of the product in a few full spins of the form (1-1.5 sec), i.e. already during distribution, while a fine aggregate shifts to this position only in 200-205 sec.
This particular variation in the drift rate of particles, which are different in size, translates into a specific (variational) structure formation of as-formed centrifuged concrete, the outer layer of which is formed mostly by coarse aggregate with an interlayer of cement-water paste; the closer to its inner surface, the higher the content of small particles of dense aggregate and cement-water paste. To control this process during an acquisition of a three-layer vibration centrifuged sample from fiber-concrete, the following conditions should be met: 1) grains of a coarse aggregate should be of the same size, 2) a porous aggregate must be used.

As a result, whereas a variational nature of concrete density is manifested not in the inhomogeneity of the cement stone structure alone, but also in the pattern of the aggregate grains distribution across the product wall thickness, the centrifugal force acting proportionally to the weight of a spinning solid body will influence the formation of layers in the process of consolidation during vibration centrifugation.

2. Experimental program and research results
A research was conducted in laboratory settings of Don State Technical University, diagrams of stress-deformation of concrete samples and their separate layers, which were acquired through various molding processes, were plotted and analyzed.

A surface scanning procedure consists in the following. A certain volume ABCD of wall thickness \( h_c \) is separated from the tubular element of an annular section (Figure 2), and a dispersion of the average concrete mix density over the depth and length of a product is determined. That said, the literature data suggests that the wall thickness should be \( 1/10 \) of the cross section diameter, therefore, if the inner diameter of the form under consideration is 165 mm, the wall thickness of the product is taken as 16.5 mm.

Physical and mechanical properties of the molded centrifuged product samples are listed in table 1. The results of surface scanning are given in table 2.

Different concrete mixes with varied combinations of aggregate and dispersed fiber were studied.
Table 1. Physical and mechanical properties of centrifuged concrete samples.

| No. of a concrete sample | Sample weight, g | Sample volume, cm³ | The average density of a sample, kg/m³ | Estimated compression strength, MPa |
|--------------------------|------------------|--------------------|----------------------------------------|-----------------------------------|
|                          |                  |                    |                                        | vibrated concrete | centrifuged concrete |
| 1                        | 5837.3           | 2308.13            | 2528                                   | 29.1  | 39.8 |
| 2                        | 5870.8           |                    | 2543                                   | 29.2  | 40.0 |
| 3                        | 5903.1           |                    | 2557                                   | 30.0  | 41.0 |
| 4                        | 5789.5           |                    | 2508                                   | 28.1  | 38.4 |

Table 2. The results of surface scanning by layers.

| No. of a concrete sample | Characteristics of surface scanning rate by layers | Compression strength, MPa |
|--------------------------|---------------------------------------------------|---------------------------|
|                          | outer     | middle   | inner     | outer | middle | inner |
| 1                        | 4940      | 4891     | 4741      | 44.2  | 42.9   | 39.4  |
| 2                        | 5110      | 4921     | 4632      | 44.4  | 43.2   | 37.8  |
| 3                        | 5120      | 4938     | 4852      | 45.2  | 44.1   | 41.5  |
| 4                        | 4890      | 4861     | 4684      | 43.0  | 42.1   | 38.3  |

Figure 3 shows a stress-strain diagram of vibration centrifuged samples of concrete. We have chosen a mix of vibration centrifuged concrete with combined aggregate (granite + lightweight expanded clay aggregate) and combined fiber (steel + basalt) for further research. Figure 4 shows the “σ-ε” diagram plotted using the obtained experimental data. In total, we studied concrete samples of the same makeup with a combined aggregate (granite + lightweight expanded clay aggregate) and combined fiber reinforcement (steel fiber + basalt fiber), yet manufactured with three different techniques: vibration, centrifugation, and vibration centrifugation. For this purpose, one diagram was plotted for vibrated concrete, which has an even distribution of properties over the cross sections, three diagrams were plotted for centrifuged concrete (CFC) and three – for vibration centrifuged concrete (VCFC) (one for each layer: outer, middle, and inner).
Figure 3. “σ-ε” Diagram of Vibration Centrifuged Concrete Samples:

- Vibration centrifuged light-weight concrete, aggregate: granite + expanded clay + steel fiber + basalt fiber
- Vibration centrifuged light-weight concrete, aggregate: granite + expanded clay + steel fiber
- Vibration centrifuged light-weight concrete, aggregate: granite + expanded clay
- Vibration centrifuged heavy concrete, aggregate: granite + basalt fiber
- Vibration centrifuged heavy concrete, aggregate: granite
- Vibration centrifuged light-weight concrete, aggregate: granite + expanded clay + basalt fiber.

Figure 4. “σ-ε” Diagram of Concrete Samples (Separate Layers) Acquired through Various Molding Processes.

3. Conclusion

The analysis of the experimental data has revealed a number of noteworthy facts.

First, the diagrams of both centrifuged and vibration centrifuged concrete samples are significantly distinct in the layers, thereby confirming that the structure of such concrete mixes has a variational nature.

Second, of all the diagrams of both centrifuged and vibration centrifuged concrete samples, the greatest strength factors are seen in the stress-deformation diagrams for the outer layer of concrete.
Third, of all the diagrams of both centrifuged and vibration centrifuged concrete samples, the smallest strength factors are seen in the stress-deformation diagrams for the inner layer of concrete.

Fourth, of all the centrifuged and vibration centrifuged concrete samples, the averaged strength factors are seen in the stress-deformation diagrams of the middle layer of concrete, which are similar to the values of the stress-deformation diagram of the outer layer of concrete.

Fifth, the smallest strength factor of all concrete samples is seen in the stress-deformation diagram of a regular vibrated concrete.

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