Extensibility of fibre reinforced concrete

Inna Korneeva

Irkutsk National Research Technical University, Department of Building Production, 664074, 83, Lermontov Street, Irkutsk, Russia

Abstract. This study compares the bending strengths of conventional fine-aggregated concrete and continuously reinforced concrete. It presents reliable statistical data based on testing mode under load conditions with constant strain rate. These prove that polypropylene reinforcing fibres should be in volumes that are able to provide compatibility of their deformation with the concrete matrix. The study establishes qualitative (in terms of structure) and statistical deformation patterns of fibre reinforced concrete that can significantly

1. Introduction

The operating experience of concrete and reinforced concrete structures occurring in adverse conditions shows that the determining factor of their limited durability is low crack resistance due to the low tensile strength of concrete. Recent studies applying target-specific approach to composites [1, 3, 5-15] show that continuous fibre reinforcement of concrete can become a solution to this. The materials used for this purpose and their physical and engineering properties should correspond with concrete matrix characteristics. Also, they should comply with basic requirements such as cost-effectiveness, energy-efficiency and sustainability. Taking into account all the factors mentioned above, it proves effective to use polypropylene fibres as reinforcing fragments because they result from waste processing of corresponding polymer production.
The study examines the structural properties of various fibre reinforced concretes focusing on different levels of their reinforcement with polypropylene fibres in terms of volume.

2. Materials and methods

Based on model approach to the structure of fibre reinforced concrete [1], the target formation was in accordance with the following parameters: maximum diameter of fibres is 10 mm; volume fraction is 0.48. At the same time, fibres with an equivalent diameter of 0.8 mm and a length of 40 mm were characterized by the parameters presented in table 1.

| Type of fibres                  | polypropylene properties (based on State All-Union Standard GOST 9550-81). |
|---------------------------------|---------------------------------------------------------------------------|
| Initial cross-section of samples, mm$^2$ | 0.5                                                                       |
| Tensile strength, MPa           | 145.54                                                                    |
| Elongation at maximum load, %   | 21.95                                                                     |
| Modulus of elasticity, MPa      | 2767                                                                      |
| Tensile strength, MPa           | 140.9                                                                     |
| Breaking elongation, %          | 22.3                                                                      |

The experimental prismatic samples were fibre-concrete mixtures, with the concrete matrix basis (cement:fine aggregate:coarse aggregate:water = 1:1.42:3.31:0.55 at C = 380 kg/m$^3$).

The volume fraction was in the range of 0÷2%. Sample storage for 28 days was in accordance with the regulations of GOST 10180-2012. Further sample storage until their testing (60 days after production) was under normal conditions.

To test the samples for bending, we used Instron; this testing complex was in the mode of constant strain rate (0.05 mm/s). During the experiment, the testing program automatically recorded deflections in the middle of the samples and fibre deformations under tension. Then, it automatically turns these data into charts: "Load-deflection" and "Stress-strain". The boundary conditions of destruction are the following criteria: deflection is 3 mm, deformation of stretched fibre is 0.03 mm/mm, otherwise samples become separated into 2 parts. There were 12 samples for each level of reinforcement to provide a statistically representative generalization of the results.
3. Discussion

Figures 1 A and B show sampled sets of charts representing "Force-deflection" relations of conventional and fibre reinforced ($\mu = 1\%$) concrete. Their visual comparison reveals a noticeable difference in kinetics during deflection load. Quantitative values of compared parameters and statistical correspondence of their distribution also differ. Taking into account the established ambiguity of the effects of fibre reinforcement on the compressibility parameters [2], it is essential to assess the effect of reinforcement level on the bending resistance.

![Figure 1. A Set of Charts "Force – deflection" A) for conventional concrete; B) for fibre reinforced concrete. First, the charts show the reduction of the maximum force experienced by the fibre concrete, as the volumes of reinforcing elements increase. At the](#)

First, the charts show the reduction of the maximum force experienced by the fibre concrete, as the volumes of reinforcing elements increase. At the
same time, to the level of optimal values (Rabinovich [1] \((\mu_{\text{opt}} \approx 1.5\div1.8\%))\), it can be viewed as a trend (reduction of 2\div8\%). Further, the strength drop becomes more significant and reaches 13\div15\%. At the same time, there are changes in the statistics of its distribution, characterized by an increase in dispersivity and coefficient of variability. Taking into account the latter, the minimum expected values of the destructive forces of fiber concrete will be 90\div95\% of the usual, without a clear dependence on the level of reinforcement.

A fundamentally important factor is the deflection dynamics at the stages of increasing the load and its reduction in the process of self-accelerating destruction. The fibre reinforcement leads to a more intensive reduction of deflection in comparison with the load, with a noticeable stabilization at the optimal level of the reinforcement (Figure 2). A similar ratio of strength kinetics and deformability confirms the effectiveness of reinforcement in terms of the total bending resistance effect of fibre reinforced concrete. The change of statistical parameters also implies the positive effect: the level of dispersivity and the range of expected values of the required security reduce significantly. As a result, the maximum expected values (at 95\% of security) of fibre concrete deflections is (65\div80)\% of conventional concrete.

**Figure 2.** Deflection at maximum load.

A characteristic and distinctive feature of fiber concrete is its ability to deform after reaching maximum load. Figure 3 presents the data showing a
manifold growth in deformation with an increase in fibre reinforcement and its stabilization in the area of optimal reinforcement volumes. Obtaining such experimental data becomes possible under conditions of providing a loading regime with a constant strain rate, and it is an indirect confirmation of a significant increase in the potential of "constrained deformation". Similar conclusions follow from the comparative evaluation of tensile strains in physical destruction of samples according to the above criteria (Figure 4). There is a trend of increasing the fibre concrete extensibility with an increase in reinforcement in the range under consideration.

**Figure 3.** Deflection at fracture.

![Deflection Ratio Chart](chart1.png)

**Figure 4.** Tensile strain at fracture.

![Tensile Strain Chart](chart2.png)
4. Conclusion

1. Reinforcement of concrete with fibres made of polypropylene in volumes that provide conditions for compatibility of their elements deformation increases its extensibility and flexural stiffness.
2. Excessive reinforcement of the concrete structure is impractical because of prevailing strength reduction (compared to an increase of stiffness).

References

[1] F. N. Rabinovich Composites based on continuously reinforced concrete. Theory and design issues, technology, structures: monograph / F. N. Rabinovich. 4th ed. Moscow: ACB, 642 p. (2011).
[2] I. Korneyeva, MATEC Web of Conferences 212 Constructive properties of concrete being finely reinforced with polypropylene fibers (2018).
[3] D. E. Kapustin Strength and deformation characteristics of fixed steel-fibre concrete formwork as a bearing element of reinforced concrete structures. Thesis of Candidate of Engineering Sc. Moscow, 211 p. (2015).
[4] Corporate Standards of National Association of Builders (NOSTROY) The Design of the transport tunnels made of fibre reinforced concrete. (2013).
[5] A. V. Buchkin Fine aggregate concrete of high corrosion resistance, reinforced with thin basalt fibre: Thesis abstract of Candidate of Engineering Sc. Moscow. 20 p. (2011).
[6] J. R. Romualdi, J.A. Mandel Tensile Strength of Concrete / Romualdi J.R., Mandel J.A. // Affected by Uniformly Distributed and Closely Spaced Lengths of Wire Reinforcement. ACI Jornal, vol. 61, no. 6, 657 p. (1964).
[7] T. V. Morgun Analysis of formation regularities of optimal structures for continuous reinforced concrete // Universities Proceedings . Construction.. No. 8. P. 58-60. (2003).
[8] A. Peled, M.F. Cyr, S.P. Shah High content of fly ash (class F) extruded cementations composites. // ACI Material Journal. – Vol. 97, no. 5, pp. 509-517 (2000)
[9] C.D. Johnston Properties of Steel Fibre Reinforced Mortar and Concrete / C.D. Johnston // Symposium on Fibrous Concrete (C80, London, 1980), The Construction Press, Lancaster, – London, pp. 29-47 (1980).
[10] T. A. H. Ahmed, O. M. A. Daoud, IOSR-JMCE, 13, Influence of Polypropylene Fibres on Concrete Properties, pp 09-20, (2016)
[11] L. Rizzuti, F. Bencardino, Contemporary Engineering Sciences, 7, Effects of Fibre Volume Fraction on the Compressive and Flexural Experimental Behaviour of SFRC, no. 8, p. 379 – 390, (2014)

[12] D. S Dharan, A. Lal, IRJET, 03 Study the effect of polypropylene fiber in concrete, p. 616, (2016)

[13] P. Sukontasukkul, Thammasalin t. J. Sc. Tech., 9, Toughness Evaluation of Steel and Polypropylene Fibre Reinforced Concrete Beams under Bending, no. 3, (2004)

[14] A. Amin, S. J. Foster, A. Muttoni, Structural Concrete, Derivation of the $\sigma$-w relationship for SFRC from prism bending tests, pp. 93-105 (2015)

[15] J. H. Hwang, D. H. Lee, H. Ju, K. S. Kim, S. Y. Seo, J. W. Kang, Materials, 6, Shear Behavior Models of Steel Fiber Reinforced Concrete Beams Modifying Softened Truss Model Approaches p. 4847-4867 (2013)