PROPERTIES OF GLASS- AND CARBON FIBER REINFORCED CEMENT COMPOSITES FOR THEIR TECHNICAL APPLICATIONS

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Abstract

The role of exact knowledge of mechanical, thermal and hygric parameters of fiber reinforced cement composites containing glass fibers and carbon fibers is analyzed in the paper. It is concluded that due to the increasing frequency of applications of fiber reinforced cement composites, the knowledge of solely mechanical parameters is not sufficient in a variety of technical applications and thermal and hygric parameters determined in various conditions become almost equally important.

Key words: fiber reinforced cement composites, mechanical properties, thermal properties, hygric properties, technical applications

1 Introduction

Cement-based materials are characterized by very good properties in compression but their brittle manner of failure under tensile or impact load was a limiting factor for their applicability range from the very beginnings. Fiber reinforcement is a traditional and effective method how to improve the toughness and durability of cement based products. The steel rod reinforcement became very popular during the whole last century and remains the most frequently used type of concrete reinforcement until now. However, in the second half of the 20th century, an application of uniformly dispersed short fibers strengthening the brittle cementitious matrices appeared with an increasing frequency. In the current practice, steel, glass, carbon and various polymeric fibers such as polyethylene, polypropylene, nylon, polyester, polyurethane, cellulose, etc., are commonly used in cement-based materials.

Glass-fiber reinforced cement composites (GFRCC) are produced by incorporating a small amount of alkali-resistant glass fiber in cement mortar to overcome the traditional weakness of inorganic cements, namely poor tensile strength and brittleness. The length and content of the glass fiber reinforcement can be chosen to meet the strength and toughness requirements of the product. Also, the type of aggregates can be varied in order to control thermal properties.

GFRCC have found their place as versatile and commercially viable materials for use in construction industry in the beginning of 1970s [1]. Currently, they are frequently applied in wall systems, utilized in form work, pipework, used for surface bonding and rendering, etc. They can also replace asbestos cement products as fire protection materials. More detailed survey of GFRCC applications can be found e.g. in [1]-[3].

Carbon fiber reinforcement has found its application first in polymeric matrices for automotive and aircraft industry. It partially replaced previously used glass fibers in such situations where superior strength properties, very low tensile strains and mass savings were necessary. The initial phases of utilization of carbon fibers in the production of composite materials were affected by their high price. Carbon fibers are produced by the controlled oxidation, carbonization and graphitization of carbon-rich organic precursors, which are already in fiber form. In the beginnings of carbon fiber production the most often used precursor was PAN (polyacrylonitrile) that gave superior carbon fiber properties but was quite expensive. The appearance of low cost pitch based carbon fibers in 1980s has led to a significant increase of various applications of carbon fibers. In the construction industry it resulted in an increasing use of carbon fiber reinforced cement composites (see e.g. [4], for details). A comprehensive survey both of properties and processing of carbon fibers and of the various types of carbon fiber reinforced composites (CFRCC) can be found in [5].

2 Basic survey of properties of FRCC

2.1 Mechanical properties

A basic survey of mechanical properties of various Portland cement GFRCC, namely bending, tensile and impact strength and Young's modulus can be found in [1] where the work until 1990 is compiled. Later, Zhang et al. [6] measured flexural strength of GFRCC with high content of fly ash, Huang et al. [7] analyzed the interfacial mechanical properties of carbon-coated GFRCC, Marikunte et al. [8] determined the flexural and tensile strength of GFRCC after hot-water durability tests, Park et al. [9] measured compressive strength, compressive modulus of elasticity, tensile strength, flexural strength of low-density/low cost GRFCC, Mu et al. [10] determined tensile strength and impact resistance of short fiber GRFCC with high slag content, Mu et al. [11] analyzed the possibilities of improving the interface bond between fiber mesh and cementitious matrix of GFRCC and used fracture toughness to evaluate the flexural behavior of GFRCC.

A basic review of the measurements of mechanical properties, durability and dimensional stability of a variety of CFRCC summarizing the research activities until 1977 was given in [12]. Later measurements of mechanical properties, particularly of specially developed new types of CFRCC can be found in [13]-[24]. Aging of GFRCC in terms of dependence of mechanical parameters on time was studied in [25]-[26].

2.2 Hygric and thermal properties

Hygric and thermal properties of both GFRCC and CFRCC were measured only rarely until now. Basic values of thermal and hygric properties, such as thermal conductivity, thermal expansion coefficients, air and water vapor permeability of GFRCC are given in [1]. Thermal conductivity and specific heat of CFRCC at room temperature were studied in [27], drying shrinkage of CFRCC in [13], [16], [28], water absorption of CFRCC in [13], wettability of carbon fibers in [29]. Hygric transport and storage parameters such as moisture diffusivity, water vapor permeability and sorption isotherms of both GFRCC and CFRCC were not yet studied at all until very recently. The same situation was with the high-temperature properties of GFRCC and CFRCC.

3 Recent measurements of the properties of GFRCC

As follows from the above survey, the mechanical properties of both GRFCC and CFRCC were in the center of interest of most researchers working on those materials within the last decades. This is quite logical taking into account why GFRCC and CFRCC were developed, i.e. to improve the tensile and flexural strength of cement based composites. However, there are numerous applications where determination of mechanical properties is not sufficient. Therefore, a comprehensive set of measurements of thermal properties of various types of GFRCC and CFRCC in both room temperature and high temperature conditions and of hygric and thermal properties after thermal and/or mechanical load was done during the solution of the research project of GA CR 103/00/0021 “Analysis of properties of fiber composites in the conditions of elevated and high temperatures, high moistures and mechanical load”. High-temperature parameters of GFRCC were measured in [30] – [32], thermal and hygric properties of GFRCC after thermal load in [32] - [34], thermal and hygric properties after thermal load and high-temperature properties of CFRCC in [35].

4 The role of exact knowledge of properties of FRCC for their technical applications

The applications of FRCC in different technical areas require specific design principles to be employed. However, one condition is common for all applications. A designer should be provided by an exact knowledge of mechanical, thermal and hygric properties of the particular FRCC. Otherwise, the assessment of mechanical and hygrothermal performance of FRCC in the particular application cannot be done in a serious way.

Among the properties of FRCC, the mechanical properties are of primary concern in all their applications because the use of fiber reinforcement was always motivated mainly by the improvement of tensile and flexural behavior of cement based materials. Therefore, the role of mechanical properties is often overestimated in the building practice and mechanical properties are the only parameters being determined.

However, knowledge of solely mechanical properties is not sufficient for a designer working with FRCC. There are several sound reasons for this statement. First, lightweight FRCC can be used as thermal insulation materials. Then, thermal properties should be known in sufficient temperature and moisture ranges. Second, FRCC can be used as fire protection materials. Here, the high temperature thermal properties such as thermal conductivity, specific heat, linear thermal expansion coefficient are supposed to be measured to assess the fire protection function of an envelope in an appropriate way. Third, for FRCC used in any wall systems both hygric and thermal properties have to be determined in sufficient temperature and moisture ranges because without this knowledge the hygrothermal performance of the wall cannot be assessed. Finally, FRCC are often employed in severe conditions. They can be exposed for instance to high temperatures, high mechanical loads and their combination. In this case, thermal and hygric properties should be determined as functions of thermal and mechanical load and their combinations.

As follows from the above mentioned, the role of knowledge of thermal and hygric parameters is in a variety of applications of FRCC very significant and these parameters should be measured with the same frequency as the mechanical parameters.

5 Conclusions

Technical applications of FRCC appear with an increasing frequency in the current practice because of their favorable properties compared to the cement based composites without any reinforcement. Therefore, the requirements to the exact knowledge of the properties of FRCC are increasing rapidly.

It has been demonstrated in this paper that the role of mechanical properties is not so dominant any more as it was only couple of years ago although they remain the most important among the FRCC parameters. Thermal parameters both in room temperature and high temperature conditions, thermal parameters after high-temperature and mechanical exposure and hygric parameters both in normal conditions and after being subjected to thermal and mechanical load become almost so important as mechanical parameters in a variety of applications of FRCC.

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References

[1] A.J. Majumdar, V. Laws, *Glass Fibre Reinforced Cement*. BSP, Oxford 1991.
[2] J. Young, *Designing with GRC*. Architectural Press, London 1978.
[3] G. True, *GRC Production and Uses.* Palladian Publications Ltd., London 1986.
[4]. Y. Ohama, Carbon-cement composites. *Carbon* 27(1989), 729-737.
[5] D.D.L. Chung, *Carbon Fiber Composites*. Butterworth-Heinemann, London 1994.
[6] Y. Zhang, W. Sun, L. Shang, G. Pan, The effect of high content of fly ash on the properties of glass fiber reinforced cementitious composites. *Cement and Concrete Research* 27(1997), 1885-1891.
[7] C.M. Huang, D. Zhu, X.D. Cong, W.M. Kriven, R.R. Loh, J. Huang, Carbon-coated-glass-fiber-reinforced cement composites I: fiber pushout and interfacial properties. *Journal of American Ceramic Society* 80(1997), 2326-2332.
[8] S. Marikunte, C. Aldea, S.P. Shah, Durability of glass fiber reinforced cement composites. *Advanced Cement Based Materials* 5(1997), 100-108.
[9] S.B. Park, E.S. Yoon, B.I. Lee, Effects of processing and materials variations on mechanical properties of lightweight cement composites. *Cement and Concrete Research* 29(1999), 193-200.

[10] B. Mu, Z. Li, J. Peng, Short fiber-reinforced cementitious extruded plates with high percentage of slag and different fibers. *Cement and Concrete Research* 30(2000), 1277-1282.
[11] B. Mu, C. Meyer, S. Shimanovich, Improving the interface bond between fiber mesh and cementitious matrix. *Cement and Concrete Research* 32(2002), 783-787.
[12] A. Briggs, Carbon Fibre-Reinforced Cement. *Journal of Materials Science* 12(1977), 384-403.
[13] Y. Ohama, M. Amano, M. Endo, Properties of Carbon Fiber Reinforced Cement with Silica Fume. *Concrete International: Design and Construction* 7 (1985), 58-62.
[14] B.K. Larson, L.T. Drzal, P. Sorousian, Carbon fibre-cement adhesion in carbon fibre reinforced cement composites. *Composites* 21(1990), 205-215.
[15] S.B. Park, B.I. Lee, Mechanical properties and applications of carbon-fiber-reinforced cement composites. *High Temperatures - High Pressures* 22(1990), 663-670.
[16] S.B. Park, B.I. Lee, Y.S. Lim, Experimental study on the engineering properties of carbon fiber reinforced cement composites. *Cement and Concrete Research* 21(1991), 589-600.
[17] P. Soroushian, M. Nagi, A. Alhozaimy, Statistical variations in the mechanical properties of carbon fiber reinforced cement composites. *ACI Materials Journal* 89(1992), 131-138.
[18] H.A. Toutanji, T. El-Korchi, R.N. Katz, G.L. Leatherman, Behaviour of carbon fiber reinforced cement composites in direct tension. *Cement and Concrete Research* 23(1993), 618-626.
[19] H.A. Toutanji, T. El-Korchi, R.N. Katz, Strength and reliability of carbon-fiber-reinforced cement composites. *Cement and Concrete Composites* 16(1994), 15-21.
[20] K. Zayat, Z. Bayasi, Effect of latex on the mechanical properties of carbon fiber reinforced cement. *ACI Materials Journal* 93(1996), 178-181.
[21] P.W. Chen, X. Fu, D.D.L. Chung, Microstructural and mechanical effects of latex, methylcellulose, and silica fume on carbon fiber reinforced cement. *ACI Materials Journal* 94(1997), 147-155.
[22] T.J. Kim, C.K. Park, Flexural and tensile strength developments of various shape carbon fiber-reinforced lightweight cementitious composites. *Cement and Concrete Research* 28(1998), 955-960.
[23] Y. Xu, D.D.L. Chung, Carbon fiber reinforced cement improved by using silane-treated carbon fibers. *Cement and Concrete Research* 29(1999), 773-776.
[24] J. Cao, D.D.L. Chung, Carbon fiber reinforced cement mortar improved by using acrylic dispersion as an admixture. *Cement and Concrete Research* 31(2001), 1633-1637.
[25] A. Katz, A. Bentur, Effect of matrix composition on the aging of CFRC. *Cement and Concrete Composites* 17(1995), 87-97.
[26] A. Katz, A. Bentur, Mechanisms and processes leading to changes in time in the properties of CFRC. *Advanced Cement Based Materials* 3(1996), 1-13.
[27] X. Fu, D.D.L. Chung, Effects of silica fume, latex, methylcellulose and carbon fibers on the thermal conductivity and specific heat of cement paste. *Cement and Concrete Research* 27(1997), 1799-1804.
[28] Y. Xu, D.D.L. Chung, Reducing the drying shrinkage of cement paste by admixture surface treatment. *Cement and Concrete Research* 30(2000), 241-245.
[29] W. Lu, X. Fu, D.D.L. Chung, A comparative study of the wettability of steel, carbon and polyethylene fibers by water. *Cement and Concrete Research* 28(1998), 783-786.

[30] J. Poděbradská, R. Černý, J. Toman, High-Temperature Measurements of Linear Thermal Expansion of Various Types of Glass-Fiber Reinforced Cement Composites. Engineering Mechanics 9(2002), 43-48.
[31] J. Poděbradská, J. Toman, R. Černý, Měření součinitele teplotní vodivosti sklocementů za vysokých teplot. Sborník Kalorimetrický seminář 2002, B. Taraba (ed.), Ostravská univerzita, Ostrava 2002, 89-92.
[32] J. Poděbradská, J. Toman, J. Drchalová, M. Totová, R. Černý, Hygric and Thermal Properties of Glass-Fiber Reinforced Cement Composites. Proceedings of the 6th Symposium on Building Physics in the Nordic Countries, A. Gustavsen, J. V. Thue (eds.), Skipnes AS, Trondheim 2002, 477-484.
[33] J. Toman, M. Totová, R. Černý, Měření měrné tepelné kapacity a součinitele tepelné vodivosti sklocementu po teplotním a tahovém namáhání. Sborník Mezinárodní český a slovenský kalorimetrický seminář 2001, B. Taraba (ed.), Ostravská univerzita, Ostrava 2001, 79-82.
[34] J. Toman, M. Totová, R. Černý, Měření součinitele vlhkostní vodivosti sklocementu po teplotním a tahovém namáhání. Sborník Kalorimetrický seminář 2002, B. Taraba (ed.), Ostravská univerzita, Ostrava 2002, 101-104.
[35] J. Poděbradská, J. Toman, J. Drchalová, M. Totová, R. Černý, Thermal and Hygric Properties of a Carbon-Fiber Reinforced Cement Composite Material after Thermal Load. Proceedings of 11th Symposium for Building Physics. P. Haupl (ed.), TU Dresden, Dresden 2002.