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IMPACT OF CHOPPED BASALT FIBRES ON THE MECHANICAL PROPERTIES OF CONCRETE

[a] Rabee Shamass*, [b] Aziz Urahman Hakimi, [c] Vireen Limbachiya

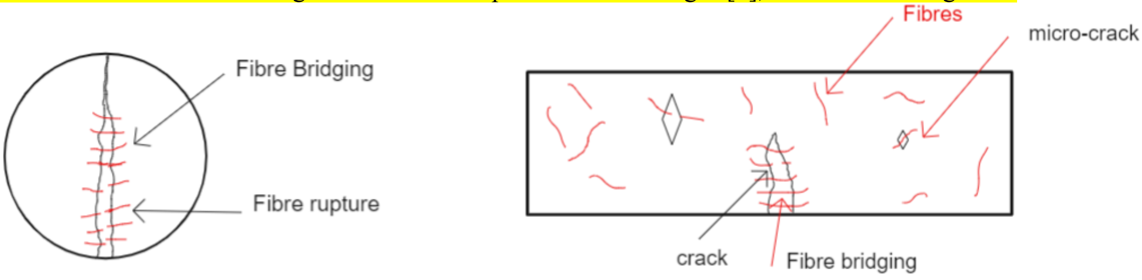
a: Civil and Building Services Engineering, London South Bank University, shamassr@lsbu.ac.uk
b: School of Civil, Environmental & Geomatic Engineering, University College London, aziz.hakimi.20@ucl.ac.uk
c: Civil and Building Services Engineering, London South Bank University, limbachv@lsbu.ac.uk
* Corresponding author: Email ID: shamassr@lsbu.ac.uk

Abstract- Basalt fibre is a novel inorganic fibre which is produced from basalt rock. In this study the impact of chopped basalt fibres on the concrete workability, compressive and tensile strength, and concrete's modulus of rupture at 7 and 28-days was investigated. The concrete used in this research was normal strength concrete with a target compressive strength of 30/37 MPa. In this research, fibre reinforced concrete samples were produced using basalt chopped fibres of two quantities (4 kg/m^3 and 8 kg/m^3) and three different fibre lengths, namely 25.4-mm, 12.7-mm, and 6.4-mm. The test findings revealed that slump decreased as the quantity of fibres increased and shorter fibres were used. The mechanical properties of concrete were affected by the fibre dosage and length. Overall, the results indicated that adding chopped basalt fibres improved the compressive, tensile, and flexural strength of concrete, particularly at early age, while slightly reducing the compressive strength at 28-days by an average of 3.9%. The results indicated that adding 4 kg/m^3 of 25.4-mm long chopped basalt fibre into concrete provided the best performance of concrete in compressive and tensile strength, and modulus of rupture.

Keywords- Basalt fibres; Fibre reinforced concrete; Mechanical properties; workability

1. Introduction

Civil engineers are keen on using construction materials that are cost effective, environmentally friendly, and robust. Concrete is known as one of the most highly consumed construction materials and plays a vital role in many aspects of everyday life. Although the plain concrete is strong in compression, it is weak in tension. Microcracks are formed in concrete during hardening stage [1] and they grow and extend in the concrete matrix when concrete is exposed to external loads. In order to sustain the developed tensile stresses, an addition of reinforcing elements in plain concrete is needed. Mixing relatively short and closely spaced fibres can constrain the development and formation of the cracking, hence, enhancing the mechanical and dynamic characteristics of plain concrete [2]. The reduction of crack width and numbers in the concrete matrix and the strength gaining are due to the bridging effect in which the fibres inside the cracks form a kind of bridges between the separated crack's edges [3], as seen in the Figure 1.



(a) (b)

Figure 1: Fibre bridging effect (a) concrete spitting, (b) concrete rupture.

The most commonly used fibres in concrete are steel and polyethylene fibres but they have a great amount of embodied energy. Among the disadvantages of using steel fibres is high susceptibility to corrosion, high specific gravity, high cost of raw material and non-uniform distribution within the concrete mixture [4]. Basalt fibres are considered a unique product made from basalt rock, a natural material that is found in volcanic rocks. They are a relatively new composite material characterized by their high corrosion and thermal resistance, their light weight (one-third of the steel weight) and high strength [5]. Basalt fibres have no toxic reaction with air or water and have no chemical reactions when they encounter other chemicals which may damage health or the environment. Basalt fibres have an excellent alkali resistance, and excellent acoustic and thermal properties [6]. Basalt fibres do not need any chemical additives or hazardous materials in the melting process; hence they are easier and safer to produce [7]. Their recyclability is also easier, unlike glass and carbon fibres which require high temperature or chemicals to recycle [8], hence basalt fibres are more environmentally friendly.

Research studies have investigated the influence of chopped basalt fibres on the mechanical properties of basalt fibre reinforced concrete (BFRC). Ayub et al. [9] investigated the effect of various dosages of chopped basalt fibres on the mechanical properties of high-performance fibre reinforced concrete. Results showed that adding chopped basalt fibres slightly improved the compressive strength of concrete while there was significant improvement in the tensile and flexural strength after 28-days. Similarly, Kizilkanat el at. [10] found that adding 0.25% of chopped basalt fibres in concrete slightly increased the compressive strength while adding 1% of fibres increased the tensile strength by 40%. In another research study, Iyer et al. [11] investigated the effect of different dosages and fibre lengths on the compressive strength and modulus of rupture of concrete at 28-days. The study found that 36-mm-long fibre and a fibre amount of 8 kg/m^3 were optimum to achieve enhancement in compressive and tensile strength of concrete. The study also found that workability decreased as the fibre length and dosage were increased. Similar research was conducted by Tumadhir and Borhan [12] using slightly shorter chopped basalt fibres (25.4 mm) with different dosage, the results indicated that the concrete's compressive strength increased with increasing chopped basalt fibres dosage up to 0.3% volume fraction. Nevertheless, when the dosage of fibres was increased to very high levels such as 0.5%, the compressive strength decreased. Ramakrishnan et al. [13] conducted an experimental study using 13-mm long chopped basalt fibres with contents varying between 0.1 to 0.5% volume fraction. The study concluded that when large dosage of fibre was added to concrete, the impact and toughness strength of the concrete were increased. However, the addition of chopped basalt fibres did not improve the compressive and flexural strengths of concrete at 28-days. Xinzhong et al. [14] concluded that the optimal basalt fibre content and length were 0.15% and 12 mm, respectively, at which the compressive strength of concrete at 7- and 28-days increased by 62.5% and 25.2%, respectively, while the tensile strength at 28-days increased by 13.26%. Jiang et al. [15] found that using 12 mm long fibre increased the compressive strength, splitting tensile and flexural strength of concrete at 28-days. They concluded that the suitable amount of the fibres was about 0.3% by volume. In contrast, Dias and Thaumaturgo [16] reported that the addition of 0.5% of chopped basalt fibres reduced the compressive strength of concrete at 28-days by 3.9%. Similarly, Jalasutram et al. [17] found that adding basalt fibres marginally reduced the compressive strength of concrete while it enhanced the tensile strength and flexural toughness.

It can be noted that the impact of length and dosage of basalt fibres on the physical and mechanical properties of concrete at 7- and 28-days is inconsistent, and further experimental investigations are required to better understand their influence on plain concrete. Therefore, the main aim of this study is to investigate the impact of chopped basalt fibres' length and dosage on the mechanical properties of concrete at early age and 28-days. The fundamental properties of BFRC such as slump, compressive strength, splitting tensile strength, and modulus of rupture are tested and analysed in this study. Two chopped basalt fibres dosages were used, namely 4 kg/m^3 and 8 kg/m^3 and three fibres lengths were used, 6.4, 12.7 and 25.4-mm, as shown in Figure 2. This study suggests optimum fibre length and dosage to achieve the best concrete performance.

2. Experimental Program

A C30/37 concrete mix was designed using BRE Concrete Mix Design [18]. The details of the mix proportions are summarised in Table 1. The maximum aggregates size used was 10 mm. The moisture content of the aggregates could change due to unpredicted weather. To avoid the discrepancies in the moisture content and their effect on the properties of the concrete, the coarse aggregates and sand were air dried inside the laboratory. A number of concrete mix trails were conducted in which the basalt chopped fibres were added either in a dried mix (i.e., after mixing the sand, aggregates and cement) or a wet mix (i.e., after mixing water with dried aggregates) to achieve satisfactory results. It was decided to mix the sand, coarse aggregates, and cement for 2-3 minutes, then add water and mix for 2-3 minutes, thereafter, the chopped basalt fibres were added and mixed for 5 minutes.

Seven mixes were prepared to test the compressive, tensile and rupture strength of BFRC at 7- and 28-days. There were two concrete mixes with 25.4-mm length fibres (4F-25.4, 8F-25.4), two concrete mixes with 12.7 -mm length fibres (4F-12.7, 8F-12.7), two mixes with 6.4 -mm length fibres (4F-6.4, 8F-6.4) and one concrete mix without fibres acting as a control mix (Plain). Each concrete mix is named based on the dosage of the basalt chopped fibres added into the concrete mix per m^3 (4 kg/m^3 and 8 kg/m^3) and the length of the basalt chopped fibres (25.4-mm, 12.7-mm and 6.4-mm). For example, 4F-25.4 denotes for a mix with 4 kg/m^3 chopped fibres with 25.4-mm length. Six standard 100×100×100 mm cubes were produced for the compressive strength test, three Ø150×300 mm cylinders for the splitting tensile strength test and three 100×100×500 mm prismatic beams for the modulus of rupture test, according to BS EN12390: Testing hardened concrete. The moulds were removed on the following day and the concrete samples were stored in a curing tank at 20ºc.

Table 1: Concrete mix design.

Target concrete grade	w/c ratio	Cement (kg/m^3)	Sand (kg/m^3)	Coarse aggregate (kg/m^3)	Max Aggregate size (mm)	Chopped basalt fibre (kg/m^3)
C30/37	0.54	463	700	927	10	4 and 8

25.4-mm chopped fibres   12.7-mm chopped fibres   6.7-mm chopped fibres

Figure 2: The chopped basalt fibre used in this study.

3. Results and Discussions

3.1 Concrete Workability

The workability of fresh concrete can be affected by many factors including aggregate properties such as shape, size and grading, water-to-cement ratio and the added fibres. In this study, the slump test was conducted according to BS EN 12350: Testing fresh concrete to determine the fresh concrete workability. Table 1 illustrates the influence of the fibres' length and dosage on the concrete workability. The workability in general decreases with increasing the quantity of basalt fibres for all fibre lengths used in this study. It can be noted that adding fibres dramatically reduces the concrete workability. For plain concrete, the slump was 245 mm. When adding 4 kg/m^3 of 25.4 -mm, 12.7 -mm and 6.4 -mm length basalt fibres, the slump reduced by 59%, 55% and 37%, respectively. Due to the high fibres surface area and content, the friction between fibres and cement paste increases, resulting in reduction of slump. Results obtained from the tests showed that workability decreased when shorter fibres were being used and as the fibres contents increases. For instance, adding 8 kg/m^3 of 25.4 -mm and 6.4 -mm fibres reduced the slump by 65%, 74% respectively. For low fibres content (i.e., 4 kg/m^3) the slump for concrete mix with 25.4-mm fibres was lower than the slump for the mix with 6.4-mm fibres. The assumption is that for shorter fibres being used with large fibres dosage in the mix, there are larger fibre distribution density and more fibres per unit volume. Therefore, the fibres are harder to distribute consistently in the concrete matrix, resulting in reduction in concrete workability [15]. Although the workability of concrete was reduced with the addition of fibres, no difficulties was found in placing and consolidating the fresh concrete using the table vibrator. It was observed that the fibres were uniformly distributed throughout the concrete without balling, bleeding, or segregation.

3.2 Compressive Strength

Table 2 shows the compressive strength results and the strength-effectiveness (%) for each BFRC concrete mix at 7- and 28-days. The strength-effectiveness of BFRC is more evident at concrete early age than at 28-days. In comparison to plain concrete, adding fibres improved the compressive strength of concrete at 7-days by an average of 28.6%. The highest strength-effectiveness was achieved when 8 kg/m^3 of 6.4 -mm basalt chopped fibres was added (38.7%), while the lowest strength improvement was achieved when 4kg/m^3 of 25.4 -mm fibres was added (20.8%). In the presence of basalt chopped fibres, the concrete compressive strength at 28-days tended to decrease by an average of 3.9%. There is a negligible reduction of the compressive strength at 28-days for 8F-6.4 (0.5%). The compressive strength reduction of BFRC at 28-days with 4 kg/m^3 and 8 kg/m^3 dosage fibres ranges from -3.5% to -7.0% and from -0.5% to -3.8%, respectively. The Scanning Electron Microscope images conducted by Jiang et al. [15] indicated that there was a good bonding between the fibres and cement matrix at early age while there was bond degradation at 28-days. This confirmed that the aging of the interface between the cementitious matrix and the fibres reduced the compressive strength of concrete at 28-days. Similar results were reported by Dias and Thaumaturgo [16] in which the inclusion of basalt chopped fibres slightly reduced the concrete compressive strength by 3.9%. The results also showed that fibre length had an effect on the strength-effectiveness of BFRC. For instance, for BFRC with 8 kg/m^3, as the fibre length reduces, the concrete compressive strength at 7-days enhances and the change in compressive strength at 28-days becomes negligible, as for 8F-6.4.

Table 2: Concrete slump test and compressive strength for different mixes

Mix	Slump (mm)	Compressive strength (MPa) 7-days		Compressive strength (MPa) 28-days	
		Measured	strength-effectiveness (%)	Measured	strength-effectiveness (%)
Plain	245	21.2	-	37.2	-
4F-25.4	100	28.1	32.5	35.8	-3.8
8F-25.4	85	25.6	20.8	35.1	-5.6
4F-12.7	110	25.9	22.2	34.6	-7.0
8F-12.7	75	27.6	30.2	36.1	-3.0
4F-6.4	155	26.9	26.9	35.9	-3.5
8F-6.4	65	29.4	38.7	37	-0.5

3.3. Splitting Tensile strength

Table 3 shows the tensile strength of concrete and the strength-effectiveness of BFRC at 7- and 28-days. The results show that the concrete tensile strength at 7- and 28-days increases with addition of basalt chopped fibres, except for the mix 4F-12.7 for which the tensile strength at 28-days slightly reduces by 4.2%. The increase in the tensile strength is assumed to be due to the bridging effect of the fibres which delays the development of macro cracks. In comparison to the plain concrete, the tensile strength for BFRC with 4 kg/m^3 dosage of 25.4-mm basalt fibres at 7-days and 28-days increased by 26.4% and 14.4 %, respectively. In general, the concrete tensile strength at 7-days increased as the amount of chopped basalt fibres increased, except for the BFRC with 25.4-mm length fibres. For instance, as the amount of fibres increases from the 4 kg/m^3 to 8 kg/m^3 the tensile strength at 7-days for BFRC with 12.7 -mm fibres increases from 7.7% to 24.7%, respectively, and from 15.4% to 21.4%, respectively, for BFRC with 6.4 -mm fibres, in comparisons to plain concrete. A similar trend is observed at 28-days as the quantity of fibres increases from 4 kg/m^3 to 8 kg/m^3 the tensile strength at 28-days increases from 14.4% to 4.2%, respectively, for BFRC with 25.4.7 -mm fibres and from 1.9% to 3.4% for BFRC with 6.4 -mm fibres, in comparisons to plain concrete. Furthermore, the results showed in general an increase in tensile strength for an increasing in fibres length, although the trend is not obvious. In comparison to the plain concrete, as the length of fibres increases from 6.4 -mm to 25.4 -mm the tensile strength of BFRC increases from 15.4% to 26.4% at 7-days, respectively, and from 1.9% to 14.4% at 28-days, respectively, for 4 kg/m^3 fibre dosage. The reason could be that the longer of the fibres being used, the higher of the pulling-out resistance of the fibres from the cement matrix and the stronger of the bridging effect of the fibres, which contributes to the tensile strength improvement.

Table 3: Concrete tensile strength for different mixes

Mix	Tensile strength (MPa) 7-days		Tensile strength (MPa) 28-days	
	Measured	strength-effectiveness (%)	Measured	strength-effectiveness (%)
Plain	1.82	-	2.64	-
4F-25.4	2.3	26.4	3.02	14.4
8F-25.4	2.06	13.1	2.75	4.2
4F-12.7	1.96	7.7	2.53	-4.2
8F-12.7	2.27	24.7	2.66	0.8
4F-6.4	2.10	15.4	2.69	1.9
8F-6.4	2.21	21.4	2.73	3.4

3.4 Modulus of Rupture (Flexural Strength)

Table 4 shows the results of the modulus of rupture and strength-effectiveness of BFRC at 7- and 28-days. Previous research indicated that adding fibres into concrete enhanced the modulus of rupture of BFRC. Kizilkanat et al. [10] stated that addition of basalt or glass fibre had beneficial effects on the flexural strength of concrete when compared with plain concrete. As expected, all BFRC specimens tested in this study showed an increase in the modulus of rupture, in comparison to plain concrete specimens. As for the tensile strength, the strength-effectiveness of BFRC is more noticeable at an early age of concrete with an average strength enhancement of 12.7%. The highest strength improvement at 7-days is achieved for BFRC with 8 kg/m^3 of 12.7 -mm basalt fibres (28.2%). When compared with plain concrete, the modulus of rupture at 7-days for BFRC with 12.7 and 6.4 -mm basalt fibres increased from 8.7% to 28.2% with increasing the dosage of basalt fibre from 4 kg/m^3 to 8 kg/m^3. The length of fibres has a significant effect on the modulus of rupture. For BFRC mixes with 4 kg/m^3 fibres, as the length of fibres increases from 6.4 -mm to 25.4 -mm, the strength at 7-days increases from 8.7% to 14.6% respectively while the strength at 28-days increases from 8.8% to 17.1%, respectively, in comparisons to plain concrete. On the other hand, for higher amount of basalt fibres, the modulus of rupture for BFRC with 24.5-mm fibres is lower than for BFRC with 12.7-mm fibres. As explained before that longer fibres provide more noticeable bridging effect. However, for high content of fibres, it is more difficult for longer fibres to distribute uniformly in cementitious composites, hence the bridging effect of fibres may be affected in some regions of the concrete mix.

Table 4: concrete tensile strength for different mixes

Mix	Modulus of rupture (MPa) 7-days		Modulus of rupture (MPa) 28-days	
	Measured	strength-effectiveness (%)	Measured	strength-effectiveness (%)
Plain	3.55	-	4.2	-
4F-25.4	4.07	14.6	4.92	17.1
8F-25.4	3.63	2.3	4.49	6.9
4F-12.7	3.88	9.3	4.59	9.3
8F-12.7	4.55	28.2	4.76	13.3
4F-6.4	3.86	8.7	4.57	8.8
8F-6.4	4.00	12.7	4.32	2.9

4. Conclusion

This study is an experimental investigation on the effect of chopped basalt fibres on the compressive, tensile, and flexural strength of BFRC at 7- and 28-days. Two dosages of fibres were used, 4 kg/m^3 and 8 kg/m^3 and three lengths of fibres were investigated, 25.4 -mm, 12.7 -mm and 6.4 -mm. Based on results obtained, it can be concluded that:

- The workability of fresh concrete decreased as the amount of fibres increased and when using shorter fibres. The slump is lower for mix with longer fibre length and lower content.
- Experiment results showed that inclusion of basalt fibres enhanced the compressive strength of concrete at 7-days by 20% to 38.7%, depending on the fibre dosage and length. However, slight reduction in compressive strength of BFRC at 28-days was observed, with an average of 3.9%. BFRC with 8 kg/m^3 of 6.4 -mm basalt fibres performed the best in compression for which negligible reduction of concrete strength at 28-days and 38.7% strength enhancement at 7-days were observed.
- Generally, the tensile strength of BFRC was increased at 7- and 28-days. The average strength-effectiveness of tensile strength of BFRC at 7-days was 18.1% while it was 3.2% at 28-days. BFRC with 4 kg/m^3 of 25.4-mm basalt fibres performed the best in tension for which the strength at 7- and 28 days was increased by 26.4% and 14.4%, respectively, in comparison to plain concrete.
- Experiment results showed that inclusion of basalt fibres enhanced the modulus of rupture of concrete at 7-days by 2.3% to 28.2%, and at 28-days by 2.9% to 17.1%, depending on the fibre dosage and length. The average strength-effectiveness of modulus of rupture of BFRC at 7- and 28-days was 12.6% and 9.7%, respectively. BFRC with 8 kg/m^3 of 12.7 -mm basalt fibres performed the best for which the flexural strength at 7- and 28 days was increased by 28.2% and 13.3%, respectively, in comparison to plain concrete.

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References

[1] M.V. Mohod, "Performance of steel fiber reinforced concrete". *Int. J. of Eng. Sci.*, *vol. 1 no. 12*, p.1-4., 2012

[2] Y.-R. Zhao, L. Wang, Z.-K. Lei, X.-F. Han, and J.-N. Shi, "Study on bending damage and failure of basalt fiber reinforced concrete under freeze-thaw cycles," *Constr. Build. Mater.*, vol. 163, pp. 460–470, 2018.

[3] M. Wydra, P. Dolny, G. Sadowski, and J. Fangrat, "Flexural behaviour of cementitious mortars with the addition of basalt fibres," *Materials (Basel)*, vol. 14, no. 6, p. 1334, 2021.

[4] C. Ipbüker, H. Nulk, V. Gulik, A. Biland, and A. H. Tkaczyk, "Radiation shielding properties of a novel cement–basalt mixture for nuclear energy applications," *Nucl. Eng. Des.*, vol. 284, pp. 27–37, 2015.

[5] R. Shamass and K. A. Cashell, "Experimental investigation into the flexural behaviour of basalt FRP reinforced concrete members," *Eng. Struct.*, vol. 220, no. 110950, p. 110950, 2020.

[6] V. J. John and B. Dharmar, "Influence of basalt fibers on the mechanical behavior of concrete—A review," *Struct. Concr.*, vol. 22, no. 1, pp. 491–502, 2021.

[7] Q. Fu *et al.*, "Dynamic compressive mechanical behaviour and modelling of basalt–polypropylene fibre-reinforced concrete," *Arch. Civ. Mech. Eng.*, vol. 18, no. 3, pp. 914–927, 2018.

[8] J. Sim, C. Park, and D. Y. Moon, "Characteristics of basalt fiber as a strengthening material for concrete structures," *Compos. B Eng.*, vol. 36, no. 6–7, pp. 504–512, 2005.

[9] T. Ayub, N. Shafiq, and M. F. Nuruddin, "Effect of chopped Basalt fibers on the mechanical properties and microstructure of high performance fiber reinforced concrete," *Adv. Mater. Sci. Eng.*, vol. 2014, pp. 1–14, 2014.

[10] A. B. Kizilkanat, N. Kabay, V. Akyüncü, S. Chowdhury, and A. H. Akça, "Mechanical properties and fracture behavior of basalt and glass fiber reinforced concrete: An experimental study," *Constr. Build. Mater.*, vol. 100, pp. 218–224, 2015.

[11] Iyer, S. Y. Kenno, and S. Das, "Performance of fiber-reinforced concrete made with basalt-bundled fibers," *Adv. Civ. Eng. Mater.*, vol. 5, no. 1, p. 20150027, 2016.

[12] M. Tumadhir and Borhan, "Thermal and Mechanical Properties of basalt fibre reinforced concrete," *International Journal of Civil and Environmental Engineering*, vol. 7, no. 4, pp. 334–337, 2013.

[13] V. Ramakrishnan, N. S. Tolmare, and V. B. Brik, "Performance evaluation of 3-D basalt fiber reinforced concrete & basalt rod reinforced concrete." 1998.

[14] W. Xinzhong *et al.*, "Experimental study on the axial compression of short basalt fiber reinforced concrete columns with spiral stirrups," *J. Eng. Sci. Technol. Rev.*, vol. 10, no. 1, pp. 55–60, 2017.

[15] C. Jiang, K. Fan, F. Wu, and D. Chen, "Experimental study on the mechanical properties and microstructure of chopped basalt fibre reinforced concrete," *Mater. Eng.*, vol. 58, pp. 187–193, 2014.

[16] D. P. Dias and C. Thaumaturgo, "Fracture toughness of geopolymeric concretes reinforced with basalt fibers," *Cem. Concr. Compos.*, vol. 27, no. 1, pp. 49–54, 2005.

[17] S. Jalasutram, D. R. Sahoo, and V. Matsagar, "Experimental investigation of the mechanical properties of basalt fiber-reinforced concrete: JALASUTRAMet al," *Struct. Concr.*, vol. 18, no. 2, pp. 292–302, 2017.

[18] D. C. Teychenne, *Design of normal concrete mixes: (BR 331)*, 2nd ed. Bracknell, England: IHS BRE Press, 1997.