

Experimental Study on Hardened Properties of High Strength Concretes Containing Metakaolin and Steel Fiber

Barham Haidar Ali[1]

[1]Ishik University, Faculty of Engineering, Erbil, Iraq
Correspondence: Barham Haidar Ali, Ishik University, Erbil, Iraq.
Email: barham.haydar@ishik.edu.iq

Received: April 10, 2018 Accepted: May 26, 2018 Online Published: June 1, 2018

doi:10.23918/eajse.v3i3p102

Abstract: In this paper the outcomes of an experimental research on mechanical properties of conventional concrete and a concrete incorporated metakaolin (MK) with and without steel fiber were dealt with. One of the ingredients of the concrete mixture was metakaolin; Portland cement was partially substituted with metakaolin (MK) as 10% by weight of the total binder content. Steel fibers with length/aspect ratios of 60/80 and hook ended was embedded into the concrete to make fiber reinforced concretes. Value of water/binder ratios (w/b) was 0.35. To know the impacts of MK and steelfiber, the mechanical behaviors of the concrete were investigated such as: compressive, flexure, and bonding strength of the concretes. At the age of 28 days in room temperature, tests were held. The level of the significance of the variance on the hardened properties of concrete was achieved through the calculation of the experimental results.

Keywords: Bonding Strength, Compressive Strength Concrete, Metakaolin, Steel Fiber, Flexure Strength

1. Introduction

Concrete is the most commonly used building material all over the world because of its versatility and availability. Especially reinforced concrete structural elements have been indispensable parts of construction works due to the ease in erection and relatively lower cost than the other structural materials. The proper adherence between reinforcing bars and concrete is the most desired feature because of the fact that structural capacity of reinforced concrete members depends on the monolithic behavior. The prominent component controlling the competence of the bond is mostly the quality of concrete because the reinforcing steel bars are obtained from a fixed manufacturing process and the properties do not significantly fluctuate compared to concrete. However, structural concretes have many different characteristics depending mainly on the amount and type of the ingredients (Mehta & Monteiro, 2006). It is reported that concrete with improved mechanical property has superior adherence with reinforcing steel bars (Ersoy, Özcebe & Tankut, 2003). Apart from its excellent properties, concrete shows a rather low performance when subjected to tensile stress. For this reason, the utilization of fibers to provide enhancement in tensile strength behavior of concrete has attracted the interest of the researchers (Bentur, Mindess & Diamond, 1985; Nili & Afroughsabet, 2012). Mechanical properties of concrete can be improved by exploitation of reinforcement with randomly oriented short separated fibers, which obstruct and/or control initiation and propagation of cracks. Fiber reinforced concrete (FRC) can keep on resisting much amount of loads even at deflections. The characteristics and performance of FRC varies depending on matrix properties as well as the fiber material, fiber concentration, fiber geometry, fiber orientation, and distribution of fiber (Yurtseven, 2004). In order to enhance the mechanical properties, particularly compressive strength, the use of some pozzolanic materials has been studied by researchers for many years (Güneyisi, Gesoglu & Tankut, 2008; Ramezanianpour & Malhotra, 1995). Pozzolans, like silica fume and fly ash, are the most usual known mineral admixtures utilized in manufacturing of high-strength concrete. These materials grant extra performance to the concrete by reacting with Portland cement hydration products to form secondary C-S-H gel, the main function part of the paste are providing strength for concrete (Neville, 1996). In the previous two decades, there has been a growing attraction in the beneficiation of metakaolin (MK) as a supplementary cementing material in concrete to enhance its features. MK is an ultrafine pozzolana, manufactured by calcination of purified kaolin clay at a temperature ranging from 650 to 900 oC to separate the chemically bound water and ruin the crystalline structure (Kakali et al., 2001; Al-Akhras, 2006). Unlike other industrial by-product materials, MK needs a thorough process of manufacturing. It has to be carefully refined to remove inert impurity and ground to particles of micron size. Research has shown that concrete mixtures containing high-reactivity MK present comparable performance to the ones with other mineral admixtures in terms of mechanical properties as well as permeability and durability properties (Coleman & Page, 1997; Klimesch & Ray, 1998). Moreover, the use of this material is also environmentally friendly due to the reduction of CO2 emission to the atmosphere by decreasing Portland cement consumption.

In this study, the integrated impact of MK and steel fiber on mechanical properties of concretes was examined through an experimental program. One water/binder (w/b) ratio has been applied to manufacture the concretes. For steel fiber reinforced concretes, steel fiber with length/aspect ratios of 60/80 was used. The steel fibers were supplemented to concrete with 0.25% and 0.75% of the volume of the concrete. The mechanical properties of the concretes were measured through compressive and flexural tensile strength testing at the end of 28 days of curing. Moreover, adherence between reinforcing steel bar and concrete were evaluated by means of bonding strength examine at the same age.

2. Methodology
2.1 Materials
2.1.1 Cement

CEM I type Portland cement having specific gravity of 3.14 and Blaine fineness of 328 m2/kg was used for making ready the concrete examine samples utilized in determination of mechanical properties. The chemical composition of the cement can be seen in Table 1.

2.1.2 Metakaolin

The metakaolin utilized in this research is a white powder with a Dr. Lange whiteness value of 87. It has a specific gravity of about 2.60, and specific surface area (Nitrogen BET Surface Area) of 18000 m2/kg. Physical and chemical properties of MK used in this research are also shown in Table 1. The source for obtaining the MK is from Czech Republic.

Table 1: Features of Portland cement and metakaolin

	Item	Portland Cement	Metakaolin
Chemical properties	CaO (%)	62.58	0.5
	SiO_2 (%)	20.25	53
	Al_2O_3 (%)	5.31	43
	Fe_2O_3 (%)	4.04	1.2
	MgO (%)	2.82	0.4
	SO_3(%)	2.73	-
	K_2O	0.92	-
	Na_2O	0.22	-
	LOI (%)	1.02	0.4
Physical properties	Specific gravity	3.14	2.60
	Fineness (m^2/kg)	327*	18000**

* Blaine specific surface area
** BET specific surface area

2.1.3 Aggregate

Fine aggregate was a mix of river sand and crushed sand whereas the coarse aggregate was river gravel with a maximum particle size of 22 mm. Aggregates were gained from local sources. Properties of the aggregates are given in Table 2. Grading of the aggregate mixture was kept constant for all concretes. Figure 1 shows the gradation of aggregate.

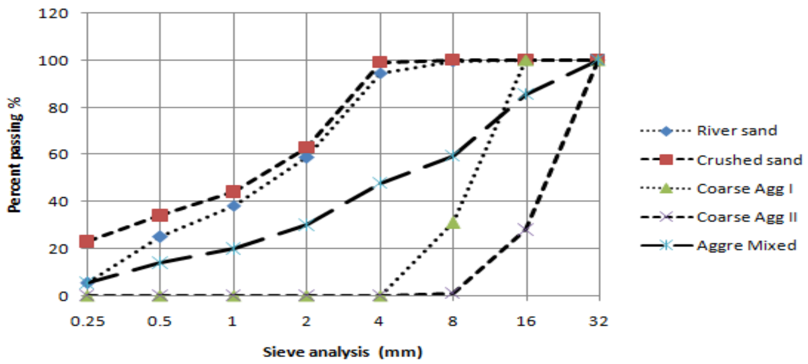

Figure 1: Grading of aggregate

Table 2: Sieve analysis and physical properties of aggregates

	Sievesize, (mm)	Passing (%)			
		Fine Aggregate		Coarse Aggregate	
		River Sand	Crushed Sand	No I (4-16 mm)	No II (16-22 mm)
Sieve Analysis	31.5	100	100	100	100
	16.0	100	100	100	27.7
	8.0	99.7	100	31.5	0.6
	4.0	94.5	99.2	1.0	0.1
	2.0	58.7	63.3	0.5	0.0
	1.0	38.2	43.7	0.5	0.0
	0.50	24.9	28.4	0.5	0.0
	0.25	5.4	16.4	0.4	0.0
	Fineness modulus	2.87	2.57	5.66	6.72
Physical Properties	Specific gravity	2.79	2.42	2.72	2.73
	Absorption, %	0.55	0.92	0.45	0.42

2.1.4 Superplasticizer

Sulphonated naphthalene formaldehyde based high range water-reducing admixture with specific gravity of 1.19 was employed to achieve slump value of 14±2 cm for the ease of handling, placing, and consolidation in all concrete mixtures. The superplasticizer was adjusted at the time of mixing to obtain the specified slump.

2.1.5 Steel Fiber

One sort of commercially available hooked end steel fibers (Dramix 60/80) was used for manufacturing of steel fiber reinforced concretes. The geometrical properties and aspect ratios of the steel fiber are given in Table 3.

Table 3: Features of steel fiber

Designation of the steel fibre	Diameter D (mm)	Length L (mm)	Aspect ratio (L/D)
SF	0.75	60	80

2.1.6 Steel Bar

16 mm diameter of reinforcing ribbed steel bars was used. The yield strength of 420 MPa was used for preparing the reinforced concrete samples to be utilized for examining the bonding strength.

2.2 Mix Proportion

A series of concrete mixture with water-to-binder ratios of 0.35 was designed to manufacture plain and MK containing concretes. MK modified concretes were manufactured by 10% substitute of the cement with MK by the weight. For manufacturing of steel fiber (SF) reinforced concretes, a type of (SF) was supplemented to the concrete by 0.25% and 0.75% of the total concrete volume. Therefore, 6 various sorts of concrete mixtures were made for testing the mechanical properties of the concretes. The specification of the concrete mixtures is shown in Table 4. The designations of each mix were produced based on containing of MK, sort of steel fiber, and volume fraction of steel fiber. For instance, 10M 0.75SF name stands for the concrete containing 10% MK and 0.75% steel fiber (SF). Freshly poured concrete samples were enclosed with plastic sheet and stocked in laboratory at 21±2 ^{o}C for 24 hours. Then, the samples were removed from the mold and transferred to a water tank for curing up to 28th day.

2.3 Examining the Samples

The concrete samples having different dimensions were used for examining. Cubic samples having 150x150x150 mm were used for compressive strength. For three point flexural tensile strength testing, prismatic samples with 100x100x500 mm dimensions were used to ensure 450 mm span length for examining. Bonding strength between concrete and reinforcement was examined on cubic reinforced concrete sample. To ensure uniform load distribution, a smooth surface is required. So, the top surface of the pullout samples was capped with gypsum coating. The details and dimensions of the pullout examining samples are shown in Figure 2. For each examine, three samples were used. Each experimental variance was defined by averaging the results gained from those samples. All of examines were held at the end of 28 day curing period.

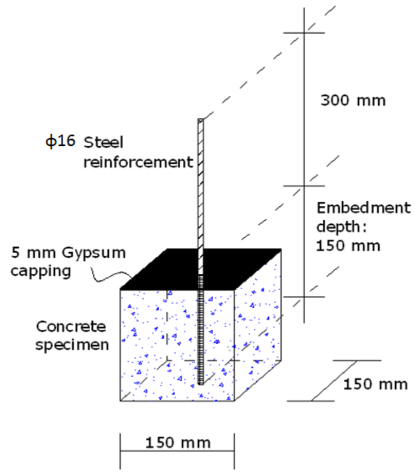

Figure 2: Details of the bonding strength examined samples

Table 4: Plain and steel fiber reinforced concretes containing metakaolin (kg/m^3)

Mix ID	w/b ratio	Water	Cement	Metakaolin	Fine Aggregate		Coarse Aggregate		Steel Fiber	SP*
					Natural sand	Crushed sand	No I (4-16 mm)	No II (16-22 mm)	SF	
Control I	0.35	157.5	450	0	663.1	284.2	568.4	378.9	0	11.25
M0-25SF		157.5	450	0	663.1	284.2	568.4	378.9	19.62	12.5
M0-75SF		157.5	450	0	663.1	284.2	568.4	378.9	58.85	13.75
Control II		157.5	405	45	660.0	282.9	565.7	377.2	0	10
M10-25SF		157.5	405	45	660.0	282.9	565.7	377.2	19.62	11.25
M10-75SF		157.5	405	45	660.0	282.9	565.7	377.2	58.85	13

*SP:Superplastizer

2.4 Test Methods

The compression test fitting to ASTM C39 (ASTM C39/C39M-12, 2012) was held on the samples by a 3000 KN capacity testing machine. Three-point flexural tensile strength complying with ASTMC293 (ASTM C293/C293M-10,2012) was implemented to the prismatic samples through 100 kN capacity bending frame. Bonding strength of the concretes was found according to (RILEM RC6 RILEM RC 6,1996). According to the standard the bonding strength, τ, is measured by dividing the tensile force by the surface area of the steel bar embedded in concrete (Equation 1). For this examine, a special modified test apparatus was established to 600 kN capacity universal testing machine.

$$\tau = \frac{F}{\pi \times d \times L} \qquad \text{(Equation 1)}$$

Where F is the tensile load at failure (N), d and L are the diameter (mm) and embedment length (mm) of the reinforcing steel bar, respectively. In this research d and L are 16 mm and 150 mm, respectively.

3. Result and Discussion

In this paper, the mechanical properties of concrete are investigated the results are shown in Table 5. Each compressive strength, bond strength, and flexural strength is discussed in the following paragraphs.

Table 5: Test results of the compressive, bond, flexural, and tensile strength

w/b	Mixes	Com. Str. (MPa)	Bond Str. (MPa)	Flex. Str. (MPa)
0.35	0MK0SF	62.7	11.7	5.8
	0MK0.25SF	66	13.1	7.1
	0MK0.75SF	72	16	7.4
	10MK0SF	62.3	12.6	7.1
	10MK0.25SF	72.4	14	7.6
	10MK0.75SF	75.7	16.9	7.9

3.1 Compressive Strength

Figure 3 shows the changes in compressive strength of the plain and MK contained concretes with the increase in the quantity of fiber reinforcement. Table 5 shows that the plain concretes compressive strength values were between 62.7 MPa and 72 MPa for specified w/b ratios of 0.35, while MK contained the ones with compressive strength values between 62.3 MPa for the previous and 75 MPa for the latter. The compressive strength results revealed that containing of MK had a slight impact on the compressive strength of the concretes. Same outcomes have been reported in some studies (Nili & Afroughsabet, 2012; Boddy, Hooton & Gruber, 2001; Kim, Lee & Moon, 2007). For instance, in the research of Güneyisi and Mermerdaş (2007) concretes containing 5% and 15% substitute level of MK yielded relatively recorded a higher value of strength than that of plain concretes. As it shown in Figure 3, rising the amount of SF concluded in ascending of the compressive strength of the concretes without depending on the addition of MK. Nili and Afroughsabet (2012) stated that 28 day compressive strengths of plain concrete produced with w/b ratio of 0.46 were 41.30 MPa, 46.35 MPa, and 47.25 MPa for steel fiber volume fractions of 0%, 0.5%, and 1.0%, respectively. Moreover, the impact of steel fiber is also obviously illustrated in Figure 3. The higher the percentage of steel fiber, the higher the ascending in compressive strength was monitored, especially for MK contained ones. For instance, the plain concretes made with steel fiber volume fraction of 0.25% and 0.75% had 66 MPa and 72 MPa, respectively. However MK contained concretes with the same parameters and percentage of steel fiber had 72.4 MPa and 75.7 MPa, respectively.

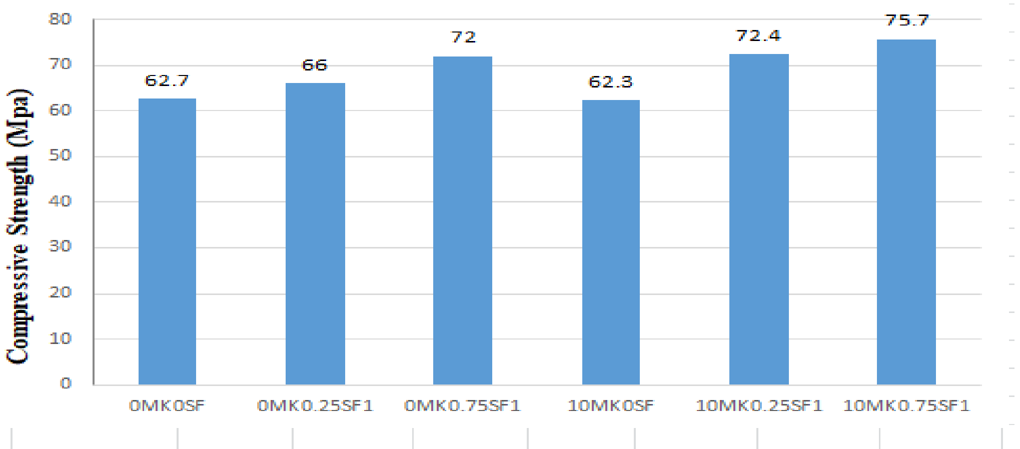

Figure 3: Effect of steel fiber and MK incorporated concretes on the compressive strength

3.2 Tensile Strength

The tensile strength of plain and MK included concretes were monitored with respect to flexure tensile strength. The test outcomes of flexural tensile strength are presented in Table 5, and Figure 4, respectively, to demonstrate the effectiveness of steel fiber reinforcement. It was stated that the main and importance contribution of the steel fibers was caused in increasing of flexural tensile strength capacity of the concrete (Kayali, Haque & Zhu, 2003). Another distinguishable result from the tensile strength examining is that unlike previous results, the contribution MK with increasing SF was observed to be better. This condition may be attributed to the distribution of the steel reinforcement within the cement matrix. Namely, the shorter steel fiber is, the more homogenous distribution may be achieved. Sanal and Özyurt (2010) investigated the effect of orientation of steel fibers on the mechanical performance of the concretes. They reported that, short-cut steel fibers have a tendency to align in the flow direction and greater orientation density in the pouring direction resulted in a greater flexural toughness.

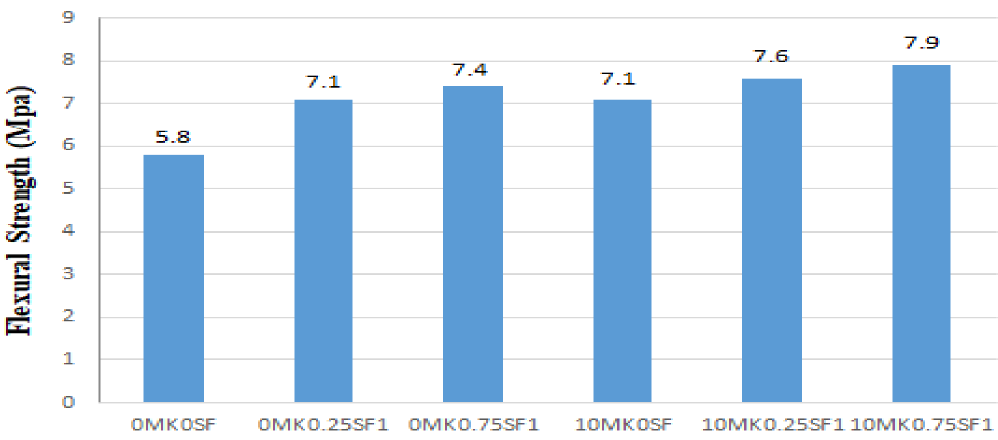

Figure 4: Effect of steel fiber and MK incorporated concretes on the three-point flexural strength

3.3 Bonding Strength

Bonding strength of the concretes versus the amount of the steel fiber reinforcement is showed in Table 5 and plotted Figure 5. The figure depicted that the ascending in the volume fraction of SF concluded in great change in the bonding strength. The observation seems to be applicable to 0% and 0.75% use of steel fiber. Nevertheless, inclusion of MK to the concretes imparted additional performance in terms of bonding strength. For instance, the highest bonding strength for MK modified concretes was monitored as 16.9 MPa, while the minimum value for plain concrete was monitored as 12.5 MPa. Therefore, 35% improvement in bonding strength capacity was achieved by combined inclusion of MK and steel fibers. Baran, Akis and Yesilmen (2012) stated that steel fibers improve the pull-out resistance of strands by controlling the crack growth inside concrete blocks. They reported that, by this method, the grade of confinement at the strand-concrete interface was ascended, which concluded in enhancement in both friction and mechanical bond components of the resistance. Their outcomes also displayed that more than 30% ascending was acquired in pull-out strength due to fiber reinforcement. Being one of the most known mineral admixtures MK is known to have comparable contribution to the mechanical and durability performance of concretes as silica fume does (Boddy, Hooton & Gruber, 2001; Güneyisi & Mermerdaş, 2007; Güneyisi et al., 2012). However, the studies regarding the effect of inclusion of MK on the bonding strength between concrete and steel bars has not yet attracted the adequate attention. The former outcomes introduced for silica fume included steel fiber reinforced concretes may underline the impact of usage of MK for this purpose. In the research of Chan and Chu (2004), the impact of silica fume on the bond properties of steel fiber in matrix of reactive powder concrete (RPC) were investigated. They carried out pullout tests in their experimental program, with the silica fume inclusion as the parent variable. They pointed out that the inclusion of silica fume in RCP matrix greatly improves the fiber–matrix bond. Abu-Lebdeh et al. (2011) also brought to light that the quality of matrix has pronounced significance on the bonding and tensile strain capacity of steel fibers in high strength concrete. Consequently, owing to its superior increment in cement matrix as an outcome of pore size refinement (Klimesch & Ray, 1998), MK assured enhancement in the pullout capacity of the reinforced concretes. Photographic views of the pullout samples examined in this research are presented in Figure 6. As it is shown, after failure, the reinforcing steel bars were separated from the concretes without steel fiber, whereas steel fiber reinforced concretes did not extricate the steel bars.

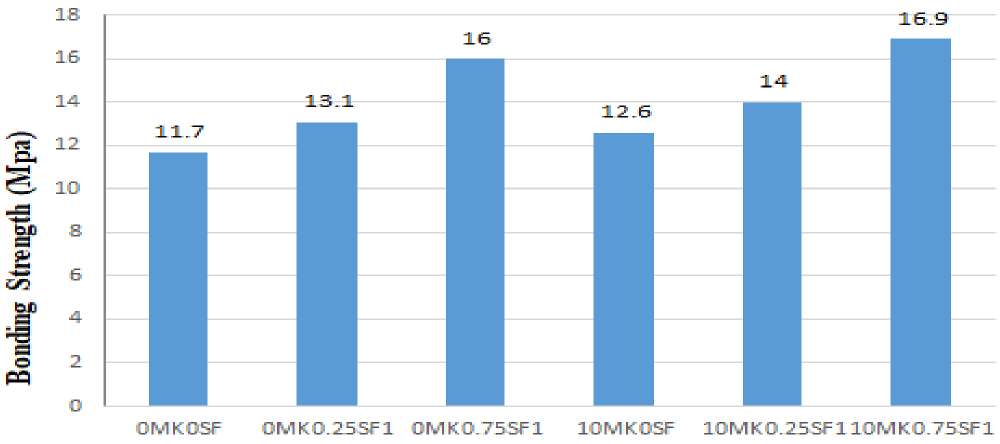

Figure 5: Effect of steelfiber and MK incorporated concretes on the bond strength

(a) (b)

Figure 6: Typical failure patterns of concretes a) without fiber reinforcement and b) with fiber reinforcement

4. Conclusion

The following outcomes are achieved according to the experimental outcomes presented above.

- The use of MK as a substitute material resulted in enhanced mechanical properties of concretes compared to plain ones for the given w/b ratios. The outcomes show that the incorporating of MK mainly impacts on increasing of bonding strength. A slight impact of MK incorporation is recorded for compressive and flexural tensile strength. The content of steel fibers also contributed to the compressive strength. The steel fibers (SF) provided higher compressive strength improvement with ascend in volume fraction. The grade of enhancement was more prominent for MK concretes than plain ones.
- By incorporation of steel fibers significant enhancement in bonding and tensile strength capacities of the concretes were observed. The steel fibers with higher volume fraction of steel fibers (SF) demonstrated higher development in bonding strength. These impacts of steel fiber reinforced concretes may be attributed to the dispersion and orientation of the steel fibers within the concrete.

References

Abu-Lebdeh, T., Hamoush, S., Heard, W., & Zornig, B. (2011). Effect of matrix strength on pullout behavior of steel fiber reinforced very-high strength concrete composites. *Construction and Building Materials*, 25, 39–46.

Al-Akhras, N.M. (2006). Durability of metakaolin concrete to sulfate attack. *Cement Concrete Research*, 36, 1727–1734.

ASTM C293/C293M-10 (2012). Standard test method for flexural strength of concrete (Using simple beam with center-point loading) Annual Book of ASTM Standard, Vol. 04-02, 3 pages. Philadelphia, USA.

ASTM C39/C39M-12. (2012). Standard test method for compressive strength of cylindrical concrete specimens annual book of ASTM Standard, Vol. 04-02, 7 pages. Philadelphia, USA.

Baran, E., Akis, T., & Yesilmen, S. (2012). Pull-out behavior of prestressing strands in steel fiber reinforced concrete. *Construction and Building Materials*, 28, 362–371.

Bentur, A., Mindess, S., & Diamond, S. (1985). Pull out processes in steel fiber reinforced cement. *International Journal of Cement Composites & Lightweight Concrete*,7(1), 29-38.

Boddy, A., Hooton, R.A., & Gruber, K. A. (2001). Long-term testing of the chloride-penetration resistance of concrete containing high-reactivity metakaolin. *Cement Concrete Research*, 31, 759-765.

Chan, Y., & Chu, S. (2004). Effect of silica fume on steel fiber bond characteristics in reactive powder concrete. *Cement Concrete Research*, 34.1167–1172.

Coleman, N.J., & Page, C.I. (1997). Aspect of the pore solution chemistry of hydrated cement pastes containing metakaolin. *Cement Concrete Research*, 27, 147-154.

Klimesch, D.S., & Ray, A. (1998). Autoclaved cement– quartz pastes with metakaolin additions. *Advanced Cement Based Mater*, 7, 109–118.

Ding, J.T., & Li, Z. (2002). Effects of metakaolin and silica fume on properties of concretes. *ACI Materials Journal*, 99, 393-398.

Ersoy, U., Özcebe, G., & Tankut, T. (2003). *Reinforced Concrete*. Ankara: METU Press.

Güneyisi, E., Gesoğlu, M., Karaoğlu, S., & Mermerdaş, K. (2012). Strength, permeability and shrinkage cracking of silica fume and metakaolin concretes. *Construction and Building Materials*, 34, 120-130.

Güneyisi, E., Gesoğlu, M., & Mermerdaş, K. (2008). Improving strength, drying shrinkage, and pore structure of concrete using metakaolin. *Materials and Structures*, 41, 937-949.

Güneyisi, E., & Mermerdaş, K. (2007). Comparative study on strength, sorptivity, and chloride ingress characteristics of air-cured and water-cured concretes modified with metakaolin. *Materials and Structures*, 40, 1161-1171.

Hooton, R. D. (1993). Influence of silica fume replacement of cement on physical properties and resistance to sulfate attack, freezing and thawing, and alkali silica reactivity. *ACI Material Journal*, 90, 143–151.

Kakali, G., Perraki, T., Tsivilis, S., & Badogiannis, E. (2001). Thermal treatment of kaolin: the effect of mineralogy on the pozzolanic activity. *Applied Clay Science*, 20, 73-80.

Kayali, O., Haque, M.N., & Zhu, B. (2003). Some characteristics of high strength fiber reinforced lightweight aggregate concrete. *Cement and Concrete Composites*, 25, 207–213.

Kim, H.S., Lee, S.H., & Moon, H.Y. (2007). Strength properties and durability aspects of high strength concrete using Korean metakaolin. *Construction and Building Materials*, 21, 1229-1237.

Mehta, P. K., Monteiro, P.J.M. (2006). *Concrete: Microstructure, Properties, and Materials*. 3rd Edn, McGraw-Hill, USA.

Neville, A.M. (1996). *Properties of Concrete*. England: Addison Wesley Longman.

Nili, M., & Afroughsabet, V. (2012). Property assessment of steel–fibre reinforced concrete made with silica fume. *Construction and Building Materials*, 28, 664–669.

Ramezanianpour, A. A., & Malhotra, V. M. (1995). Effect of curing on the compressive strength, resistance to chloride ion penetration and porosity of concretes incorporating slag, fly ash, or silica fume. *Cement Concrete Composites*, 17, 125–33.

RILEM RC 6, (1996). Recommendations for the testing and use of constructions materials bond test for reinforcement steel. 2. Pull-out test, 3 pages

Sanal, İ., & Özyurt, N. (2010). Effects of formwork dimensions on the mechanical performance of fiber-reinforced cement based materials. 9th International Congress on advances in civil engineering, 27-30 Karadeniz Technical University, Trabzon, Turkey.

Yurtseven, A. E. (2004). *Determination of Mechanical Properties of Hybrid Fiber Reinforced Concrete*. MSc thesis, METU, Ankara, Turkey.