International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Annales de Chimie - Science des Matériaux
Vol. 47, No. 5, October, 2023, pp. 297-303
Journal homepage: http://iieta.org/journals/acsm

Mechanical and Thermal Characteristics of Concrete Reinforced with Crushed Glass and Glass Fiber: An Experimental Study

Mais A. Abdulkarem

Material Engineering Department, Mustansiriayah University, Baghdad 10055, Iraq

Corresponding Author Email: maisabdulRahman@uomustansiriyah.edu.iq

https://doi.org/10.18280/acsm.470505

Received: 24 March 2023
Revised: 16 August 2023
Accepted: 23 August 2023
Available online: 31 October 2023

Keywords:
crushed glass, glass fiber, compressive strength, splitting tensile strength, thermal conductivity, flexural strength

ABSTRACT

The incorporation of waste glass and glass fiber, as replacements for fine aggregate and cement respectively, offers a sustainable strategy to mitigate landfilling and virgin aggregate extraction. The present study delves into the influence of these waste derivatives on the mechanical and thermal attributes of concrete. Fine aggregate was substituted by crushed glass shards in a weight-to-weight ratio ranging from 5% to 30%, and cement was replaced by glass fiber in a weight-to-weight ratio of 1%. Mechanical attributes such as compressive, flexural, and splitting strength were evaluated, along with thermal characteristics of the concrete. A concrete mix ratio of 1:2:4 and a water/cement ratio of 0.45 were employed. The results revealed that concrete designated as Mcf20% demonstrated superior mechanical properties compared to the reference concrete. After 28 days, compressive strength of 51.2 MPa, flexural strength of 6.5 MPa, and splitting tensile strength of 3.78 MPa were recorded for Mcf20% concrete, signifying the beneficial effects of the combined use of glass fiber and crushed glass. Furthermore, an inverse relationship was observed between the percentage of waste additives and thermal conductivity. This investigation underscores the potential of recycling glass and glass fiber as eco-friendly additives in concrete, improving both mechanical properties and thermal performance, thus endorsing their use in structural and architectural concrete applications.

1. INTRODUCTION

Concrete serves as the cornerstone of global infrastructure expansion. Nevertheless, the escalating demand and consequent depletion of traditional resources for concrete manufacturing have posed significant challenges, particularly considering the increasing costs of building materials. A plausible solution lies in using recycled materials as substitutes for the currently necessary natural resources in concrete production. This approach harbors the potential for cost reduction and minimizes waste directed to landfills. Various waste materials, such as glass, recovered plastic, wood ash, rice husk ash, and olive waste, can be repurposed into concrete. Even environmentally harmful waste products, such as vehicle tires, can be utilized [1].

When reduced to fine particles, waste glass displays pozzolanic properties. It can react with calcium hydroxide released during the hydration of cement to form additional calcium silicate hydrate gel [2]. This reaction enhances the microstructure and properties of the hardened concrete paste. Studies have demonstrated that fine glass powder can bolster the compressive and flexural strength of concrete when used as a cement replacement [3]. The integration of short, discrete fibers presents an effective technique for reinforcing the concrete matrix. Glass fiber, in particular, can restrain crack formation and provide post-crack ductility [4], thereby improving the tensile and flexural performance of concrete. The combination of crushed glass and glass fiber, serving as aggregates and reinforcement respectively, could potentially enhance both mechanical and thermal properties of concrete [5].

The current study aims to investigate the effects of incorporating fine crushed waste glass and glass fiber on the compressive strength, tensile strength, flexural strength, fracture toughness, and thermal conductivity of concrete at 28 days. We evaluate the effects of different dosage levels on the measured mechanical and thermal characteristics, intending to optimize the glass and glass fiber content to produce durable, high-performance concrete in a sustainable manner.

Previous research carried out by Alani et al. [6] revealed that replacing fine aggregate with waste glass (WG) aggregate significantly decreased the screeds' thermal conductivity. Similar outcomes were reported by Krishnamorthy and Zujip [7], where partial substitution of fine aggregate by WG fine aggregate, ranging from 10% to 50% in concrete, led to a gradual decrease in thermal conductivity as the content of the recycled glass in a specimen increased. Moreover, Guo et al. [8] suggested that a particularly high ratio of natural aggregates substituted with WG might decrease the thermal conductivity of architectural mortars. Beyond their practical characteristics, such architectural cement mortars could potentially be employed as facade materials due to their aesthetic features.

Fibers, such as carbon, glass, aramid, and polypropylene, have been found to improve various properties of concrete, including tensile strength, compressive strength, durability, fatigue characteristics, cavitation, shrinkage characteristics, erosion resistance, impact resistance, and serviceability [9].

More specifically, as the fiber content increases, the concrete becomes more impact-resistant, robust, and better at water absorption. Moreover, the fatigue properties of fiber-reinforced concrete (FRC) are enhanced.

Rahmani et al. [10] tested polypropylene, steel, and glass fibers for their ability to withstand electrical resistance, gas permeability, water penetration, and scaling resistance to deicing chemicals. The gas and water absorption capacity of steel fibers was found to be improved. Kumar et al. [11] demonstrated the analysis of M30 grade concrete by incorporating glass fiber. This experiment used glass fibers 14 microns in diameter with different percentages (0%, 0.4%, 0.8%, 1.2%, and 1.6%) by weight of cement and a water-cement ratio of 0.45. The study confirmed that adding 1.2% glass fiber to the weight of cement in concrete could increase strength by up to 17.36% compared to ordinary concrete, flexural strength by up to 35%, and split tensile strength by up to 40%. The addition of glass fiber was found to enhance these properties, with flexural strength being more improved compared to compressive strength.

In comparison to unreinforced concrete, the fiber-modified concrete exhibited marked changes in thermal characteristics, as stated by Ozger et al. [12]. By replacing part of the sand with nylon fibers (5 g/m3), an approximate 16% increase in the level of thermal conductivity and an approximately 50% increase in specific heat was obtained compared to plain concrete. Zhang et al. [13] also observed similar increases in thermal conductivity values for fiber concrete. A mere 0.80% addition of carbon and glass fibers in length (with a constant 0.50 water to cement ratio) resulted in a 14.30% and 12.70% increase respectively compared to plain concrete. Conversely, the inclusion of 2% 6 mm polypropylene and 6 mm basalt fiber led to a decrease in thermal conductivity (7.80% for basalt fiber and 13.20% for polypropylene fiber).

The primary objective of this study is to explore the potential of various forms of glass waste as substitutes for some of the basic materials in concrete production and to examine the properties of the resulting concrete. This approach carries significant economic implications due to the potential for reusing materials that would otherwise be discarded as waste, consequently transforming them into construction materials.

2. THE MATERIALS

2.1 Cement

In the present research, ordinary Portland cement (OPC) (I) that is made in the Kabaisa cement factory was used. Table 1 shows the chemical composition of the cement that has been utilized. In this research, it is noteworthy that the values in the table above were obtained from the Kabaisa Cement Factory and have been confirmed to Iraqi Standard-Specification (IQ.S.) No. 5/1984 [14].

2.2 Fine aggregate

In the present research, the fine aggregate that was utilized had been obtained from the Al-Nabaey area. Before its incorporation into the concrete mix, sand was sieved on 4.75mm sieve. Table 2 physical properties of fine aggregate and Table 3 illustrates the grading Grading of the sand, which corresponds to IQS No. 45/1984 [15].

Table 1. Chemical composition of the cement

Oxide Chemical Composition	Content % of Cement	Specification Limits
Fe_2O_3	3.25 ± 0.1	-
Al_2O_3	5.70 ± 0.3	-
SiO_2	21.5 ± 0.5	-
CaO	60.25 ± 1.0	-
MgO	2.70 ± 0.3	< 5%
SO_3	2.50 ± 0.2	< 2.8%
Na_2O	0.20	-
K_2O	0.42	-
Insoluble Residue	0.5	< 1.5%
Free Lime	1.5	-
Loss on Ignition	0.7	< 4%

Table 2. Aggregate's physical characteristics, both coarse and fine

Property	ASTM	Fine Aggregate	Coarse Aggregate
Bulk specific gravity	ASTM C127 and C128	2.62	2.628
Apparent specific gravity	ASTM C127 and C128	2.690	2.689
Percent wear (Abrasion of Loss – Angeles)	ASTM C 127 and C128	-	26.1
Present water absorption	ASTM C127 and C 128	0.614	0.586

Table 3. Grading of fine aggregate & crush glass

Sieve Size (mm)	Cumulative Passing %		Limit of Iraqi Specification No.45/1984
	Sand	Crushed Glass	
4.75	97	98	90-100
2.36	78	87	75-100
1.18	56	77	55-90
0.06	34	64	35-59
0.30	10	20	8-30
0.15	1	7	0-10

2.3 Coarse aggregate

In the present work, coarse aggregate was utilized from the Al-Nibaey area with a maximal particle size of 12 mm, and physical properties listed in Table 2.

2.4 Crush glass

Table 4. Chemical composition of crushed glass

Oxide Chemical Composition	Content % of Crushed Glass
Fe_2O_3	0.55
Al_2O_3	2.01
SiO_2	72.67
CaO	9.6
MgO	6
SO_3	0.17
Na_2O	8.42
K_2O	0.13
Insoluble Residue	-
Free Lime	-

It was collected from a window shop and washed with clean water to remove the dust and dirt. The glass was crushed by a grinding machine. Then the crushed glass was sieved by a sieve analysis machine, and sand gradients were added. Tables 3 and 4 show the chemical composition of crushed glass and Show the grading of crushed glass similar to the grading of fine aggregate.

2.5 Glass fiber

Clean the glass fibers to remove any surface coatings, oils or impurities. This can be done by soaking in a solvent acetone and then rinsing with water then it has chopped strands into short discrete lengths a 5 mm length. The amounts used were (1%) percent by cement weight, and the density of fiberglass is 2.58 g/cm^3.

2.6 Water

Ordinary tap water is utilized for all of the mixes when preparing cubes and curing.

3. SPECIMEN PREPARATION

In this study, two types of waste are used, and cement will be replaced with 1 percent glass fiber. A percentage of reused crushed glass is used to replace the sand (fine aggregate). The significant proportion will range from 5% to 30% recycled glass aggregate, with 1 sample of normal mixed concrete serving as a control sample. The concrete mixture will be poured into the mold and compacted with a vibrating machine. The specimen will then be allowed to dry for 24 hours before curing. At the age of one day, the mold was removed from test specimens. All of the specimens have been kept in a water tank until the test, which was 28 days after casting. By systematically varying the crushed glass content within the practical range, its effects can be thoroughly assessed, especially in combination with the 1% glass fiber dosage, to determine optimal mixtures for performance objectives. The proportions allow demonstration of the reuse potential for these two waste materials in concrete. The mixing proportions are shown in Table 5.

Table 5. Mixing proportion of all sample

Sample		Cement [kg/m^3]	Fiber Glass [kg/m^3]	Fine Aggregate [kg/m^3]	Crush Glass [kg/m^3]	Coarse Aggregate [kg/m^3]	w/c
M0	0%	380	-	760	-	1520	0.45
Mfc5	(1%+5%)	376.2	3.8	722	38	1520	0.45
Mfc10	(1%+10%)	376.2	3.8	684	76	1520	0.45
Mfc15	(1%+15)	376.2	3.8	646	114	1520	0.45
Mfc20	(1%+20)	376.2	3.8	608	152	1520	0.45
Mfc25	(1%+25%)	376.2	3.8	570	190	1520	0.45
Mfc30	(1%+30%)	376.2	3.8	532	228	1520	0.45

4. TESTS

4.1 Compressive strength test

Standard cubes of 150 mm have been utilized, based on BS 1881: Part 116 [16], for casting and testing for determination of compressive strength at 28 days. The machine that has been utilized in this testing is a hydraulic compression machine with a 2000 kN capacity. The mean value of three specimens at 28 days of age has been utilized for the determination of compressive strength for control concrete in addition to partial replacement mixtures.

4.2 Flexural strength test

The rupture modulus has been tested with the use of 50×50×250 mm that have been prepared based on the ASTMC78-10 [17]. In design codes, flexural strength has been represented as [the rapture modulus (fr)]. According to ASTM, based on the standard, the flexural strength may be estimated by using the 3-point loading test. A testing machine of 30 kN capacity has been utilized in order to test all of the prisms in this work. This test showed the significance of the bends and breakage occurring in the materials. The value of the rupture modulus is characterized by the use of the formula:

$$fr=3PL/2bd^2 \tag{1}$$

where, P: represents the maximal load in N; b: represents the width of fracture cross section in mm; L: represents the length of the specimen between the supports in mm; d: represents the height of fracture cross section in mm.

Prisms have been casted and cured in identical conditions as compressive strength test specimens.

4.3 Splitting tensile strength test

The concrete splitting tensile strength has been experimentally evaluated with the use of a standard cylinder with d=150 mm and h=300 mm dimensions, based on ASTM C 496/C 496M [18]. The specimens were tested using an electrical testing machine with capacity of 2000 kN. This test was conducted at age of 28 days.

4.4 Thermal conductivity test

Thermal insulation is a basic objective and an important requirement in our facility. In this research, the thermal conductivity coefficient K is found, where the thermal conductivity represents the measure of thermal conductivity. which is the number of thermal units passing through a unit area of the material with a thickness that is equal to 1 unit and during 1 unit time when the difference between the temperature degrees on both sides of the body is 1 degree, and in the metric system, the unit used is W/mK. The following equation was given by ACI that relates the dry density to the thermal conductivity coefficient for dried models.

$$K=0.027\times e^{0.00125\rho} \tag{2}$$

where, K: thermal conductivity coefficient; ρ: density of dry sample; e: exponential function.

5. RESULTS AND DISCUSSION

5.1 The strength compressive of glass fiber

The results in Figure 1 show that the compressive strength of concrete is increased by up to 1% as replacement by glass fiber increases at 28 days. The mixture with a 1 percent substitution of the cement with glass fiber achieved an increase in the value of the strength of 18.3 percent. Using glass fiber can be seen to marginally improve compressive strength. The resistance to fracture will, however, increase if the orientation of the fiber is at a right angle to the direction of the applied load [19]. The decrease in compressive strength with increasing fiber content may be attributed to both the disturbance in the mix's homogeneity and the orientation of the fiber and to mitigate this effect use vibratory mixing actions or secondary agitation after initial mixing to better separate and distribute the fibers. Also, Tamp fiber concrete in thinner layers to reorient fibers parallel to the poured surface as far as possible.

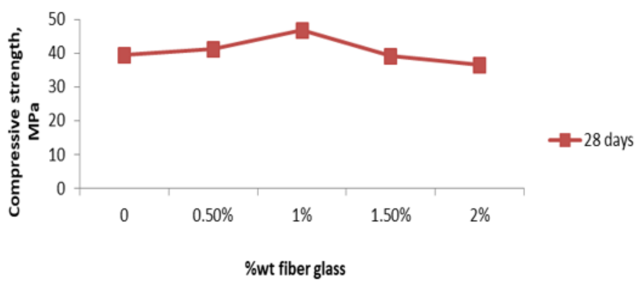

Figure 1. Variations of the compressive strength (cement replacement by fiberglass)

5.2 Thermal conductivity of glass fiber

For 0.5 GF–2 GF samples, the Figure 2 shows a reduction in the value of the thermal conductivity has been observed, respectively, at 9% and 20%. Such phenomena have been found to be highly associated with porosity changes. Lower values in the thermal conductivities for the glass fiber concrete have also been reported by Nagy et al. [20]. They were able to reduce the thermal conductivity from 2.83 W/mK to 2.67 W/mK, or around 5.60%, by adding glass fiber concrete at a rate of 0.30.

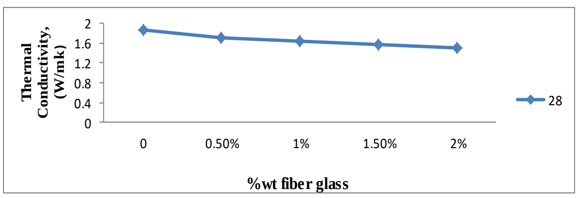

Figure 2. Variations of thermal conductivity when cement was replaced by fiberglass

5.3 Study the effect of crush glass with optimization of fiberglass

Results have shown that replacing cement with fiberglass at a percentage of 1 percent realized higher strength; therefore, the optimal percentage will be performed with the use of 1 percent fiberglass, and the fine aggregate has substituted various crushed glass percentage values (from 5 to 30 percent).

5.4 Compressive strength

Figure 3 illustrates the effects of the waste materials on the compressive strength of the concrete at 28 days of curing. When the percentage of waste materials increased, the compressive strength increased. The optimal value of compressive strength has been 51.2 MPa at Mcf20%. The increase in the value of the strength over that of a control could result from the angular nature of the glass aggregate, which has a greater surface area in comparison with naturally rounded particles of the sand. Such an increase in the surface area provides the ability for greater bonding with cement paste, which leads to a stronger concrete matrix [21]. Malik et al. [22] incorporated waste glass aggregates up to 25% and tested 28-day strengths. They achieved maximum compressive strength at 20% glass replacement, within the 5-30% range presently studied. Moreover, the effects of glass fiber increase the strength because adding fibers prevents the propagation of the cracks that result from the loadings or forces [23]. Poutos and Nwaubani tested concrete at 28 days with 0.5% and 1% glass fibers. They reported 15% strength gains at 1% fiber content, comparable to the present work [24]. Then, compressive strength will drop when the amount of waste materials is increased by 30% because of the reduction in the adhesion between the glass particles and the cement paste (i.e., reference). The results of this research suggest that the glass particles' angular nature could play a bigger role in the witnessed strength reduction. It has been proposed that where the glass aggregate exists in higher proportions, there's insufficient cement paste available in the mixture to facilitate the bonding with all of the particles, which leads to the formation of microscopic voids, negatively affecting the strength of the concrete.

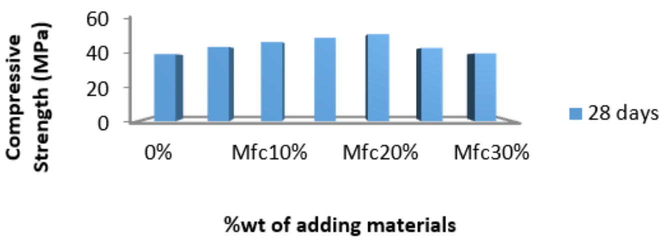

Figure 3. Effect of waste materials on mortar's compressive strength at 28 days

5.5 Flexural strength

The values of a 28-day flexural strength have been observed to tend to be higher than the plain mixture by 3.57%, 6.96%, and 11.2% as the added material content increased by Mfc 10%, Mfc 15%, and Mfc 20%, respectively. Which exhibits the considerable pozzolanic reaction that happened throughout this period. The impact of waste materials (glass fiber plus glass waste) on the flexural strength of mortar at 28 days of curing is depicted in Figure 4. Flexural strength was best measured at Mcf 20% at 6.5 MPa. This demonstrates that a significant pozzolanic response occurred during this time. The values of a 28-day flexural strength have been observed to tend to be higher than the plain mixture by 3.57%, 6.96%, and

11.2% as the added material content increased by Mfc 10%, Mfc 15%, and Mfc 20%, respectively. Which exhibits the considerable pozzolanic reaction that happened throughout this period. The impact of waste materials (glass fiber plus glass waste) on the flexural strength of mortar at 28 days of curing is depicted in Figure 4. Flexural strength was best measured at Mcf20% at 6.5 MPa. This demonstrates that a significant pozzolanic response occurred during this time. The fine glass particles undergo a pozzolanic reaction forming additional CSH that densifies the cement paste over time, refining the pore structure and improving the transition zone between glass aggregates and cement paste. This results in stronger aggregate bonding and load transfer in the microstructure. The additional CSH increases flexural strength by providing greater resistance to bending stresses. CSH deposition around glass fibers also enhances their crack bridging ability, improving post-crack ductility and fracture resistance. These microstructural enhancements manifest as increased flexural strength over extended curing, attributable to gradual CSH formation and its impacts on fiber-matrix interaction [25].The differences in aggregate cement paste bonding are the causes of this. As for the distribution and orientation of the fibers within the specimen, if a failure occurs in a zone where there are fibers, those fibers will be resistant to rupture; if a failure occurs in a zone where there are no fibers, flexural strength will be reduced [26].

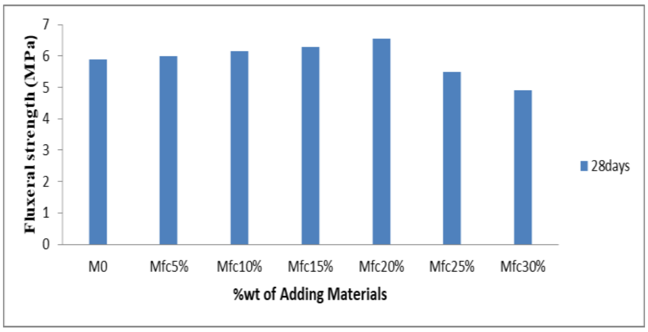

Figure 4. Effects of waste materials on flexural strength of mortar at 28 days

5.6 Splitting tensile strength

In Figure 5, results have shown that, in general, tensile strength has increased with increasing the curing time for all of the mixtures. Where Cement hydration in early curing is also still progressing, so matrix densification is incomplete. This results in relatively lower tensile strength enhancement initially [1]. A comparison of the tensile strengths of the different mixtures shows that an Mfc5% substitution of waste materials had little effect on the tensile strength value.However, additionally increasing the substitution had a considerable impact on tensile strength at an early stage of the curing process, whereas the opposite was true for mature concrete. In other words, the tensile strength of the concrete with the Mcf20% substitution of the waste materials was considerably higher in comparison with that of control concrete at a curing time of 28 days. The 28-day splitting tensile strength has been 3.78 MPa for Mcf20% substitution of the concrete, increasing by as much as 14.19% in comparison with the controlled mixture. It may be a result of the glass-mixed concrete's hydration process progressing, reducing permeability, and the irregular glass's geometry enhancing the binding between the cement paste and aggregate. A pozzolanic reaction may also counteract this tendency at a later stage of hardening and aid in enhancing the splitting tensile strength at the age of 28 days [27].

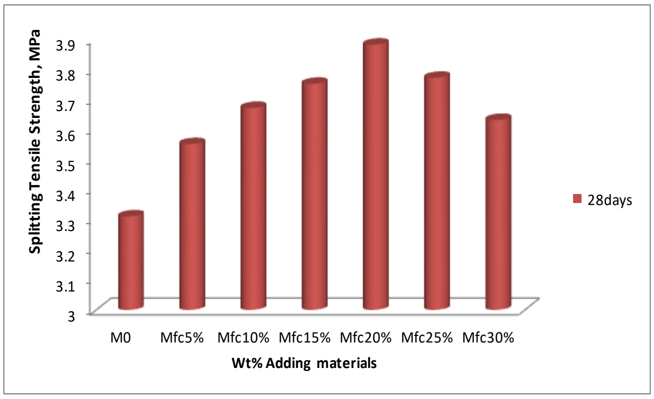

Figure 5. Effect of adding materials on the splitting tensile of concrete at 28 days

5.7 Thermal conductivity

It is observed in Figure 6 that the coefficient of the thermal conductivity has been considerably reduced in the case where the added materials have been present. Which results from the changes in the air voids, filled with moisture or water, resulting in the increase of the thermal conductivity [28]. This attribute is being measured in order to determine whether the concrete used for plastering buildings has superior thermal insulation, which helps to stop temperature leakage from the inside to the outside or vice versa. It is shown how the weight fractions of crushed glass and fiberglass affect the heat conductivity of concrete specimens. It is evident that as the percentages of crushed glass and fiberglass in concrete increased, the thermal conductivity of concrete specimens showed a constant decline in values. This is due to the fact that glass fiber and crushed glass have less thermal conductivity than the matrix of cement mortar. As a result, the increased thermal insulation of the concrete specimens is attributable to the glass crush and glass fibers' naturally low thermal conductivity. In addition, the inclusion of two different types of glass in a composite results in the generation of air in the matrix, which reduces density. Lower conductivity improves energy efficiency in buildings by reducing heat flow through walls and roofs. This reduces HVAC load and leads to savings in energy costs.

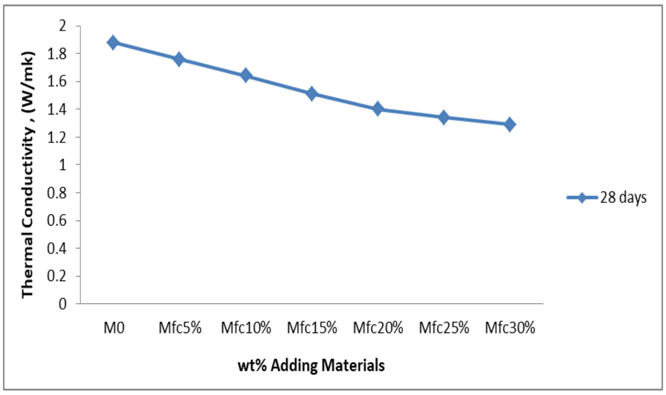

Figure 6. Effect of adding materials on thermal conductivity of concrete at 28 days

6. CONCLUSIONS

From the investigations that have been carried out, the following conclusions have been made:

(1) The pozzolanic effects of the waste materials in mortar are more noticeable after 28 days. The optimal waste materials' percentage, giving the maximal value of the compressive and flexural strength values, is Mfc20%, and the values are 51.2 MPa and 6.5 MPa, respectively. The peak strengths at Mfc20% can be attributed to optimal recycled material dosages; the 1% glass fibers provided reinforcement through crack control while the 20% crushed glass exhibited sufficient pozzolanic reactivity to densify the matrix without excessive cement dilution. The high amorphous silica in the fine glass reacted to form additional CSH gel refining the microstructure. However, as glass content increased beyond 20%, the lowering calcium content and weaker glass particles exceeded the benefits of the pozzolanic reaction, contributing to the downward strength trend. Thus, Mfc20% represented an ideal balance where the enhancement mechanisms of the fibers and glass powder were maximized without detrimental cement dilution effects.

(2) The value of the tensile strength has been increased by increasing the curing time for all of the mixtures. A tensile strength comparison between varieties of the mixtures indicated that a 5% substitution of the waste materials had little impact on tensile strength; however, additional increases in the replacement had led to a considerable impact on tensile strength at an early stage of curing and that demonstrate the need to prolong curing duration before structural testing or loading of crush glass/glass fiber concrete elements.

(3) The thermal conductivity decreased significantly when materials were added to the concrete. This is because the glass is crushed, and glass fiber has a lower thermal conductivity compared to that of a concrete matrix. In hot climates, heat gain through building elements containing crush glass/glass fiber concrete is decreased. This reduces cooling loads leading to energy savings. The reduced heat flow lowers indoor temperatures and improves occupant thermal comfort in extremely hot weather. Fire resistance is enhanced due to slower heat penetration, which is especially beneficial in hot, dry regions where fire risk may be higher. Thinner sections with equivalent insulation capacity can be designed to take advantage of weight and material savings.

ACKNOWLEDGMENT

The author thanks Al-Mustansiriya University (www.uomustansiriyah.edu.iq) in Baghdad, Iraq, for aiding in the current investigation.

REFERENCES

[1] Mehta, P.K., Monteiro, P.J. (2014). Concrete: Microstructure, properties, and materials. McGraw-Hill Education.

[2] Shao, Y., Lefort, T., Moras, S., Rodriguez, D. (2000). Studies on concrete containing ground waste glass. Cement and Concrete Research, 30(1): 91-100. https://doi.org/10.1016/S0008-8846(99)00213-6

[3] Soroushian, P. (2012). Strength and durability of recycled aggregate concrete containing milled glass as partial replacement for cement. Construction and Building Materials, 29: 368-377. https://doi.org/10.1016/j.conbuildmat.2011.10.061

[4] Majumdar, A.J., Laws, V. (1991). Glass fibre reinforced cement. BSP Professional Books.

[5] Nwaubani, S., Poutos, K. (2013). The influence of glass fibres, glass powder and glass aggregates on selected properties of concrete. Construction and Building Materials, 43: 548-553. https://doi.org/10.1016/j.conbuildmat.2013.02.046

[6] Alani, A., MacMullen, J., Telik, O., Zhang, Z.Y. (2012). Investigation into the thermal performance of recycled glass screed for construction purposes. Construction and Building Materials, 29: 527-532. https://doi.org/10.1016/j.conbuildmat.2011.11.021

[7] Krishnamoorthy, R.R., Zujip, J.A. (2013). Thermal conductivity and microstructure of concrete using recycle glass as a fine aggregate replacement. International Journal of Emerging Technology and Advanced Engineering, 3(8): 463-471.

[8] Guo, M.Z., Chen, Z., Ling, T.C., Poon, C.S. (2015). Effects of recycled glass on properties of architectural mortar before and after exposure to elevated temperatures. Journal of Cleaner Production, 101: 158-164. https://doi.org/10.1016/j.jclepro.2015.04.016

[9] Seshadrisekhar, K., Chandramouli, P., Srinivasarao, P. (2009). Durability studies on glass fiber reinforced concrete. ARPN Journal of Engineering and Applied Sciences, 4(1): 56-62.

[10] Rahmani, T., Kiani, B., Sami, F., Fard, B.N., Farnam, Y., Shekarchizadeh, M. (2011). Durability of glass, polypropylene and steel fiber reinforced concrete. In Proceedings of the International Conference on Durability of Building Materials and Components, Porto, Portugal, pp. 12-15.

[11] Kumar, M., Sharma, E.S., Vikram, E. (2019). Improving properties of M30 grade of concrete by adding glass fibers. International Journal of Trend in Scientific Research and Development, 3(4): 1509-1513. https://doi.org/10.31142/ijtsrd19359

[12] Ozger, O.B., Girardi, F., Giannuzzi, G.M., Salomoni, V.A., Majorana, C.E., Fambri, L., Baldassino, N., Di Maggio, R. (2013). Effect of nylon fibres on mechanical and thermal properties of hardened concrete for energy storage systems. Materials & Design, 51: 989-997. https://doi.org/10.1016/j.matdes.2013.05.018

[13] Zhang, T., Zhang, Y., Zhu, H., Yan, Z. (2021). Experimental investigation and multi-level modeling of the effective thermal conductivity of hybrid micro-fiber reinforced cementitious composites at elevated temperatures. Composite Structures, 256: 112988. https://doi.org/10.1016/j.compstruct.2020.112988

[14] Iraqi Standard No. (5). (1984). Portland Cement. Central Organization for Standardization Quality Control, Baghdad. https://scholar.google.com/scholar?hl=en&q=+Iraqi+Standard+specifications+for+Portland+cement%2C+%28IQS%29+No.+5%2F1984%2C+Baghdad+%281984%29.

[15] Iraqi Standard No. 45. (1984). Rubble of Natural Resources Used in Concrete Construction. Central Agency for Standardization and Quality Control, Baghdad. https://scholar.google.com/scholar?hl=en&q=+Iraqi+St

andard+specification+for+aggregate+from+natural+sources+for+concrete+and+construction%2C+%28IQS%29+No.+45%2F1984%2C+Baghdad%2C+1984.

[16] BS 1881, part 116. (1989). Method of determination of compressive strength of concrete cubes. British Standards Institution. https://doi.org/10.3403/00049171U

[17] ASTM C78 / C78M-10. (2010). Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). ASTM International, West Conshohocken, PA. https://doi.org/10.1520/C0078_C0078M-21

[18] ASTM C496/C496M. (2011). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, 4(2). https://www.astm.org/c0496_c0496m-17.html.

[19] Marsh, H.N., Clarke, L.L. (1974). Glass fiber reinforced cement base materials. Special Publication, 44: 247-264. https://doi.org/10.14359/17898

[20] Nagy, B., Nehme, S.G., Szagri, D. (2015). Thermal properties and modeling of fiber reinforced concretes. Energy Procedia, 78: 2742-2747. https://doi.org/10.1016/j.egypro.2015.11.616

[21] Adaway, M., Wang, Y. (2015). Recycled glass as a partial replacement for fine aggregate in structural concrete–Effects on compressive strength. Electronic Journal of Structural Engineering, 14(1): 116-122. https://doi.org/10.56748/ejse.141951

[22] Malik, M.I., Bashir, M., Ahmad, S., Tariq, T., Chowdhary, U. (2013). Study of concrete involving use of waste glass as partial replacement of fine aggregates. IOSR Journal of Engineering (IOSRJEN), 3(7): 08-13. https://doi.org/10.9790/3021-03760813

[23] Mohamed, M.A., Moh, M.A., Akasha, N.W., Elgady, I.Y.I. (2016). Experimental study on effects of fiberglass and fiber waste in concrete mixes. International Journal of Engineering Science & Research Technology, 5(10): 485-493.

[24] Poutos, K.H., Nwaubani, S. (2013). Strength development of concrete made with recycled glass aggregates subjected to frost curing conditions. International Journal of Application or Innovation in Engineering & Management, 2(2): 19-28. https://repository.uwl.ac.uk/id/eprint/2673

[25] Shi, C., Wu, Y., Riefler, C., Wang, H. (2005). Characteristics and pozzolanic reactivity of glass powders. Cement and Concrete Research, 35(5): 987-993. https://doi.org/10.1016/j.cemconres.2004.05.015

[26] Ismail, Z.Z., Al-Hashmi, E.A. (2009). Recycling of waste glass as a partial replacement for fine aggregate in concrete. Waste Management, 29(2): 655-659. https://doi.org/10.1016/j.wasman.2008.08.012

[27] Abdallah, S., Fan, M. (2014). Characteristics of concrete with waste glass as fine aggregate replacement. International Journal of Engineering and Technical Research (IJETR), 2(6): 11-17.

[28] Krishnamoorthy, R.R., Zujip, J.A. (2013). Thermal conductivity and microstructure of concrete using recycle glass as a fine aggregate replacement. International Journal of Emerging Technology and Advanced Engineering, 3(8): 463-471.