Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Static and dynamic performance of different concrete mixtures for the protection of aircraft shelters

To cite this article: M Wagih *et al* 2023 *J. Phys.: Conf. Ser.* **2616** 012047

Static and dynamic performance of different concrete mixtures for the protection of aircraft shelters

M Wagih[1], I M Kamal[1,2], A E Soltan[1] and M A E M Ali[1]

[1] Department of Civil Engineering, Military Technical College, Cairo, Egypt
[2] Director of the Military Technical College, Cairo, Egypt

E-mail: eng.wagih91@gmail.com

Abstract. Concrete is the most significant construction material in the world. However, extreme static and dynamic loads placed on infrastructure in recent decades have led to structurally catastrophic disasters. In addition, recent weapons can significantly impact the safety of humans and infrastructures. Newly developed concrete shields are designed to protect against severe loading conditions such as impact loads. Therefore, due to the rapid progress in weapons production, such as projectiles and bombs, there is a critical need to protect aviation buildings and aircraft shelters from such destructive impacts. In this study, the static and dynamic performance of concrete shields produced by nationally available magnetite, hematite, graphite, steel fibers, and steel mesh constituents were evaluated. Test results showed that implementing graphite, hematite, and magnetite powder in concrete shelters' production slightly decreased the static behaviour of produced mixtures. On the other hand, superior impact resistance was achieved by incorporating steel fibers and steel mesh in aircraft concrete shields.

***Keywords*:** Aircraft Shelters; Concrete; Magnetite; Hematite; Impact Resistance.

1. Introduction

Concrete, deformed steel reinforcing bars (rebar), and pre-stressing strands have seen an extensive application as a building material. As a result of its durability and effectiveness against impact and dynamic loads, RC (concrete with steel rebar) has been widely used in protective structure building for decades [1]. Recent years, however, have seen an increase in the frequency with which civil constructions or buildings are subjected to high-load conditions like hits, explosions, and flames from a wide range of causes. The resilience of buildings against impact loading, detonation waves, and fragment penetration has been a hot area of study, particularly in the context of military and defense establishments. The limited energy absorption capacity and brittle nature of concrete, which leads to fragmentation, make standard reinforced (RC) and fiber reinforced concrete (FRC) constructions are adequate under sever loading conditions. Concrete enhanced with continuous textiles, discontinuous short fibers, steel mesh, etc., has been proposed by researchers as a way to address the shortcomings of conventional concrete when subjected to impacts and explosions. Important public buildings, military fortifications and airport shelters have been constructed using reinforced concrete shields [2].

Many researches had conducted experimentally and numerically on the impact resistance of different concretes [3,4]. Research into the impact resistance of steel, polypropylene, and cellulose FRC was conducted using tests developed by ACI committee 544 and the oscillating pendulum (Charpy type) test [5,6]. Researchers have favored the use of discontinuous fibers made from materials like steel, polymer, carbon, and basalt because of their many benefits, including (1) their simplicity to incorporate into concrete mixtures, (2) their efficiency in increasing the material's resistance to impact and blast through fiber bridging, and (3) their lower cost compared to alternative approaches [7]. Ali et al., (2017) summarized the static mechanical and dynamic qualities of engineered cementitious composites made from polyvinyl-alcohol fibers [3]. The previous work can be helpful to researchers and engineers interested in adopting FRCs for protective constructions under excessive loads. Alfayez et al., (2019) conducted a simple drop-weight impact instrumented test to evaluate the impact resistance of plain concrete, steel, and waste rubber FRC [8]. The fracture energy was doubled when steel fibers and waste rubber were used. Thus, steel fibers and mesh were utilized in reinforcing the proposed concrete mixtures in this study. Also, magnetite and hematite were the main replacement constituents for conventional aggregates used in this research. Since they are iron ore based in nature, magnetite and hematite were identified as the most magnetic of all naturally occurring minerals on Earth [9,10]. Magnetite and hematite are characterized by high density and crushing strength relative to traditional concrete aggregates.

In this study, the mechanical properties and dynamic performance of different concrete mixtures were investigated. The study aims at illustrating the effect of utilizing locally available concrete constituents such as graphite, magnetite, and hematite to fully replacing traditional constituents. The addition of steel fibers and steel mesh to various concrete mixes was also tested for impact resistance and tensile strength.

2. Experimental Work

2.1 Materials and Mixture Proportions

The proposed concrete mixtures were produced utilizing ordinary portland cement CEM 1 (52.5 N), following ASTM C150 standards [11]. Sand, dolomite, silica fume, magnetite aggregate, magnetite powder, hematite aggregate, hematite powder, graphite, steel fibers, and wire steel mesh were also utilized. In order to regulate the material's workability, a high-range water-reducing substance (superplasticizer) was included. The different concrete mixture proportions as a percentage of cement weight and abbreviation definitions are shown in table 1 and table 2, respectively. The properties of the used materials are listed and illustrated in table 3 and figure 1, respectively.

Table 1. Various concrete mixtures.

Mixture ID	OPC (Type I)	Silica fume	sand	Dolomite	Magnetite aggregate	Magnetite powder	Hematite aggregate	Hematite powder	W/C (ratio)	HRWRA	Graphite	Steel fiber (% V_f)	Steel mesh (layer)
NC	1	0.1	1	2	--	--	--	--	0.35	2%	--	--	--
MS	1	0.1	1	--	2	--	--	--	0.35	2%	--	--	--
MM	1	0.1	--	--	2	1	--	--	0.35	2%	--	--	--
HH	1	0.1	--	--	--	--	2	1	0.35	2%	--	--	--
MMG	1	0.1	--	--	2	1	--	--	0.35	2%	0.1	--	--
MMGS	1	0.1	--	--	2	1	--	--	0.35	2%	0.1	1	--
MMGSM	1	0.1	--	--	2	1	--	--	0.35	2%	0.1	1	1

Table 2. Abbreviation definitions.

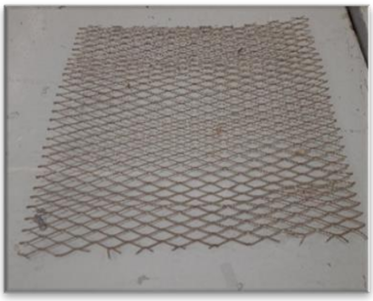
Abbreviation	Definition
NC	Normal concrete mixture contains sand and dolomite.
MS	A mixture containing sand and magnetite aggregate (full replacement of dolomite)
MM	A mixture containing magnetite aggregate (full replacement of dolomite) and magnetite powder (full replacement of sand)
HH	A mixture containing hematite aggregate and hematite powder
MMG	A mixture containing magnetite aggregate and magnetite powder with graphite addition
MMGS	A mixture containing magnetite aggregate and magnetite powder with graphite and steel fiber addition
MMGSM	A mixture containing magnetite aggregate and magnetite powder with graphite, steel fiber, and steel mesh addition

Table 3. Utilized material properties.

Material	Size	Specific gravity
Cement	50 µm	3.15
Silica Fume	0.1 µm	2.2
Magnetite Aggregate	Maximum nominal aggregate size of 20 mm.	5.2
Magnetite Powder	325 µm	5.2
Hematite Aggregate	Maximum nominal aggregate size of 20 mm.	5
Hematite Powder	Maximum particle size of 4.75 mm	5
Graphite	6.4 µm	2.26
Steel Fibers	A diameter of 0.8 mm and a length of 15 mm	7.8
Steel Mesh	A thickness of 1 mm, an opening with dimensions of 10 mm x 26 mm	7.8



(a) (b) (c)

(d) (e)

Figure 1. Concrete components; a) graphite, b) magnetite, c) hematite, d) steel fibers, and e) steel mesh.

2.2 Specimens Preparation, Casting, and Curing

The experimental work includes the preparation of 3 cubes of 100 mm x 100 mm x 100 mm, three cylindrical moulds of 100 mm x 200 mm, and a concrete slab with dimensions 400 mm x 400 mm x 100 mm for each proposed mixture, as shown in figure 2, in order to determine the different static and dynamic characteristics of the produced concrete mixtures.


Figure 2. Mixtures preparation and pouring.

Firstly, cement, silica fume, aggregates, and other ingredients were dry-mixed in a concrete mixer for three minutes without the addition of water or superplasticizer. Then, after three minutes of steadily adding the mixing water and superplasticizer to the dry ingredients, a uniform mixture was attained. Then, the steel fibers were added gradually to the wet constituents to obtain a uniform distribution of the steel fibers. The concrete mixture was then poured into the moulds. For the MMGSM mixture, the steel mesh was placed in the specimen during concrete pouring and placed at 2 cm from the bottom of the specimen. After 24 hours, the formwork was taken off, and the specimens were placed in clean water for curing, where they stayed for 28 days before being tested.

2.3 Test Procedures

2.3.1 *Compressive Properties*

Three cubic specimens from each concrete mixture were tested using a 2000 KN (ELE) compression testing machine at the age of 28 days to evaluate the compression properties for each mixture according to ASTM C39 standards.

2.3.2 *Indirect Tensile Strength*

Three cylindrical specimens from each concrete mixture were tested according to ASTM C496 standards at the age of 28 days using a 2000 KN (ELE) testing machine to determine the uniaxial tensile properties of each mixture, as shown in figure 3. By equation (1), the uniaxial tensile strength was calculated as follows:

$$T = \frac{2 * P}{\pi * l * d} \tag{1}$$

For this equation, T is the tensile strength in MPa, and P is the external force in N. In mm, the tested cylindrical specimen's length and diameter are *l* and *d*, respectively.

Figure 3. Indirect tensile strength test.

2.3.3 *Impact test*

Following the recommendations of ACI Committee 544 [5], the impact test was conducted on the various concrete panels (400 mm x 400 mm x 100 mm) at 28 days age, as presented in figure 4. The various concrete specimens were subjected to an impact load, with each strike capable of producing 67.95 J. This results from a 45 N steel mass dropping freely from a height of 151 mm. As crack propagation (N_1) and fracture (N_2) became visible, the number of drops that were created up to those points was recorded. Equation (2) was used to calculate the impact energy following ASTM D5628 rules as follows:

$$I = N_i * h * w * f \quad (2)$$

Where I is the impact energy in Joule, N_i is the number of hits, h is the height in millimeters, w is the weight of the steel ball in kg, and f is a constant of 9.806 x 10^{-3}.

Figure 4. Preparation of drop weight impact test.

3. Results and discussions

3.1 Compressive properties

After 28 days of curing, the concrete was tested for compressive strength to see how the various mixes performed. The designed compressive strength was 50 MPa. The obtained compressive strength ranged from 35 to 56 MPa, as illustrated in figure 5. Generally, the replacement of concrete constituents with various proposed materials in this study resulted in a reduction in compressive strength. For example, the compressive strength was decreased by about 10.27% and 19.67% for specimens MS and MM, respectively, compared to the NC sample. The reduction of compressive strength of the MS sample is attributed to the failure that takes place in the surrounding zone of magnetite aggregate; due to its superior crushing strength. Similarly, the further reduction in compressive strength of the MM sample is due to incorporating fine material (magnetite powder) in concrete production as a replacement of sand. The production of concrete samples with hematite aggregates reduced the compressive strength of the HH sample by about 22.42% compared to the MM sample. This is ascribed to the weaker crushing strength of hematite relative to magnetite aggregate. Furthermore, implementing more fines addition in concrete production (graphite) led to a further reduction in compressive strength. For example, the compressive strength of the MMG specimen was decreased by about 27.08% compared to the control specimen. On the other hand, a little to negligible improvement in the compressive strength occurred owing to steel fiber addition (MMGS) relative to the MMG specimen.

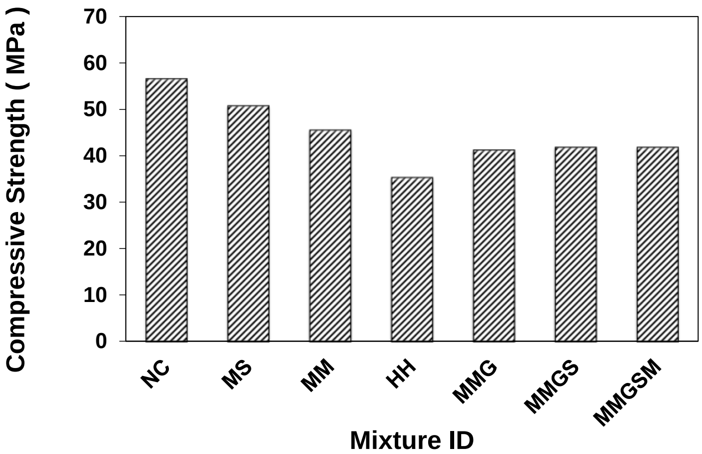


Figure 5. Compressive strength of various conductive concrete mixtures.

3.2 Splitting Tensile Properties

The splitting tensile properties of various concrete specimens measured after 28 days are shown in figure 6. The obtained tensile strength ranged from 3.1 to 7.2 MPa. Generally, the replacement of concrete constituents with magnetite and hematite, also graphite addition, resulted in a slight reduction in the splitting tensile strength. Conversely, upon implementing the steel fibers in concrete production, the tensile behaviour of the concrete mixtures was improved. Results showed that the mixtures MS, MM, HH, and MMG had a reduction in tensile strength by up to 14.89%, 18.71%, 32.22%, and 23.91% relative to the control mixture, respectively. This is attributed to incorporating fine materials (graphite, magnetite, and hematite powder) in concrete production as a replacement of sand. On the contrary, the inclusion of steel fibers in concrete manufacturing increased the tensile properties by up to 56.52% compared to NC concrete. This is explained by the enhanced fiber-matrix internal bonding that enhanced the tensile properties.

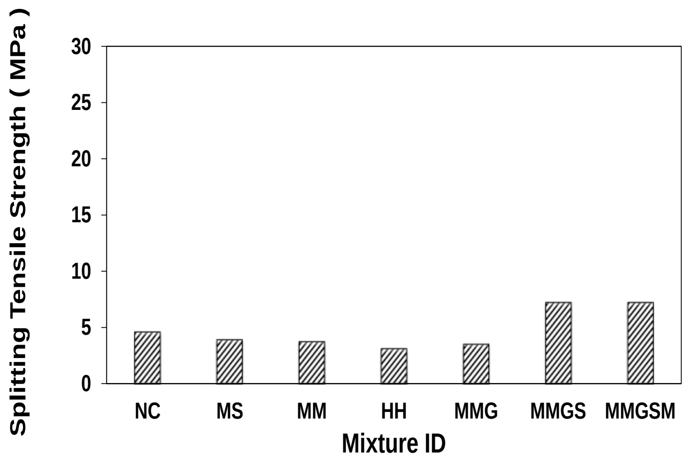


Figure 6. Splitting tensile strength of different conductive concrete specimens.

3.3 Impact Resistance

The drop weight impact test was used to evaluate the impact resistance of various concrete mixes. The impact resistance was calculated for every concrete slab up to the first crack and failure. Figure 7 and figure 8 show the acquired drop weight impact test results. As presented in figure 7, the sustained impact energy up to the first crack (I_1) of MS, MM, HH, and MMG panels was decreased by up to 7.14%, 14.29%, 28.57%, and 28.57% relative to the control mixture, respectively. Conversely, I_1 was generally enhanced owing to utilizing steel fibers and mesh in concrete reinforcing. For instance, I_1 of MMGS and MMGSM concrete slabs was increased by up to 185.80% and 250.05% compared to the NC slab.

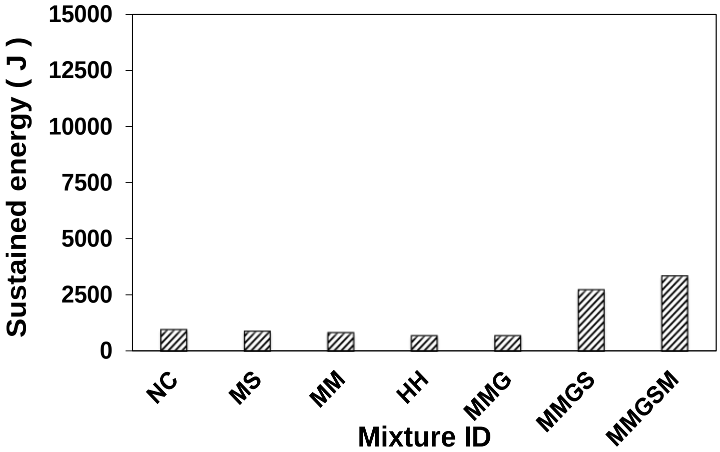


Figure 7. Sustained impact energy up to first crack I_1.

Similarly, as illustrated in figure 8, the sustained impact energy up to fracture (I_2) of MS, MM, HH, and MMG concrete shields decreased by up to 4.17%, 8.24%, 16.54%, and 20.78% compared to the NC concrete shield, respectively. This could be ascribed to incorporating fine materials (magnetite and hematite powder) as a replacement of sand and graphite addition in concrete manufacturing. Countering that, a superior value of I_2 was achieved due to the utilization of steel fibers and mesh in concrete reinforcing. For example, the I_2 value of MMGS and MMGSM concrete slabs was enhanced by up to 406.48% and 577.27%, respectively, compared to a conventional concrete slab. This could be ascribed to the enhanced ductile behaviour of such reinforced concrete slabs compared to the brittleness of fibreless concrete shields.

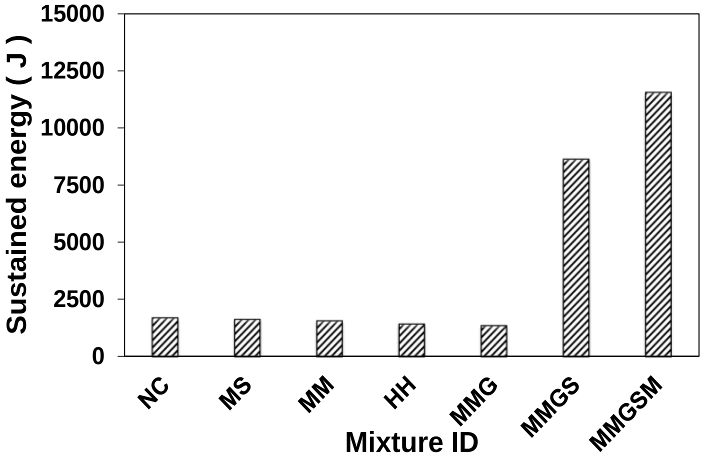


Figure 8. Sustained impact energy up to fracture I_2.

3.4 Failure Mode

The failure mechanism of different concrete slabs is demonstrated in figure 9. As shown in the figure, the fracture in the NC specimen is accompanied by a single crack, while a notable improvement occurs after utilizing steel fibers and then adding steel meshes to the concrete specimen. Due to the improved impact resistance made possible by the proposed concrete mixtures, repeated cracking was accomplished in MMGS and MMGSM slabs at the point of fracture.

Figure 9. The failure mechanism of different concrete slabs (NC, MMGS, and MMGSM).

4. Conclusion

In this research work, an experimental study was conducted to evaluate the static and dynamic performance of concrete mixtures, probably for shielding utilized in aircraft shelters. The following is a summary of the key results:

- The compressive strength of various concrete specimens containing magnetite powder and aggregate typically decreased in comparison to NC specimen.
- Incorporating hematite aggregates and powder into concrete resulted in significant reductions in both compressive and tensile strengths.
- The addition of graphite powder slightly reduced the static and dynamic properties of conductive concrete specimens.
- The tensile performance of designed concrete mixtures followed the same pattern as their compressive properties, but it was improved by including steel fibers in the concrete mixture.
- The dynamic properties of concrete specimens were significantly enhanced by adding steel fibers and wire mesh.
- The 1st crack impact resistance of concrete shields was double that of NC owing to the steel fibers addition, while it was four times its resistance up to fracture.
- Superior impact resistance was achieved due to implementing steel mesh in concrete panels. The 1st crack impact resistance of such panels was about triple its resistance relative to NC, while it was six times its resistance up to fracture.

Based on the aforementioned conclusions, future research will evaluate the shielding effectiveness of the aforementioned concrete shields under the effect of electromagnetic pulse under various frequencies.

References

[1] Vivas J C, Zerbino R, Torrijos M C and Giaccio G 2020 *Constr. Build. Mater.* **264** 120200

[2] Yoo D and Banthia N 2019 *Cem. Concr. Compos.* **104** 103389

[3] Ali M A E M, Soliman A M and Nehdi M L 2017 Hybrid- fi ber reinforced engineered cementitious composite under tensile and impact loading *JMADE* **117** 139–49

[4] Nehdi M L 2019 applied sciences Experimental and Numerical Study of Engineered Cementitious Composite with Strain Recovery under Impact Loading

[5] Shah S P, Wilson C K, Zellers R C, Zollo R F, Molloy H J and Pearlman S L 2009 Measurement of Properties of Fiber Reinforced Concrete **89** 1–11

[6] Specimens P 2015 Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics 1 1–17

[7] Info A 2021 Journal of Building Engineering Im pa ct re si st an ce of st ee l fi be r - re in fo rc ed se lf - co mp ac ti ng co nc re te (S CC) at hi gh st ra in ra te s **38**

[8] Alfayez S, Ali M A E M and Nehdi M L 2019 infrastructures Eco-E ffi cient Fiber-Reinforced Preplaced Recycled

[9] Guan B, Ding D, Wang L, Wu J and Xiong R The electromagnetic wave absorbing properties of cement-based composites using natural magnetite powders as absorber `

[10] Khairi M, Roslan A, Ismail M, Hong A, Rawi M and Zin M 2019 High-density concrete : Exploring Ferro boron effects in neutron and gamma radiation shielding *Constr. Build. Mater.* **215** 718–25

[11] Cement H and Apparatus A 2016 Standard Specification for 1–9