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Effect of sustainable/durable composite materials on dynamic performance of aircraft shelters.

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Effect of sustainable/ durable composite materials on dynamic performance of aircraft shelters.

M A Y Hafez[1], N M A Nagy[1], M Rashad[1], M A E M Ali[1]

[1] Civil Engineering Department, Military Technical College, Cairo, Egypt

E-mail: Eng.Mohahafez@gmail.com

Abstract. Aircraft shelter technology has been evolving over years along with the global technological revolution. They first appeared in the 20th century with the main purpose of protecting parked aircraft. Recently, they are considered a globally important topic in the aerospace field, especially for shielding military aircraft. On the other hand, the civil revolution nowadays is extremely unsustainable. The world is facing vital problems due to the massive consumption of non-renewable resources and pollution of the environment and atmosphere. Sustainability development is not an option anymore; it is the only choice to survive. Therefore, there is a demanding need to push the boundaries of sustainability and go through a green revolution by using Eco-friendly materials and searching for alternatives for non-renewable resources. In this study, sustainable composite materials that are probably used as impact shields in aircraft shelters that are cheaper than typical ones were studied. The applicability of utilizing silica fume and steel slag as partial and full replacements for non-renewable resources in the composite mixture was established. Fiberglass and steel meshes were also implemented as reinforcing elements. The performance enhancement of using such materials in composite mixtures was investigated. Results showed that utilizing silica fume and steel slag enhanced the compressive strength of sustainable composite mixtures by about 9.38%. Similarly, superior dynamic performance was achieved by approximately 800% using different reinforcement techniques.

Keywords: Aircraft Shelters; Composite Materials; Impact; Sustainability; Impact Resistance Test

Introduction

Constructing aircraft shelters is one of the most common technologies in the fortification field that developed over the years through vast testing techniques using various materials and structural systems [1]. Aircraft shelters first appeared in the late 20th to protect aircrafts against possible hostilities. The Cold War was the reason behind those types of shelters to emerge, especially for military airports [2]. For decades, many composite materials have been used in aircraft shelters industry whereas concrete was the most demanding material that could be used [3]. United States Air Force (USAF) established the first concrete aviation shelter followed by the North Atlantic Treaty Organization (NATO) concrete aviation shelters [2]. Concrete had made a great revolution in the construction industry, especially in the fortification field since it could be established in any shape and had enhanced mechanical properties [1]. Heavy and tough aggregates are more suitable to conduct concrete elements with impact resistance that could be used in establishing aircraft shelters [3].

On the other hand, the world is facing serious problems due to the irreparably damaging usage of raw materials and non-renewable resources in nature in addition to polluting the environment and atmosphere

[4]. Sustainability development has become a worldwide development model and the main terminology of international aid organizations [5]. However, concrete is considered the main consumer of non-renewable materials like aggregates and water, besides it includes cement which is the main source of greenhouse gas and CO_2 emissions [6]. There is a demanding need to adopt the concept of using new Eco-friendly materials that could be used as alternatives to concrete constituents [6,7]. Silica fume (SF) and steel slag (SS) are two of the most common types of by-products that could be used as cement and aggregate replacers, respectively [6]. SF is characterized by its fine and reactive particles that is used to enhance the mechanical properties and durability of concrete mixtures [6] while, SS is characterized by its dense and hard particles accompanied by sharp edges and tiny pores that is used to enhance the mechanical properties and workability of concrete mixtures in terms of impact, crushing and erosion resistance [8].

According to El-Sharara et al. [3], ilmenite and serpentine could be used in constructing concrete aircraft shelters as coarse and fine aggregate replacers but they are still more expensive materials and don't meet the requirements of sustainability. Additionally, Stillion and Orletsky [9], stated that typical aircraft shelters are considered a very expensive way to shield aircrafts since the cost of a shelter for a single aircraft in 1999 was about four million dollars without including the cost of utilized equipment and spare parts of aircrafts. In this research, the main aim was to conduct cheaper concrete aircraft shelters with impact resistance under the regulations and concepts of sustainability by utilizing Eco-friendly materials so the dynamic performance of sustainable concrete mixtures containing SF and SS with cheaper reinforcement techniques was illustrated.

Experimental work

2.1 Materials Specifications and quantities

The designed sustainable concrete mixtures were prepared using 42.5N graded Type I ordinary Portland cement (OPC) of a specific gravity of 371 kg/m^2, according to ASTM C150 standards [10]. Sika Fume® was used as a product of SF of a bulk density of 300 kg/m^3. According to ASTM C1240 [11], SF was used as a partial cement replacer with a percentage of 10% since the acceptable percent is up to 15% of cement weight. Additionally, traditional silica sand was used as fine aggregates, while SS with a diameter of not more than 20 mm was used as a full replacer for coarse aggregates to achieve the desired sustainable design. Furthermore, Sikament® N as a high-range water reducer admixture (HRWRA) with a percentage of 2% was used to reduce water content and improve the workability and surface finish of concrete panels. The utilized HRWRA was chosen based on ASTM C494 specifications [12]. Upper and lower reinforcement meshes were used as reinforcement tools for the designed sustainable concrete panels with welded steel and fiberglass. The utilized meshes were SM is a welded mesh of carbon galvanized steel of dimensions of 12 x 12 mm while, FG is an orange-colored fiberglass plaster mesh made of fiberglass yarn and a modified acrylate copolymer glue with dimensions of 12 x 12 mm. Table 1 shows the proportions of the designed concrete mixtures.

Table1. Quantities of used materials.

Mixture ID	OPC	Sand	W/cb	SF	SS	Dolomite	HRWRA
Normal Concrete (NC)	1.000	2.150	0.400	0.100	0.000	3.235	0.020
Steel Slag Concrete (SSC)	1.000	2.150	0.400	0.100	3.235	0.000	0.020
Steel Mesh Concrete (SM)	1.000	2.150	0.400	0.100	3.235	0.000	0.020
Fiberglass Concrete (FG)	1.000	2.150	0.400	0.100	3.235	0.000	0.020

2.2 Materials preparation, casting, and curing

Steel cubic molds of dimensions of 100 mm x 100 mm x 100 mm were utilized to prepare the desired concrete samples for compressive strength evaluation. First, the dry contents were mixed for one minute, and the HRWRA and water were blended in parallel. Then, the water was added to the dry mix and mixed together until achieving a homogenous mixture. Thereafter, the concrete was poured into the molds and compacted. After 24 hours, the cubes were ejected and submerged in clean and fresh water for curing and up to the testing ages of 7 and 28 days.

Likewise, concrete panels of dimensions of 400 mm x 400 mm x 100 mm were set from the different concrete (NC, SSC, SM, and FG) mixtures. The concrete samples were prepared as per the aforementioned steps as shown in figure 1. The steel and fiberglass meshes were placed as one layer on the upper and lower surfaces of concrete panels as shown in figure 2. After 24 hours, the panels were ejected and left in clean and fresh water for curing until the testing age of 28 days.

Figure 1. Preparation of different sustainable concrete panels.

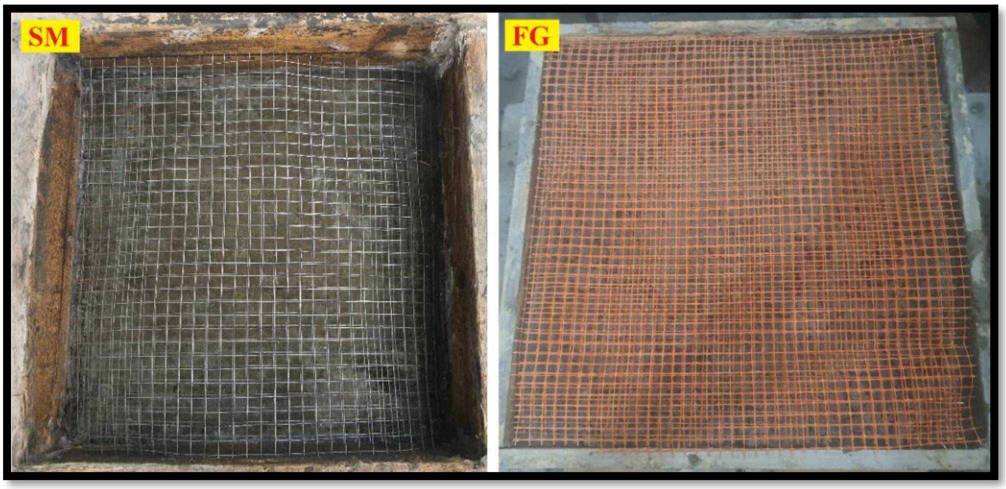

Figure 2. Utilizing SM and FG as reinforcement techniques.

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2.3 Tests methods

2.3.1 Compressive strength. The compressive strength test was performed using a compression-testing machine with a maximum loading of 2000 kN. Twenty-four cubic samples of dimensions of 100 mm x 100 mm x 100 mm as presented in figure 3 were set from the different concrete mixtures for compressive strength test at aging of 7 and 28 days according to ASTM C39 guidelines [13].

Figure 3. Compressive strength test setup.

2.3.2 Impact test. A drop-weight impact test was performed on various concrete (NC, SSC, FG, and SM) panels of dimensions of (400 mm x 400 mm x 100 mm) at 28 days according to the American Concrete Institute (ACI) Committee 544 [14]. A ball made of steel weighing 4.5 kg was used to free fall from 1600 mm height repeatedly causing an impact energy of 70.61 J per hit on each panel. The test apparatus is displayed in Fig. 4. As the dropping ball hit the surface of the panel, the number of hits was counted and recorded until the appearance of crack propagation (upper face and lower face first crack), followed by fracture [15]. The sustained impact energy was calculated using equation (1) according to ASTM D5628 guidelines [16]:

$$I = N_i . h . w . f \quad (1)$$

Where I represents the impact force energy in Joule, while N_i is the number of hits, h is the falling height in mm, w is the mass of the steel ball in kg, and f is a factor for conversion to joules that equals to 9.806 x 10^{-3}.

Figure 4. Drop weight impact testing.

Results and discussion

3.1 Compressive strength

The compressive strength was evaluated at maturity ages of 7 and 28 days for the different concrete mixtures. As shown in figure 5a and figure 5b, the compressive strength of NC was 27 and 38 MPa at 7 and 28 days, respectively. After implementation of SS as a full replacement for coarse aggregates, a minor enhancement of about 9.38% and 6.61% in the compressive strength occurred at 7 and 28 days, respectively. This could be attributed to the expected behavior of hard and dense material such as SS, which could generally enhance the mechanical properties of concrete mixtures. Similar observations were achieved elsewhere [8].

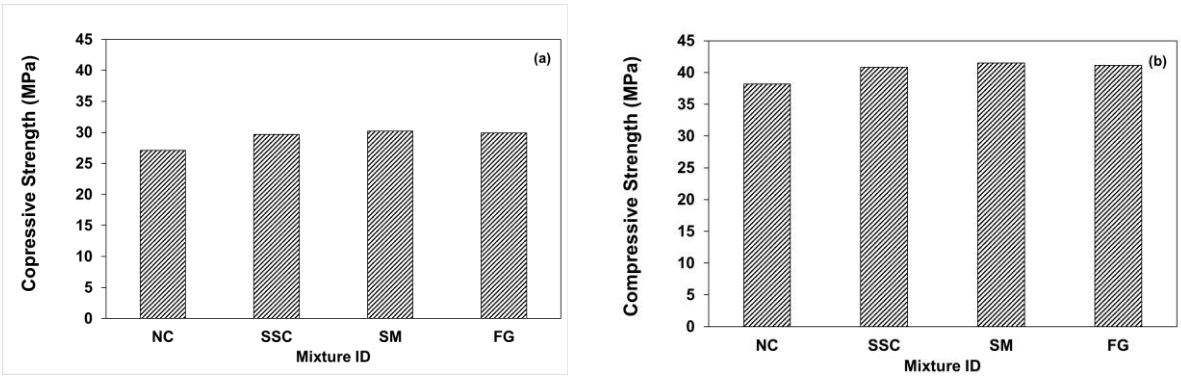

Figure 5. The compressive strength of different concrete samples at; a) 7 and b) 28 days.

3.2 Impact resistance

A drop weight impact test was conducted to determine the impact resistance of the designed sustainable concrete panels. The upper face impact diameter, sustained impact energy up to first crack at upper and lower faces, and fracture energy were illustrated. As shown in figure 6, the impact diameter was generally increased owing to implementing SSC, FG, and SM in concrete production compared to the control mixture, which reflects an enhanced resistance of such panels against impact load. As demonstrated in the figure, the SM reinforced sample recorded the largest impact diameter followed by FG and SSC panels, while the smallest impact diameter was recorded by NC sample.

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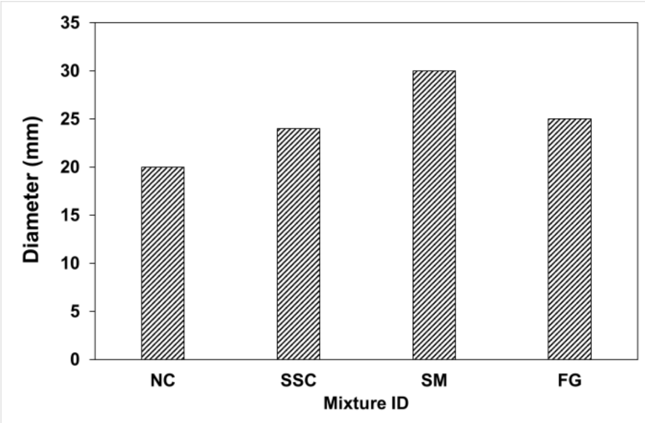

Figure 6. Upper face impact diameter of various concrete panels.

Figure 7a and figure 7b showed the sustained impact energy up to 1st crack at the upper and lower faces, respectively. The impact resistance is slightly increased, as a result of using SS as coarse aggregate replacer. A noticeable enhancement in the impact resistance of concrete panels was achieved owing to usage of steel and fiberglass meshes as reinforcement elements. A superior increase in the 1st crack impact resistance at the upper and lower faces of the panels by about 407.1% and 800% relative to NC sample, respectively, due to SM reinforcing of the panels. While, the FG panel achieved an enhancement in the 1st crack impact resistance at the upper and lower faces of the sample by about 300% and 600%, respectively, compared to the control panel.

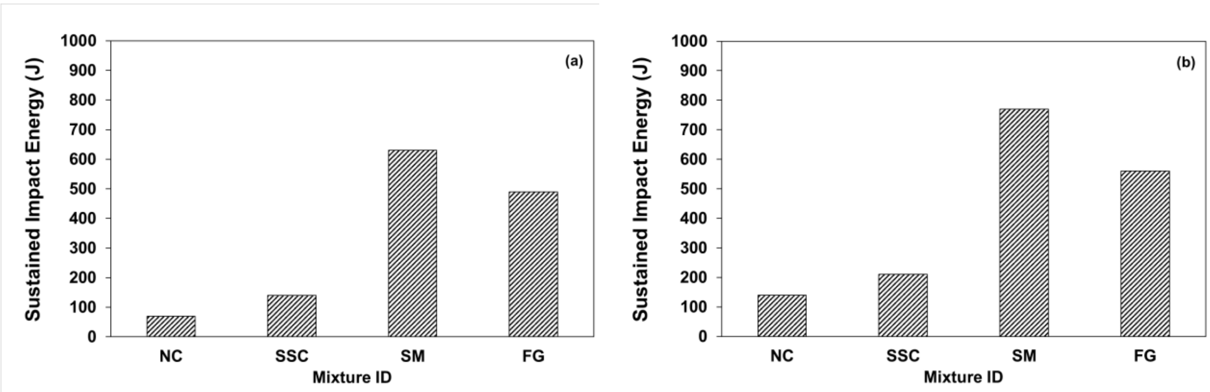

Figure 7. Sustained impact energy up to 1st crack on; a) upper face and b) lower face.

Similarly, figure 8 showed the sustained impact energy up to fracture. The impact resistance of SS panels was slightly increased by about 25.1% compared to that of NC panel owing to enhanced performance of concrete mixtures produced with SS aggregates. Likewise, the fracture impact resistance was generally increased due to panel's reinforcement. For instance, the sustained impact resistance of SM and FG panels up to fracture was enhanced by about 364.2% and 122.5% compared to that of NC control panel, respectively.

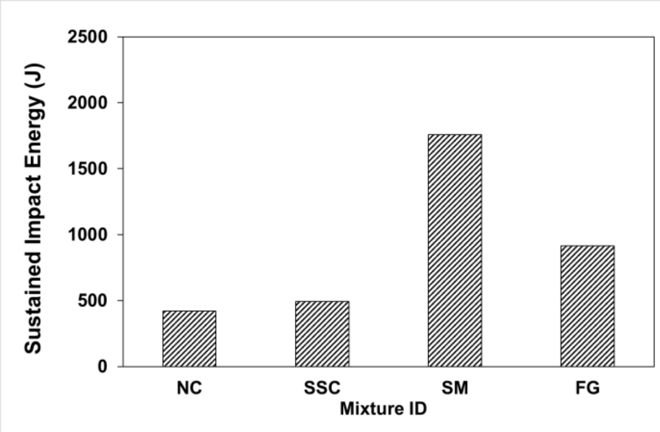

Figure 8. Sustained impact energy up to fracture of the various concrete panels.

On the other hand, figure 9 showed the failure mode of different concrete panels. Fracture occurs in NC with single crack while an obvious enhancement takes place after using SS as a full replacement for coarse aggregates, followed by incorporating steel or fiberglass meshes in concrete reinforcement. The single crack which observed in NC transferred to multiple cracking in all other reinforced panels. A multiple cracking was achieved in SSC, SM, and FG panels at fracture owing to enhanced impact resistance which achieved by the designed sustainable concrete mixtures.

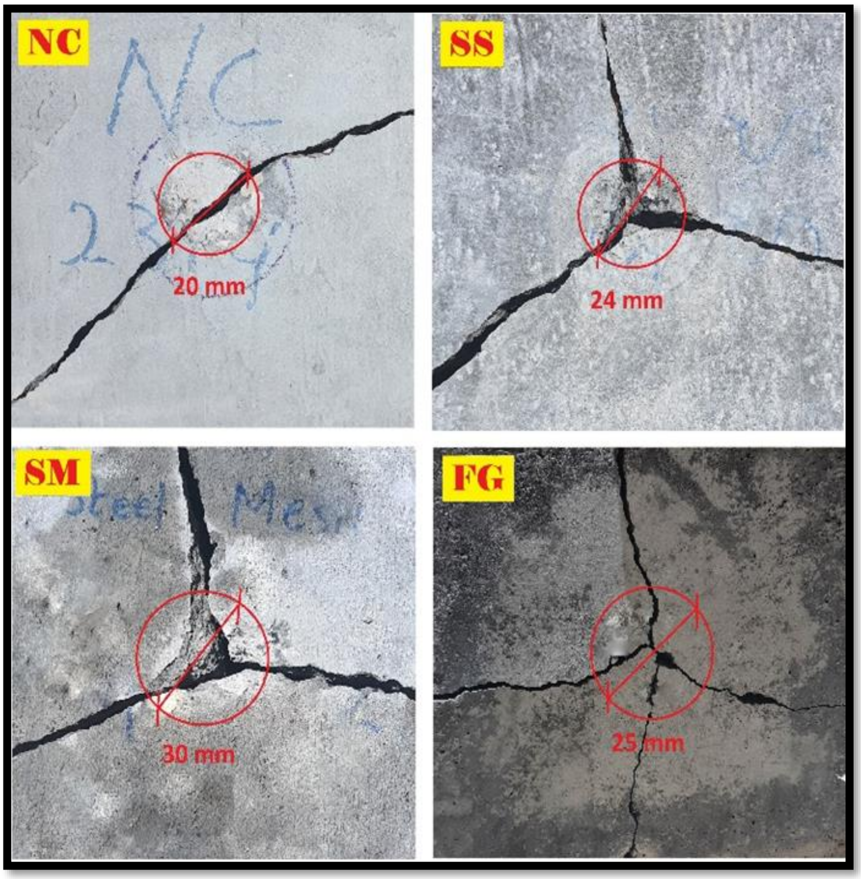

Figure 9. Failure mode of different concrete panels.

Summary and conclusion

In this research, an experimental investigation was performed to estimate the static and dynamic performance of sustainable/durable concrete mixtures with different reinforcement techniques that could be used in production of aircraft shelters. The main conclusions are summarized as follows:

- The utilized by-product SS enhanced the compressive strength by up to 9% of concrete mixtures and also established the concepts of sustainability by replacing conventional coarse aggregate in the mixture.
- SM and FG meshes are two effective reinforcement techniques that could be used in shielding of aircraft shelters since they enhanced the impact resistance of concrete mixtures.
- The impact diameter and failure mode were generally improved due to SM or FG reinforcement of concrete panels since they increased the coherence and strength of concrete panels.
- The sustained impact energy up to 1st crack at upper/lower faces and fracture was generally increased using SM or FG as reinforcement tools by up to 800% compared to non-reinforced concrete.
- Although a superior impact resistance was achieved using steel mesh reinforcement compared to that acquired by fiberglass reinforcement, however, the later has a superiority in presenting durable contender to traditional steel reinforcement.
- SS as a coarse aggregate replacer is considered a multi-functional material since it enhanced the mechanical properties of concrete mixtures besides being a waste and cheap material that meets the requirements of sustainability by reducing the depletion of dolomite in nature.

The static and dynamic performances of sustainable concrete mixtures with different reinforcement techniques opened the way for further research to examine the applicability of utilize different sustainable mixtures with various by-products and new reinforcement techniques in shielding of aircraft shelters.

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