Experimental Study of the Combined Effect of Aggregate and Steel Fibres on Penetration Resistance of Reinforced Concrete Panels

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Abstract

Concrete has been used as a construction material in defence applications such as command bunkers and hardened shelters to protect personnel and equipment against the penetration of missiles. Plenty of research work had been carried out in which it is considered that the presence of aggregates at the target impact face would enhance its penetration resistance. Consequently, it can be concluded that the most important ingredient in the concrete mix is aggregate, as it has the most pronounced effect on the compressive and shear strength of concrete. But, yet, the effect of the type and size of aggregate on the penetration resistance of target concrete have not been widely investigated. Also, concrete has high compressive strength compared to metals since it is a heterogeneous material that suffers certain limitations such as low tensile strength. The addition of steel fibres to concrete mix increases its tensile and bond strength and may be used to enhance the penetration resistance of concrete against missiles. Consequently, the parameters that have a direct effect on shear strength are the type and size of coarse aggregate, on the other hand, the use of steel fibers has proven to enhance the bond strength of concrete. The improvement of shear and bond strength of concrete would positively reflect in an enhanced impact and penetration resistance of concrete panels. These parameters cannot be investigated through numerical simulation and should be studied through parametric experimental study. Accordingly, in this paper, two stages sequential experimental program is planned and carried out to study the combined effect of these parameters on penetration resistance of concrete panels. The objective of stage (I) is to determine the type and maximum grain size of coarse aggregate that would improve the shear strength and penetration resistance of concrete panels. Based on the results obtained in stage (I), the identified aggregate type and size is used in concrete mixes used in stage (II). The objective of stage (II) is to study the influence of adding steel fibres on bond strength and penetration resistance of concrete panels. The results acquired from the experiments carried out lead to the conclusion that the use of properly sized coarse aggregates plays a significant role in absorbing part of the projectile's kinetic energy at the beginning of the penetration process. Incorporating steel fibres in concrete enhanced the mechanical properties of brittle cementations composites arise from load transfer from the brittle matrix to the fibres and the bridging effect of the fibres across cracks. Also, it reduced the front face damage that takes place in concrete as it increased the bond strength of concrete and reduced the crack propagation through the whole specimen so that damage becomes confined to a more localized volume.

Keywords

Penetration resistance; Aggregate type and size; Steel fibres; Concrete shear strength; Concrete bond strength.

1. Introduction

Concrete has been used as a construction material in defense applications such as command bunkers and hardened shelters to protect personnel and equipment against the penetration of missiles. A. kilic et al.[1] used five different aggregate types (gabbro, basalt, quartsite, limestone and sandstone) to examine the influence of aggregate type on the strength characteristics and abrasion resistance of high strength silica fume concrete. The results proved that the type of aggregate has an influence on the mechanical properties of concrete. Plenty of research work had been carried out [2,3,4] based on the suggestions that the presence of aggregates at the target impact face would enhance its penetration resistance. Dancygier and Yankelevsky [5] studied the effect of adding a layer of basalt aggregates, consisting of two different nominal aggregate sizes, 10 mm and 20 mm, respectively at the impact face. Consequently, it can be concluded that the most important ingredient in the concrete mix is aggregate, as it has the most pronounced effect on the strength of concrete. However, the penetration resistance of target concrete is greatly affected by the type and size of aggregate; such parameters have not been widely investigated.

Despite the high compressive strength of concrete compared to metals, it is a heterogeneous material that suffers certain limitations such as low tensile strength. Structural engineers have overcome this weakness through the use of reinforcing steel. This combination of concrete and steel serves to enhance the overall flexural strength of concrete. The addition of steel fibres to concrete mix increases its tensile strength and may be used to enhance the penetration resistance of concrete against missiles. Eduardo and Manuel [6] conducted an experimental research work that is oriented and executed to obtain a design method for steel fibre concrete barriers against small projectiles and debris. Mahmoud Nili, V. Afroughsabet [7] investigated the impact resistance and mechanical properties of steel fibre-reinforced concrete with water-cement ratios of 0.46 and 0.36, with and without the addition of silica fume. Hooked steel fibres with 60-mm length and an aspect ratio of 80, with three volume fractions of 0%, 0.5% and 1% were used as the reinforcing material. The results demonstrate that when steel fibres is introduced into the specimens including silica fume, the impact resistance and the ductility of the resulting concrete are considerably increased. S.T. Quek et al. [8] developed a functionally-graded (FG) cementitious panel consisting of PE-fibrous ferrocement, calcined bauxite aggregates and conventional mortar to resist high-velocity small projectile penetration. The results indicated that FG-panels have superior impact resistance compared to plain mortar targets in which all FG-panels remained intact. Y. Mohammadi et al. [9] studied the impact resistance of steel fibre reinforced concrete containing fibres of mixed aspect ratio. An experimental investigation was planned in which 108 plain concrete and SFRC beam specimens of size 100*100* 500 mm were tested under impact loading. It has been observed that concrete containing 100% long fibres at 2.0% volume fraction gave the best performance under impact loading. G. Ramakrishna and T. Sundararajan [10] investigated the resistance to impact loading of cement mortar slabs reinforced with four natural fibres and subjected to impact loading using a simple projectile test. Four different fibre contents (0.5%, 1.0%, 1.5% and 2.5%—by weight of cement) and three fibre lengths (20mm, 30mm and 40mm) were considered. The results obtained have shown that the addition of the above natural fibres has increased the impact resistance by 3–18 times than that of the reference (plain) mortar slab.

Based on the comprehensive literature it is found that, among the parameters that are expected to influence impact and penetration resistance of concrete panels are: shear and bond strength. The parameters that have a direct effect on shear strength are the type and size of coarse aggregate [11], on the other hand, the use of steel fibres has proven to enhance the bond strength of concrete. These parameters cannot be investigated through numerical simulation and should be studied through parametric experimental study. Accordingly, two stages sequential experimental program is planned and carried out to study the influence of these parameters on penetration resistance of concrete panels. The objective of stage (I) is to determine the type and maximum grain size of coarse aggregate that would improve the shear strength and penetration resistance of concrete panels. Based on the results obtained in stage (I), the identified aggregate type and size is used in concrete mixes used in stage (II). The objective of stage (II) is to study the influence of adding steel fibers on bond strength and penetration resistance of concrete panels.

2. Penetration Resistance Test Set up, Procedure and Data Collection

The Gas gun test rig shown in Figure (1) is used to carry out the penetration resistance tests for plain concrete specimens subjected to projectile impact. Aircraft 23 mm cannon (figure (2-a)is used to fire the projectile which is blunt-nose steel penetrator 23 mm diameter and 64 mm length as shown in Figure (2-b). Details on material properties of the penetrator can be found in [14]. The impact velocity was measured and recorded for every shot with calibrated electro-optical velocity measurement device connected with data acquisition-computer system as the average measured velocity was 980 m/s.

The specimens were mounted on a stationary steel frame placed in front of the gun at a distance of 50 m from the gun nuzzle where the concrete panel surface (550x550) was normal to the missile path. In order to satisfy simply supported boundary conditions and prevent the movement of the specimen backwards, the panels are mounted as shown in Figure (3-a). There is no special measures were taken to provide fully fixed boundary conditions, which has no effect on the penetration process due to the high velocity of missile. The parameters measured in this test include: penetration depth, front damage area, front crack diameter, rear damage area and rear crack diameter. The equivalent diameter of the damaged area (Deq) is calculated based on equation (1), [15]

$$D_{eq} = \sqrt{d_1 * d_2} \quad (1)$$

Where: (d1) and (d2) are the maximum and minimum values of measured damage diameter respectively as shown in Figure (3-b).

3. Concrete Panels Preparation

The concrete mixes are designed according to the Absolute Volume Method recommended by the (ACI) [12]. Standard procedures were followed to prepare, manufacture and test fresh and hardened concrete specimens to ensure that all concrete mixes have the same targeted mechanical properties: compressive strength (35 MPa after 28 days), splitting tensile strength (3MPa) in accordance with ASTM C496 and (3.6 MPa) flexural strength in accordance with ASTM C78. Details of concrete mix design, material selection and properties and concrete panels' preparation can be found in [13].

4. Experimental Program Stage (I)

The objective of this stage of the experimental program is to determine the type and the maximum grain size of coarse aggregate that develop relatively higher shear strength of plain concrete panels. Consequently, two types of coarse aggregate were assigned, (gravel and basalt). The gravel is a type of coarse aggregate that has a rounded shape, while basalt is that type that has sharp edges shape. Three gravel samples were used with different grain size (20, 40, and 60mm) identified as (G-20, G-40 and G-60) respectively, while one sample of basalt is used with 40mm grain size, identified as (BZ-40). The dimensions of plain concrete panels selected as (550 x 550 x 200 mm) to avoid the effect of concrete panels' ends during penetration test since the smallest dimension of panel should be greater than 20 times projectile diameter (23 mm) [16].

Four penetration tests were carried out during this stage to investigate the influence of each grain size of the two types of the coarse aggregate. Each specimen consists of two plain concrete panels set back to back to achieve a total thickness equal to 400 mms as shown in Figure (4). For each penetration test, three specimens are prepared and tested to average the measured test parameters.

4.1 Test Results of Stage (I)

The measured parameters: the penetration depth, the maximum and minimum values of damage diameter for front and rear faces are illustrated in Table (1). The equivalent diameter and the relative percentages are calculated and listed as well. Figure (5) shows the experiments of different specimens of stage (I).

The initial condition for projectile velocity used in numerical simulation in all analytical tests is equal to 980 m/sec, directed in the negative Z direction as shown in Fig. 3(a).

5. Experimental Program Stage (II)

Based on the results obtained in stage (I), the concrete mix, used in stage (II), is manufactured using coarse aggregate of maximum grain size equal to 60mm as it proves to relatively improve the penetration resistance for the assigned projectile. Based on the objectives of the current research, stage (II) is planned and carried out to investigate the influence of adding steel fibres to concrete mix to enhance the bond strength. The fibres used are steel fibres obtained by cutting steel wire meshes commercially known as 1538 provided by METAL-X Company and shown in Figure (6). These fibres are added to the specimens as a volume fraction of the whole specimen. Four different levels of steel fibres (0.5%, 1%, 1.5% & 2%) are mixed with the concrete ingredients identified as (SF-1, SF-2, SF-3 & SF-4) respectively. Four penetration tests were carried out during this stage of the experimental program. The specimen assigned for each penetration test is two concrete panels (550 x 550 x 200 mm) as shown in Figure (4). For each penetration test, three specimens are prepared and tested to average the measured test parameters.

5.1 Test Results of Stage (II)

The measured parameters: the penetration depth, the maximum and minimum values of damage diameter for front and rear faces and cracks in both faces are illustrated in Table (2). The equivalent crack and damage diameter and the relative percentages are calculated and listed as well. Figure (7) shows the experiments of different specimens of stage (II).

Conclusions and Discussion

Table (1) illustrates the results of parametric study carried out in stage (I), for the same grain size of gravel and basalt (40mm), the gravel has proved to have relatively favorable influence in penetration resistance over basalt type. Increasing the grain size of gravel from 20mm to 40 mm and then to 60 mm, improved the penetration resistance as it reduced the penetration depth from 40 cm to 20 cm as shown in Figure (8). This indicates that the use of properly sized coarse aggregates plays a significant role in absorbing part of the projectiles kinetic energy at the beginning of the penetration process.

Table (2) illustrates the results of parametric study carried out in stage (II). However, the use of steel fibers does not affect the penetration resistance; it is significantly influences the mechanical properties of concrete. The effectiveness of incorporating fibers in terms of enhancing the mechanical properties of brittle cementations composites arises from load transfer from the brittle matrix to the fibers and the bridging effect of the fibers across cracks propagating in the matrix. Steel fibers used in concrete reduced the front face damage that takes place in concrete as it increased the tensile strength of concrete and reduced the crack propagation through the whole specimen so that damage becomes confined to a more localized volume. The front face damage was reduced significantly from 66.74 cm, for fiber content of 0.5%, to 35.35 cm, for fiber content of 2%, resulting in a reduction of 52.8% in the front face damage diameter. Also, the crack diameter decreased from 65.1 cm for fiber content of 0.5% to 37.08 cm for fiber content of 2% resulting in a reduction of 43% of the front crack diameter. The use of steel fibers increased the tensile and bond strength of concrete and reduced the crack propagation so the crack diameter reduced significantly as the percentage of fiber increased.

References

[1] A. Kılıc et al., 'The influence of aggregate type on the strength and abrasion resistance of high strength concrete', Cement & Concrete Composites 2008;30,p. 290–296.
[2] Zhang MH, Shim VPW, Lu G, Chew CW, 'Resistance of high-strength concrete to projectile impact', International Journal of Impact Engineering 2005;31(7),p.825-841.
[3] Anderson WF, Watson AJ, Kaminskyj AE, 'The resistance of SIFCON to high velocity impact'. Proceeding of the Second International Conference on Structures under Shock and Impact, Portsmouth (U.K.); 1992, p. 89-98.
[4] Maalej M, Quek ST, Zhang J, 'Behaviour of hybrid-fiber engineered cementitious composites subjected to dynamic tensile loading and projectile impact', ASCE Journal of Material Civil Eng 2005;17(2),p.143-152.
[5] Dancygier AN, Yankelevsky DZ, 'Effects of reinforced concrete properties on resistance to hard projectile impact', ACI Structural Journal 1999;96(2),p.259-269.
[6] Eduardo Moreno Almansa, Manuel Fernandez Canovas, 'Behaviour of normal and steel fiber-reinforced concrete under impact of small projectiles', Cement and Concrete Research 1999;29, p.1807–1814.
[7] Mahmoud Nili , V. Afroughsabet, 'Combined effect of silica fume and steel fibers on the impact resistance and mechanical properties of concrete', International Journal of Impact Engineering ,2010; 37,p.879-886.
[8] S.T. Quek , V.W.J. Lin , M. Maalej, 'Development of functionally-graded cementitious panel against high-velocity small projectile impact', International Journal of Impact Engineering,2010; 37, p. 928-941.
[9] Y. Mohammadi , R. Carkon-Azad , S.P. Singh , S.K. Kaushik , 'Impact resistance of steel fibrous concrete containing fibres of mixed aspect ratio', Construction and Building Materials,2009; 23,p. 183–189.ACI committee 549, "State-of-the-Art Report on Ferrocement", American Concrete Institute, Technical Report no. 549R-97, 1997.
[10] G. Ramakrishna , T. Sundararajan, 'Impact strength of a few natural fibre reinforced cement mortar slabs', Cement & Concrete Composites,2005; 27,p. 547–553.
[11] S.T. Quek a, V.W.J.L.a., M. Maalej, 'Development of functionally-graded cementitious panel against high-velocity small projectile impact'. International Journal of Impact Engineering, 2010. 37: p. 928-941.
[12] Technical committee 211.1, A.C.I., 'Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete', Manual of Concrete Practice, ACI, 2002. ACI 211.1-91.
[13] A. K. Taha, 'Using of Ferrocement Technology to Resist Penetration', M. Sc. Thesis, Military Technical College, Cairo, Egypt, 2013.
[14] Mamdouh E. Mohamed et. al. 'Experimental Analysis of Reinforced Concrete Panels Penetration Resistance', 13th International Conference on aerospace sciences and aviation technology Military Technical College, Cairo, Egypt, 2009.
[15] Avraham N. Dancygier et. al. 'Response of high performance concrete plates to impact of non-deforming projectiles', International Journal of Impact Engineering,2007. 34: p. 1768–1779.
[16] Fouda, A.A., 'Increasing Fortifying Ability for Fortifications and Command Centres to Resist Penetration of Missiles'. Engineer Corps of Egyptian Armed Forces- Department of Military Engineers, Technical Report No. (211307), 2004.

Table (1): Penetration test results for stage (I)

NO	Specimen	Penetration depth (X)		Damage Dim. (front face) (cm)				Damage Dim. (rear face) (cm)			
		cm	%	d_1	d_2	D_{eq}	%	d_1	d_2	D_{eq}	%
1	BZ	40	100	77	65	70.74	90.9	77	60	68	87.4
2	G-20	40	100	77	77	77	100	25	40	31.6	40.6
3	G-40	34	85	77	77	77	100	5	3	3.87	5
4	G-60	20	50	77	77	77	100	-	-	-	0

Table (2): Penetration test results for stage (II)

NO	Specimen	Penetration depth (X)		Damage Dim. (front face) (cm)				Crack Dim. (front face) (cm)			
		cm	%	d1	d2	Deq	%	d1	d2	Deq	%
1	SF-1	20	100	77	35	51.91	66.74	77	55	65.1	83.7
2	SF-2	20	100	70	26	42.66	54.85	70	45	56.12	72.15
3	SF-3	20	100	50	30	38.73	49.79	60	30	42.43	54.55
4	SF-4	20	100	40	15	24.49	31.49	55	25	37.08	47.67

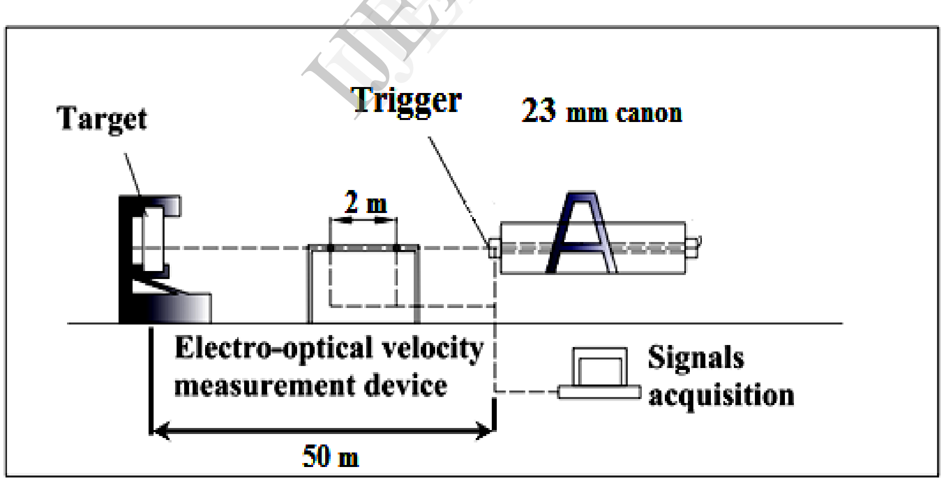


Figure (1): The Gas gun test rig.

Figure (2-a): Aircraft 23 mm cannon

Figure (2-b): The 23 mm API Missile.

Figure (3-a): Steel mounting frame.

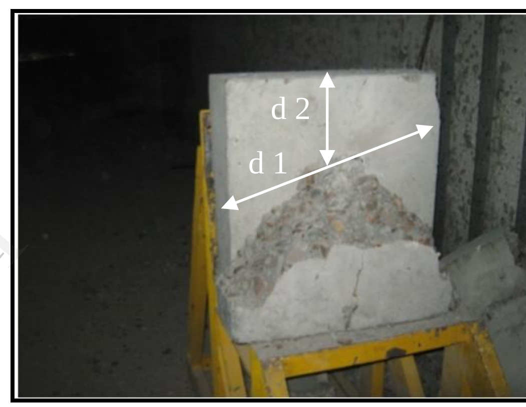


Figure (3-b): maximum and minimum damage diameters.

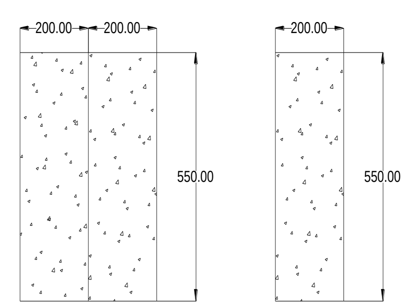


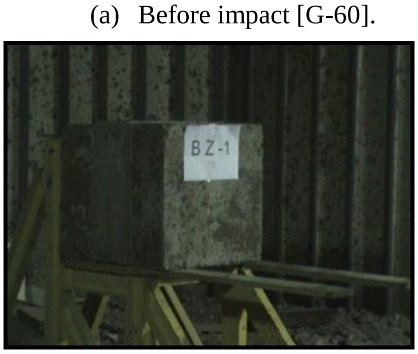
Figure (4): Dimensions of concrete panels.

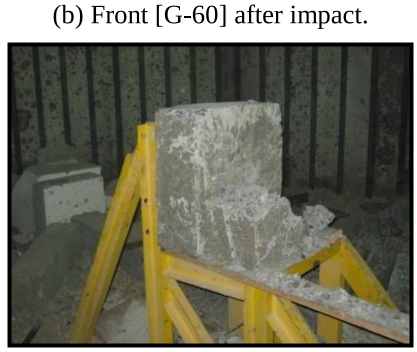


(a) Before impact [G-20]. (b) Front [G-20] after impact. (c) Rear [G-20] after impact.


(a) Before impact [G-40]. (b) Front [G-40] after impact. (c) Rear [G-40] after impact.


(a) Before impact [G-60]. (b) Front [G-60] after impact. (c) Rear [G-60] after impact.






(a) Before impact [BZ]. (b) Front [BZ] after impact. (c) Rear [BZ] after impact.

Figure (5): Experiments of different specimens of stage (I).

Figure (6): Steel Fibres used in Experiments of Stage (II).

(a) Before impact [SF-1]

(b) After impact [SF-1]

(c) Before impact [SF-2]

(d) After impact [SF-2]

Figure (7): Experiments for different specimens of stage (II).

(e) Before impact [SF-3]

(f) After impact [SF-3]

(g) Before impact [SF-4]

(h) After impact [SF-4]

Figure (7): Experiments for different specimens of stage (II) (cont.).

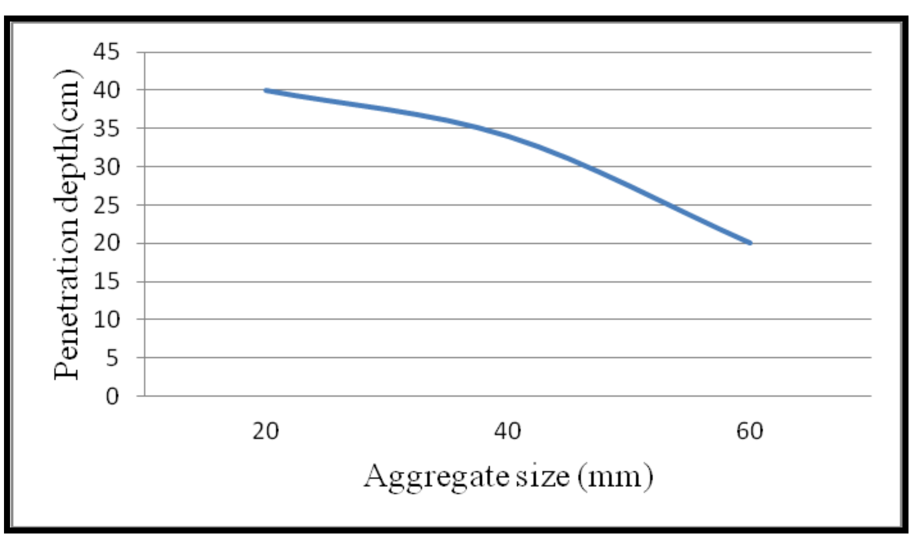


Figure (8): Penetration depth against coarse aggregate grain size.