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EXPERIMENTAL STUDY OF HEAVY CONCRETE BEHAVIOR UNDER FREE-AIR BLAST AND SURFACE

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ABSTRACT

In designing defensive structures, often dynamic loadings such as blast and impact is taken into account. With the progress of technologies of ballistic shield, preparing materials with the ability to withstand dynamic loads is considered by many scholars. For this ability, the concrete has a vast usage as an effective material. The present research, toward this end, will exhibit experimental and analytical processes of heavy concrete (high density) blast resistance and improving its behavior against the explosion, compared to conventional concretes. The research is conducted through 3 stages: 1- Final mixing plans are, presented and after sampling, testing physical and mechanical properties, according to BS and ASTM standards, of cubic specimens with a size of 15 cm by15 cm and cylindrical specimens with a size of 15 cm by 30 cm is done and results are given 2- in order to study the explosive resistance, specimens sizing 50×50×10cm were prepared and after preparing the conditions of field test using TNT explosive, placing the explosive at 0, 10 and 20 cm distances, an explosion was performed on the pieces. 3- conclusion: after experimental studies, it was found that special heavy concrete for this research has better performance compared with conventional concrete.

Keywords: dynamic loadings, heavy concrete, explosion, physical and mechanical properties, explosive resistance

The attacks which lead to an explosion can cause breakdowns and damage to structures and infrastructures and, on the other hand, may threaten many lives. To reduce the effects of explosive loads, we can use modern methods of engineering like creating protection shields. Some of these cases are: using concrete foundation slabs reinforced with FRP (Antoniades et al., 2007; Gee-Joo et al., 2007). or using new materials such as high performance fibrous concrete and heavy concrete.

In recent years, highly important studies have been performed in this field, often on conventional concretes. Among these studies, one can point to the tests performed on reinforced concrete (RC) by Mays (1999) and also the test on steel fibers reinforced concrete by Lok (1999) under the explosion loads. Mosalam, using an analytical model, studies RC slabs sizing 2.64×2.64×0.76 m via FRP carbon fiber with a width of 0.46 m and a thickness of 0584 mm, on the tension surface, in two directions under blast loading (Mosalam and Mosallam, 2001; Mosallam et al., 2009). Wu et.al studied the explosion test on high performance fibrous concrete slabs and FRP carbon fibers reinforced slab, and assessed the results using compressive measurement sensors and displacement (Wu et al., 2009). Wang W, et al assessed the laboratory procedure, measuring the effect on explosive resistance in unilateral slabs of RC using square concrete slabs (Wang et al., 2012). Khalid Mosalam performed a nonlinear transient analysis of bilateral reinforced concrete slabs reinforced with CFRP under the explosive loading, via finite element method (Khalid et al., 2001). Morishitaet.al performed contact detonation tests on concrete slabs using Pentolite explosive; in this test, the effect of the compressive strength of concrete and the rate of strength, using reinforced bars, was investigated (Morishita et al., 2004; Morishita et al., 2000). Luiccino (2006) , in a laboratory study, examined the numerical simulation of distanced air explosion test on concrete pavement sizing 3×1.5×0.15 m, compared in the plastic range and numerical simulation with two different codes (Bibiana et al., 2006). M Zineddin used 3 types of RC

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slabs sizing 90×152×3353mm to study their behavior and dynamic response under the impact loading (Zineddin and Krauthammer., 2007). Ohkubo et.al, in an experimental study, concluded that the compressive strength of concrete and the interval of reinforcement, in preventing the concrete slabs from local damage and failure resulting from explosion, is not effective To resolve this problem, aramid and carbon fibrous reinforcement effect was examined which was very useful in finding a solution to this shortcoming (Ohkubo et al., 2008). M.Beppuet.al, through an experimental process and via numerical simulation, studied the local damage on concrete panels using impacts resulting from rigid projectiles by high velocity. In this research, disruptive behavior based on recorded images of cameras with high frame rates and strain gauge with the strain sensor deployment on concrete panel was examined (Beppu et al., 2008). Richard, in a laboratory study, investigated the impact effect on sandwich beams comprising two layers of steel on top and bottom and a lightweight concrete core (SCS); in order to predict the force Chutes ratio in the cross section of sandwich beam from an elastic – plastic analysis was used (Richard et a;., 2009). Wang, Konietzky and Huang (2009) performed a blast holes elastic-elastic-hydrodynamic analysis in fibrous RC; for this research, he used the material model of MAT-Elastic-Plastic-Hydro in LS-DYNA software and the nonlinear behavior model of damage-softening of effective stress curve and plastic strain (Wang et al., 2009). Coughlin et.al, in a laboratory research, performed a computer simulation of protective wall behavior made of concrete fibers and subjected to explosive tangential. They tested 2 types of FRC composed of 4 fibrous concrete walls and two types of FRCs steel fibers with different values against the vehicle carrying explosives in Air Force laboratory, Florida (Coughlin et al., 2010).

According to estimates, no study has been done on the explosive strength of heavy concrete; yet, Yu-Cheng Kan et. al, in a laboratory study, studied the strength and fracture toughness of heavy concrete including different steel aggregates based on ASTM standard and rupture properties provided by Karihaloo and Nallathamb(RILEM Report 5, Fracture Mechanics Test Methods for Concrete, 1991) (Kan et al., 2004). In case of physical and mechanical properties and attenuating properties of heavy concrete, one can point to Yoshihiro Asano's researches in the field of heavy concrete's effects on Photo neurons in two domains of 3 and 8 Gev (Yoshihiro, 2011). Kaplan has conducted extensive researches, up to 1989, on different types of nuclear radiation shielding concretes, and heavy and juicy aggregate, and in this regard, he presented different features and their applications (Kaplan, 1989). This research, is an analytical laboratory process from physical, mechanical properties and also, heavy concrete explosive strength, where the objective is to compare the physical and mechanical properties of ordinary and heavy concrete and to study the strength of heavy concrete in comparison with the ordinary concrete and also the effect of density on anti-explosion property of concrete. To perform this test, we used concrete pieces sizing 50×50×10cm in non-reinforced mood and we tried to make experimental conditions close to real conditions. According to a set of similar parameters, heavy concrete and conventional concrete were designed, so that there will be one dominant rule when comparing their general properties.

STUDY OF MATERIALS AND GENERAL DESCRIPTION OF TESTS OF MECHANICAL PROPERTIES

Introduction of Materials for Making Concrete Specimens

Materials for making conventional and heavy concrete are as follows:

1- Heavy aggregates of iron ore with a nominal size ranging from 0 to 0.475 mm as fine and 12.5-4.75 and 30-12.5 mm as coarse and 2- typical aggregates ranging from 0 to 0.475 mm as sand and ranging from 4.75 to 9.5 mm of fine sand and 19-9.5 mm nominal size range as coarse sand 3-Concrete Additives Inorganic Chemistry 121 The pozzolanic properties (gel Micro silica) 4- Water 6- Super Lubricants

Method of Manufacturing and Testing Prototypes of Concrete

To determine the mixing concrete, the specific volume method was used. This method is suggested, especially, for determining the ratios of heavy concrete mixtures. Also, in mixed plans considered as an alternative for materials with different densities, this method is more suitable. To this end, equation 1 was used for determining the material mixing ratio:

$$\frac{CA}{\rho_{CA}}+\frac{FA}{\rho_{FA}}+\frac{C}{\rho_{C}}+\frac{SF}{\rho_{SF}}+\frac{SP}{\rho_{SP}}+W+a=100($$

In the above formula, a, W

For the concrete mix design, the following values have been considered as standard:

1- Minimum characteristic compressive strength based on standard samples 250kg/cm^2.
2- At least a 35 cm slump.
3- Maximum water-cement ratio set at 0.6.
4- Minimum Density of conventional and heavy concrete to improve conditions as follows: 2200kg/m^3 and 3200kg/m^3, respectively.

To determine the required average compressive strength, as a standard for determining concrete mixing ratios, the U.S. Concrete Regulation (ACI Committee 211, 2002) was used:

$f_{cm}=f_c+95$

$f_{cm}=$ 250+95= 345 kg/cm^2

f_c is the characteristic compressive strength and f_{cm} is the required compressive strength.

Then, the average compressive strength, based on standard cylindrical specimens and cubic specimens sizing 15×15 cm was 345 kg/cm^3 and 405 kg/cm^3, respectively.

Manufacturing Methodology of Final Concrete Samples

In order to manufacture the final specimens, five types of concrete mixture were used (table 1) including conventional and heavy concretes.

Table 1. Heavy and conventional concrete's final mixture plan (amounts are in kg/m^3)

Row	specimen code	cement	total water	gravel	sand	micro silica Gel	super lubricant	Theoretic density
1	NC-350-4	364.4	164.5	760	577.6	−−−	−−−	2375
2	NC-350-6	350	154	724	690	24.92	2.49	2376
3	HC350-4	350	184.45	1225	1290	−−−	---	3704
4	HC350-6	350	168.5	1400	1225	−−−	2.44	3795
5	HC350-8	360	156.28	1437.5	1263	26.6	2.25	3831

Manufacturing Methodology of Concrete Final Specimen

Based on ASTM C637 and ASTM C33, the density and absorption of the aggregates water in saturated mood, with dry surface for fine and coarse aggregates, using experimental methods of ASTM C128, ASTM C127 and uncompressed and compressed dry density tests with standard beams were performed based on ASTM C29 standard. The results are shown in table 2.

Table 2. *Density and water absorption and Specific gravity (density) of fine and coarse aggregates*

Aggregate's nominal size(mm)	**0−4.75**	**4.75−19**
Aggregate's density	5.23	5.12
Water absorption of aggregates	3.64	0.74

Uncompressed specific gravity kg/m^3	2815	2675
Specific weight of the bar kg/m^3	3343	2715

Aggregation of Iron Ore

Based on the ASTM C637 standard which defines the standard properties for aggregates used in heavy concretes, fine and coarse aggregation must be done according to certain restrictions given in the technical properties of ASTM C33. Grain aggregates using standard sieves were done in accordance with ASTM C 136. The results of heavy aggregate aggregation are shown in figures 1 and 2.

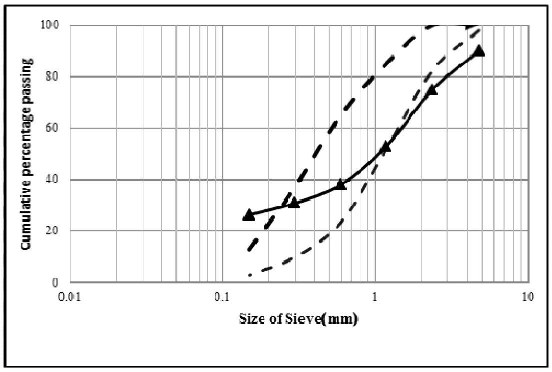


Figure 2. aggregation of fine ore graph according to ASTM

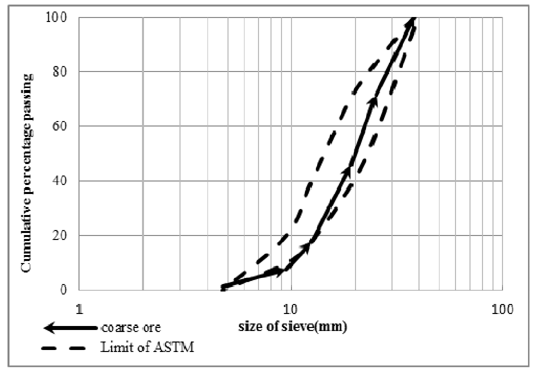


Figure 1. aggregation of coarse ore graph according to ASTM

Density, Water Absorption, and Final Specific Gravity (density) of Typical Aggregates

General descriptions including density, water absorption, and final specific gravity (density) of typical aggregates after aggregation modification are presented in table 3.

Table 3. Density, water absorption, and final specific gravity (density) of typical aggregates

Aggregate's nominal size(mm)	**0−4.75**	**4.75−19**
Aggregate's density	2.63	2.76
Water absorption of aggregates	0.366	4.97
Uncompressed specific gravity kg/m^3	1629	1438
Specific weight of the bar kg/m^3	1768	1629

Aggregation of Typical Aggregates

Coarse aggregate gradation and a heavy fine in Figures 3 and 4 are shown.

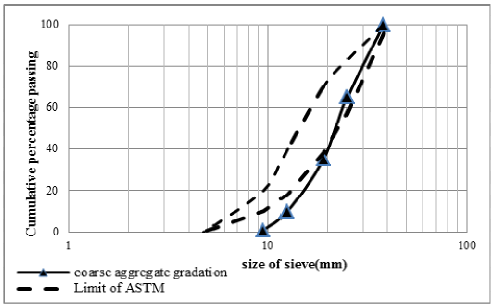


Figure 4. A typical gravel gradation chart based on ASTM standard

Results of Experiments to Determine the Mechanical Properties of Concrete

To investigate the mechanical and physical properties of final concretes including conventional and heavy concretes, some physical properties tests were conducted comprising of: experiments to determine the density and tensile strength and compressive strength, elastic modulus, and water absorption.

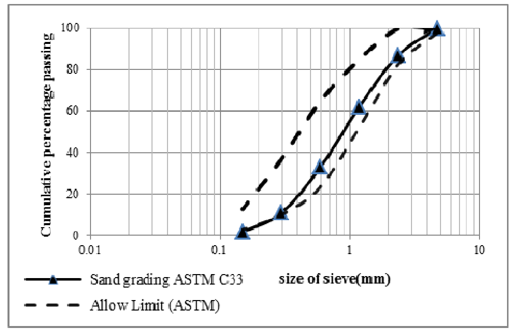


Figure 3. A typical sand gradation chart based on ASTM standard

Results of Experiments to Determine the Density of Concrete

To determine the density of a 28 days hardened concrete, Archimedes balance was used. The saturation density values with dry surface for the concretes are presented in table 4 and figure 5.

Table 4. Density of hardened concrete test results

Row	specimen code	Specific gravity of Mode (SSD) Kg/m^3	ratio of concrete density to typical concrete without additives
1	NC-350-4	2375	1
2	NC-350-6	2376	1.008
3	HC350-4	3704	1.571
4	HC350-6	3795	1.62
5	HC350-8	3831	1.625

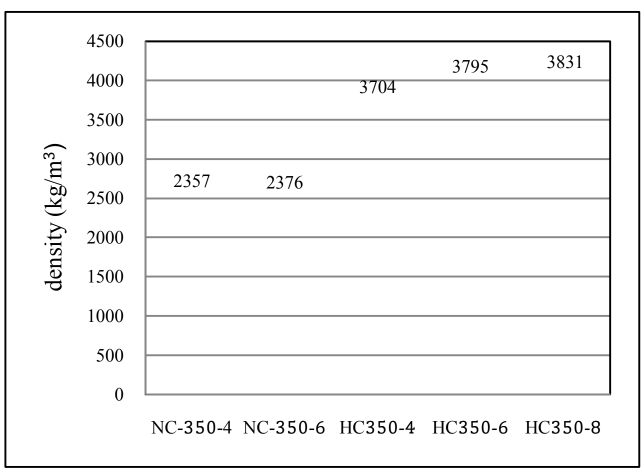


Figure 5. Comparison of the density of hardened concrete test results

CONCRETE COMPRESSIVE STRENGTH TEST RESULTS

The concrete compressive strength test using cubic samples sizing 15×15 cm and cylinder samples sizing 15×30 cm was conducted and the results were compared; the results are shown in table 5 and Figure 6.

Table5. Concrete compressive strength final test results

Row	Specimen code	Concrete compressive strength at age of 28 days(kg/cm^2)	
		Cubic 15×15cm	Cylinder 15×30cm
1	NC-350-4	508	462
2	NC-350-6	615	520
3	HC350-4	514	428
4	HC350-6	667	567
5	HC350-8	760	645

The tensile strength tests of cylinder samples (15×30cm), using split method, (Brazilian) were performed. The results are presented in table 6. Figure 7 shows the results of their comparison.

TENSILE STRENGTH TESTS RESULTS

Table 6. Concrete Tensile strength final test result

row	specimen code	tensile strength (Brazilian method) kg/cm^2	ratio of tensile strength to compressive strength
1	NC-350-4	46.89	0.1
2	NC-350-6	53.96	0.1
3	HC350-4	46.17	0.1
4	HC350-6	57.20	0.1
5	HC350-8	64.94	0.1

The results of tensile strength in table 6 show that the ratios of tensile strength to compressive strength are similar in both cases.

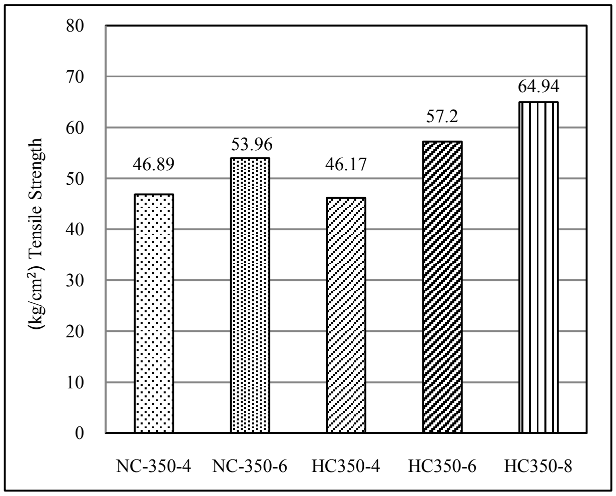


Figure 7. Comparison of Tensile strength test results of final concrete

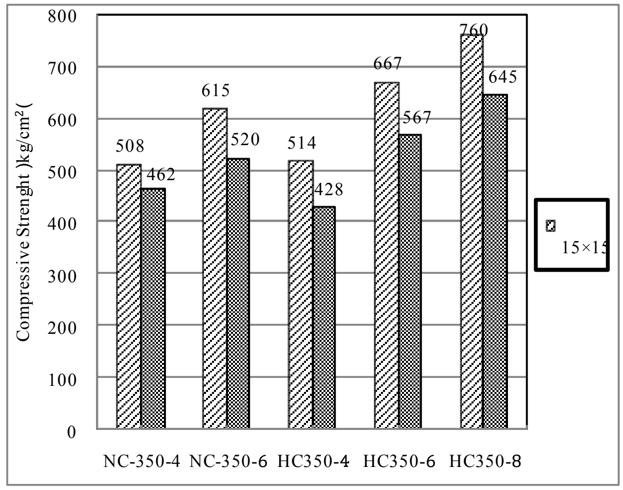


Figure 6. Comparison of compressive strength test results of concrete specimens with different dimensions

ELASTIC MODULE DETERMINATION TESTS RESULTS

The elastic module for all concretes using 15×30cm cylinder specimens was determined. The results are shown in table 7.

Table 7. *Results of elastic module for final concretes*

row	specimen code	Elastic module of tendinous (kg/cm^2)
1	NC-350-4	1.81×10^5
2	NC-350-6	2.21×10^5
3	HC350-4	1.86×10^5
4	HC350-6	2.37×10^5
5	HC350-8	2.93×10^5

RESULTS OF WATER ABSORPTION TEST

The water absorption of concrete was determined using BS method. The lower the water absorbed, the higher the concrete strength against offensive chemical factors will be. The results of water absorption in concrete are presented in table **8:**

Table 8. *Results of water absorption of final concrete (in percentage)*

row	specimen code	Water absorption (%)
1	NC-350-4	1.51
2	NC-350-6	1.39

3	HC350-4	0.89
4	HC350-6	0.63
5	HC350-8	0.49

CONCRETE BLAST TEST

The explosive strength of the concrete test was done on 50×50×10 cm cubic pieces through two methods of tangential and distance explosive. In the first case, the objective was the explosive strength and in the second it was similar to the first plus the effect of explosion wave on the concrete.
Then, to make conditions closer to real conditions, four x rectangular cans, sizing 3×10×10 cm, in the inner bearing were built (Figure 8).

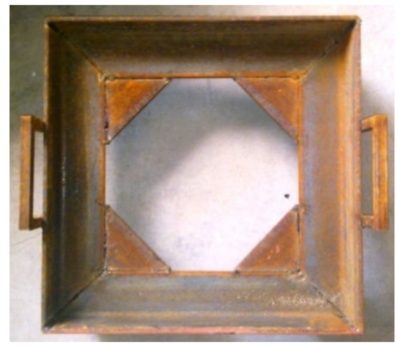


Figure 8. Support used for explosion test

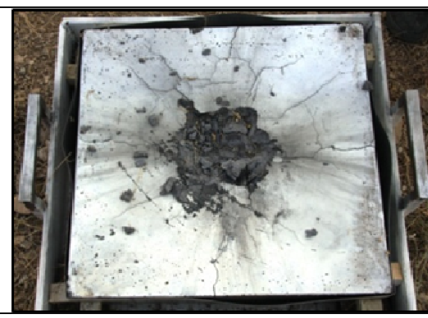
In distanced explosion, to establish the explosive with distance, a stool was used such that the distance of the explosive (height of target) could be set with a string (Figure 9).

Figure 9. Metal stool to establish the explosive

First Stage: Explosion Test- Contact Explosion

In the first stage, the explosive material is on the component tangential. A specimen of plan NC-350-4, 2 pieces from NC-350-6, 1 piece from NC-350-4, 1 piece from HC-350-6, and 1 piece from HC-350-8 were selected. A general description of the first stage of the test is presented in table 9. In all the tests, it was tried to use identical support conditions and directions for both pieces. Also, it was attempted to select materials which are mostly the same physically and mechanically. According to table 9,in the first and second steps, pieces from NC-350-6 and in the third step, pieces from NC-350-4 were chosen as control.

Table 9. First stage of explosion test-contact explosion

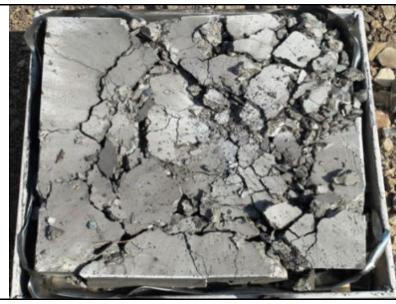
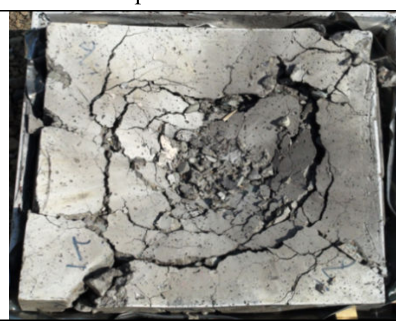
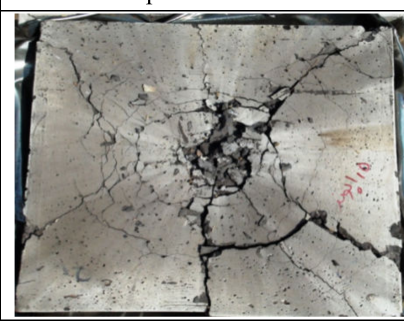
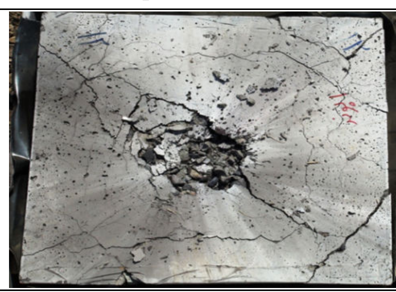
row	Distance (cm)	Explosive weight (Ibm)	region of demolition	
			conventional concrete	heavy concrete
1	0	0.5		
			code space : NC-350-6	code space : HC350-8
2	0	0.154		
			code space : NC-350-6	code space : NC-350-6
3	0	0.154		
			code space : NC-350-4	code space : HC350-4

In the final test, due to pieces' harness in the space between the support and the pieces, it is seen that the damage is lower than the third row, while the amount of explosives were the same.

Second Stage of Explosion Test-Distanced Explosion

In the fourth stage, the explosive material is on the component tangential with a 10 cm distance. A specimen of plan NC-350-4, 2 pieces from NC-350-6, 1 piece from NC-350-4, 1 piece from HC-350-6, and 1 piece from HC-350-8 were selected. A general description of the first stage of the test is given in table 9. In all the tests, it was tried to use identical support conditions and directions, for both pieces. Also, we tried to select materials which are mostly the same from a physical and mechanical point of view. According to table 9, in the first and second steps, pieces from NC-350-4 and in the third step, pieces from NC-350-6 were selected as control. In this stage, in all the tests, the space between the support and the pieces was suppressed.

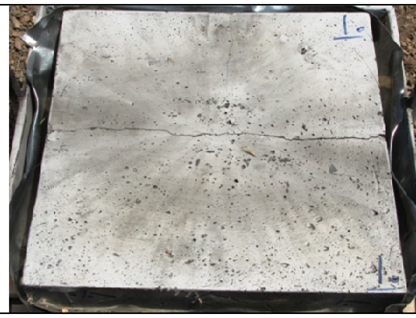
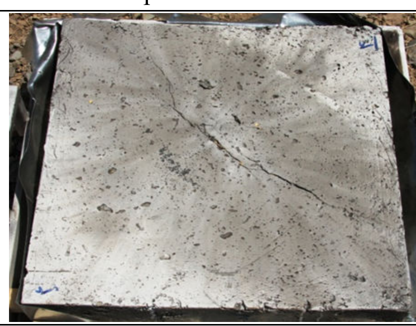
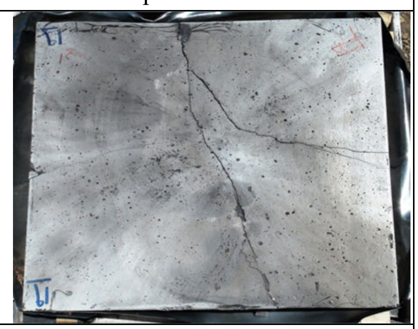
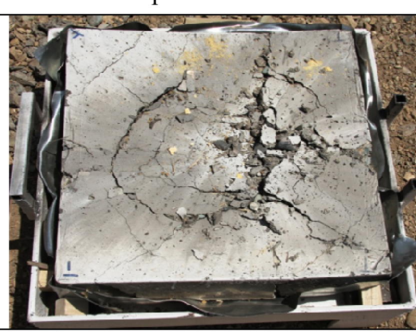
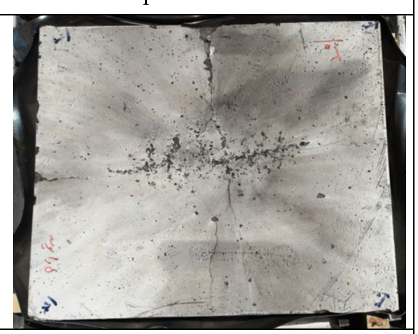
Table 10. Second stage of explosion test-distanced explosion

row	Distance (cm)	Explosive weight (Ibm)	region of demolition	
			conventional concrete	**conventional concrete**
1	10	2		
			code space : NC-350-4	code space : HC350-6
2	10	1.5		
			code space :NC-350-4	code space : HC350-6
3	10	1		
			code space : NC-350-6	code space : HC350-8

Third Stage of Explosion Test-Distanced Explosion

During the third stage, the explosive material is on the component tangential with a 20 cm distance. A specimen of plan NC-350-4, 2 pieces from NC-350-6, 1 piece from NC-350-4, 1 piece from HC-350-6, and 1 piece from HC-350-8 were chosen. A general description of the first stage of the test is presented in table 9. In all the tests, we tried to use identical support conditions and directions for both pieces. Also, it was tried to select materials which are mostly the same physically and mechanically. According to table 9, in the first and second steps, pieces from NC-350-4 and in the third step, from NC-350-6 were opted as control. In this stage, in all the tests, the space between the support and the pieces was suppressed.

Table 11. Third stage of explosion test-distanced explosion

row	Distance (cm)	Explosive weight (Ibm)	region of demolition	
			conventional concrete	conventional concrete
1	20	0.5		
			code space : NC-350-6	code space : HC350-4
2	20	1		
			code space :NC-350-4	code space : HC350-6
3	20	1.5		
			code space : NC-350-4	code space : HC350-6

CONCLUSION

Conclusion from Mechanical and Physical Properties Tests of Final Concrete Samples and Their Comparison

Using primary concrete tests and comparison of the results, finally, to create the final concrete, five types of mixing plans were formed and tested**.** The plan includes two samples of conventional concrete (control) and three samples of heavy concrete. The results show that the maximum density of heavy concrete is %61 more than conventional concrete **.**

The maximum compressive strength for heavy concrete was %24 higher than conventional concrete; albeit, this number is different for cubic samples. This shows that we cannot use a determined change coefficient for all concretes. In general, the results show that the strength of all concretes is more than the average strength for cubic (345 kg/cm^2). Thus, the objective is attained.

The results of tensile strength show that the maximum tensile strength of cubic samples of heavy concrete is %20 higher than conventional concrete.

The results of elastic module show that the maximum elastic module of heavy concrete is %32 higher than conventional concrete.

The comparison of water absorption shows that the water absorption of heavy concrete is %64 less than conventional concrete **.**

Conclusion from Visual Investigation of Explosion Test and Results Comparison

1- Observing disruption images of pieces caused by explosion and comparing them in all explosives shows a better strength against explosive loading for heavy concrete.

2- Disruption type of concrete shows that, in heavy concrete, width of cracks and depths of holes and aggregates detachment is much less.

3- Displacement of explosive materials in the maximum displacement of heavy concrete is less than conventional concrete.

4- Strength against disruption in all heavy concrete pieces shows that the compressive strength is an appropriate property against explosive loading; however, observing HC350-4 plan shows that besides the low compressive strength of the discontinuities resulting from the explosion it has got a higher strength. Therefore, it is not true that a higher compressive strength means a better quality in the case of the desirability of concrete against explosives as a basic principle.

5- Explanations in 4have shown the same theory for tensile strength.

6- The investigation of explosive strength shows that, all heavy concrete materials, because of their high specific weight and density, operate better against explosion. In fact, the present research and the conducted explosion tests show that concrete density, as a basic factor, is effective in the strength against explosion.

REFERENCES

Antoniades KK, Salonikios TN, Kappos AJ, Kappos AJ.; 2007. Evaluation of hysteretic response and strength of repaired R/C walls strengthened with FRPs; Eng Struct;29(9):2158_71.

Rougier VC, Luccioni BM.; 2007. Numerical assessment of FRP retrofitting systems for reinforced concrete elements", Eng Struct; 29(8):1664_75.

Sheikh SA, Li Y, "Design of FRP confinement for square concrete columns", Eng Struct; 29(6):1074_83, 2007.

Ali MSM, Oehlers DJ, Griffith MC, Seracino R.; 2008. Interfacial stress transfer of near surface-mounted FRP-to-concrete joints", Eng Struct; 30(7):1861_8.

Gee-Joo Ha, Yun-Yong Kim, Chang-Geun Cho.; 2008. Groove and embedding techniques using CFRP trapezoidal bars for strengthening of concrete structures". Eng Struct; 30(4):1067_78.

Mays GC, Hetherington JG, Rose TA.; 1999. Response to blast loading of concrete wall panels with openings", ASCE J Struct Eng; 125(12):1448-50.

Lok TS, Xiao JR.; 1999. Steel-fibre-reinforced concrete panels exposed to air blast loading. Proc Inst Civil Eng Struct Build", 134:319-31.

Mosalam KM, Mosallam AS.; 2001. Nonlinear transient analysis of reinforced concrete slabs subjected to blast loading and retrofitted with CFRP composites", Compos Part B Eng; 32:623-36.

Mosallam A, Haroun M, Mosalam KM.; 2001. Repair and rehabilitation of reinforced and unreinforced concrete slabs with polymer composites", In: Forde MC, editor. Proceedings of the structural faults Repair-2001. London, UK. Edinburgh UK: Engineering Technics Press; July 4-6, A keynote paper, CD-ROM.

Wu C, Oehlers DJ, Rebentrost M, Burman N.; 2009. Whittaker AS, "Blast testing of ultrahigh performance fiber concrete slabs and FRP retrofitted RC slabs, Eng Struct;31:2060-9.

Wang et al.; 2012. Experimental study on scaling the explosion resistance of a one-way square reinforced concrete slab under a close-in blast loading", International Journal of Impact Engineering.

Khalid M. Mosalam , Ayman S. Mosallam.; 2001. "Nonlinear transient analysis of reinforced concrete slabs subjected to blast loading and retrofitted with CFRP composites , PII: S1359-8368(01)00044-0, Published by Elsevier Science Ltd.

Morishita M, Tanaka H, Ando T, Hagiya H.; 2004. Effects of concrete strength and reinforcing clear distance on the damage of reinforced concrete slabs subjected to contact detonations. Concrete Research and Technology;15(2):89–98 [in Japanese].

Tanaka H, Tuji M.; 2003. Effects of reinforcing on damage of reinforced concrete slabs subjected to explosive loading. Concrete Research and Technology; 14(1):1–11 [in Japanese].

Morishita M, Tanaka H, Ito M, Yamaguchi H.; 2000. Damage of reinforced concrete slabs subjected to contact detonations. Journal of Structural Engineering", JSCE; 46A:1787–97 [in Japanese].

Bibiana Maria Luccioni, Mariela Luege.; 2006. Concrete pavement slab under blast loads, International Journal of Impact Engineering 32, 1248–1266.

Zineddin M., T. Krauthammer.; 2007. Dynamic response and behavior of reinforced concrete slabs under impact loading, International Journal of Impact Engineering 34, 1517–1534.

Ohkubo K., M. Beppu, T. Ohno, K. Satoh.; 2008. Experimental study on the effectiveness of fiber sheet reinforcement on the explosive-resistant performance of concrete plates, International Journal of Impact Engineering 35, 1702–1708.

Beppu M., K. Miwa, M. Itoh, M. Katayama, T. Ohno.; 2008. Damage evaluation of concrete plates by high -velocity impact, International Journal of Impact Engineering 35, 1419–1426.

Richard Liew J.Y., K.M.A. Sohel, C.G. Koh.; 2009. Impact tests on steel_concrete_steel sandwich beams with lightweight concrete core, Engineering Structures 31, 2045_2059.

Wang Z.L., H. Konietzky, R.Y. Huang.; 2009. Elastic–plastic-hydrodynamic analysis of crater blasting in steel fiber reinforced concrete", Theoretical and Applied Fracture Mechanics 52, 111–116.

Coughlin A.M., E.S. Musselman, A.J. Schokker, D.G. Linzell.; 2010. Behavior of portable fiber reinforced concrete vehicle barriers subject to blasts from contact charges", International Journal of Impact Engineering 37, 521–529.

Kan et al.; 2004. strength and Fracture Toughness of Heavy Concrete with Various Iron Aggregate Inclusions", Nuclear engineering and Design (228), P. 119.

Yoshihiro Asano.; 2011. Application of heavy concretes to the shield materials of synchrotron radiation beam lines", Radiation Measurements 46, 546-550.

Kaplan, M.F.; 1989. concrete radiation shielding, First published, London, Longman, capt(5,6,8,9).

ACI committee 304.; 1996. heavy concrete, measuring, mixing, transporting, and placing (ACI 304.3R-96), Detroit, American concrete institute.

ACI Committee 211.; 2002. standard practice for normal, heavy weight, and mass concrete (ACI 211.1-91)", American concrete institute.