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Evaluation of Protective Layers on Masonry Structures against Impact

Eman M. Abouzaid[a], Amr A. Abdelrahman[b], Eehab A.B. Khalil[c], Moustafa Abass[d]

[a] Research Assistant – Construction Research Institute – National Water Research Center.
[b] Professor – Structural Engineering Department – Ain Shams University.
[c] Professor – Construction Research Institute – National Water Research Center.
[d] Assistant Professor – Structural Engineering Department – Ain Shams University.

ملخص البحث:
تعتبر المنشآت الهيدروليكية في مصر من أقدم المنشآت علي مستوي العالم كما انها تعتبر الأكثر تعقيدا. تقل مقاومة هذه المنشآت نتيجة لتدهور في العناصر الإنشائية التي تتكون من الطوب نتيجة التأثير الهيدروليكي للمياه. و أحمال الصدم الناتجة من السفن و الأجسام الطافية فوق سطح المياه و التي تؤثر علي سلامة و أداء المنشأ الهيدروليكي.تم إعداد برنامج بحثي لتصميم خلطات أسمنتية ذات تكلفة إقتصاديةتستخدم كطبقات حماية للمنشآت الهيدروليكية القديمة لمقاومة أحمال الصدم .

Abstract

Hydraulic structures in Egypt are considered to be one of the oldest buildings throughout the world and its system is considered to be one of the most complex. The strength of these structures reduced due to deterioration in masonry elements for the hydraulic effect of the water. Impact load due to ship collision and debris on hydraulic structures is one of the most significantly decreasing factors that affect its durability of these structures. This necessitates the use of unusual techniques that would enhance the efficiency of operation and upgrade of such structures to current codes of practices.

One of these techniques is the use of different cementious mixes as a protective layer on masonry hydraulic structures, these mixes are tested and prepared in the lab with different admixtures as (Plasticizer, Adhesive, Fiber, Rubber, and Fly Ash) with different ratios for Fiber (3% & 4%), Rubber (30% & 40%) as sand replacement by volume. The standard compressive, and splitting strength tests were conducted to judge the effect of the added admixtures on concrete behavior. Moreover, impact testing program was applied to specific specimens, with dimensions 200 mm width and height, and 50 mm thickness. The number of blows to first crack load and ultimate was determined. The relationship between the mechanical properties and impact resilience is also presented. The results showed that as the percent of fiber increased, the resistance to impact increased. The variation in results was discussed. Fiber-4% of the sand volume exhibited the best impact resistance, estimated about five times over control mix, with ratio of 83% reduction of compressive strength.

KEYWORDS: Impact resistance, Hydraulic Structures, Masonry Structures, Protective layers, Rubber, Fiber, Fly Ash.

1. INTRODUCTION:

Masonry walls are the most widely common element utilized in buildings or structures; for example, retaining walls because of its low cost, ease accessibility, good sound or heat isolation properties, and locally available material. Brick and concrete blocks are the most widely common type of masonry being used in industrialized countries and might be either weight-bearing or used as a veneer.

The relationship between brick and mortar with their properties and its constituents are required for mathematical modeling of structures with masonry walls, and the properties of materials are also required. Masonry are also used in hydraulic structures as barrages, regulators, dams, culvert, and syphon, and the current research will focus on hydraulic structures and its of rehabilitation.

Burned red brick from alluvial deposit from Nile valley was the main construction material for buildings during the 19th and 20th centuries. The bearing walls system was the main structural system implemented in barrages that control the flow of water in the hydraulic system in Egypt.

The durability and strength of bricks depend on the quality of mortar, its type and workmanship. It also depends on the pattern in which the units are assembled, which can significantly affect durability of the overall masonry construction.

The science of hydraulic structures seldom looks at the rehabilitations of old existing structures. The usual problems are associated with operation due to the strong velocities downstream the gates and/or the erosion and failures during the design or the construction phases of the project, and failures as a result of impact loads due to ships collision. The extent and diversity of such structures is not commonly known around the world except in some countries. Egypt is facing the problem of replacing such number of structures in short time where the finances are not sufficient to cover such task. Options of rehabilitation are explored as an alternative to full replacement implementing traditional and unusual techniques.

Traditional construction materials for regulators and barrages vary between bricks, plain concrete and reinforced concrete. Application of any other types of material such as steel was restricted to the mechanical and movable parts of the structure including the main item, the gates and movable bridge. Applying any methodology of rehabilitation of such structures, the hydraulic requirements superimposes several strains on the implemented solution and the duration of application. The interference with the hydraulic dimensions must be kept to a minimum if not unchanged. The use of concrete and bricks was in cases of replacement and extension of piers parallel to the flow. Any thickening was not allowed except in the special case of raft with some adjustment to the hydraulic efficiency of operation as has occurred in Assuit Barrage and Dairot Group of Regulators.

Deterioration of masonry structures includes weathering of stone or brick and erosion of mortar from joints, as shown in Figure 1. Physical damage can include spalling, cracking and even loss of stones or brick. This study discusses the evaluation of protective layers as the methods of one for protection of aged masonry structures because of the deterioration that might occur as a result of ship collision.

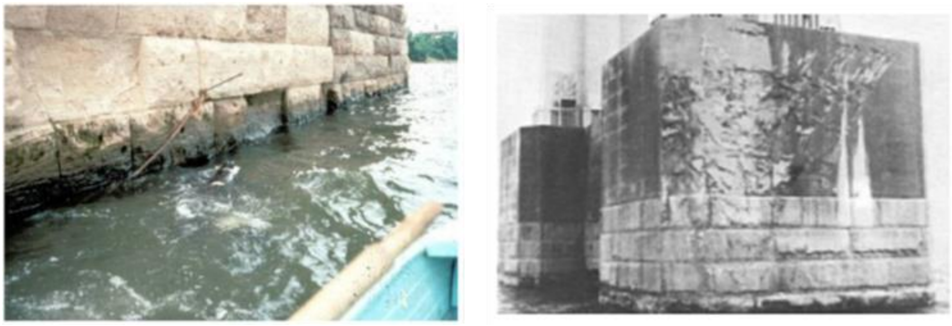


FIGURE1. Deteriorated Masonry due to Impact

2. EXPERIMENTAL WORK

2.1 Material

All test specimens were fabricated using locally available materials. Type (I) ordinary Portland cement CEM I (52.5N) was utilized. Fly Ash (FA), as by products is used as a partial replacement of cement. The local natural siliceous sand used was with specific gravity of 2.65 Kg/m^3. The coarse aggregate used is natural gravel with maximum aggregate size of 9 mm and specific gravity of 2.65 Kg/m^3. Plasticizer ADDICRETE DM2 is used as an admixture for producing the high quality and less permeable concrete used in the water and underground structures bridges, foundations, water tanks, final roofs and concrete elements subjected to weathering conditions was used. ADDIBOND 65, which is a versatile adhesive with a wide range of applications, was used for improving the properties of cement mortar and concrete, specifically with regards to bond strength to different building materials, and impermeability to water. Crumb rubber with a maximum size of 2 mm is used as a partial replacement of sand by volume. It is produced by grinding waste tires with special technique. A polypropylene shortcut fiber produced from "CMB" Company in Egypt was used. The fibers are mixed with the screed, mortar or concrete to minimize cracks and improve its properties use with different volume ratios (3%, and 4%). In this research, two different volume ratios of crumb rubber (30%, and 40%) were used. In addition, a concrete mix with no rubber was used as a control mix.

2.2 Testing Program

The concrete mix proportions for 10 different mortar mixes were conducted; the first 5 mixes were prepared containing FA, while the other remaining mixes were prepared without FA, are shown in Table 1.

TABLE 1. Mix Proportions

Mix Name.	Fiber	Rubber	Water	Portland cement	Coarse aggregate	Fine aggregate	Addicrete DM2	Addibond 65	Fly ash
	(Kg)	(Kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
Control	—	—	13	25	97	65	2.5	0.25	—
R-30%	—	7.06	13	25	97	57.87	2.5	0.25	—
R-40%	—	9.42	13	25	97	55.64	2.5	0.25	—
F-3%	2.04	—	13	25	97	62.64	2.5	0.25	—
F-4%	2.72	—	13	25	97	62	2.5	0.25	—
Control-Flyash	—	—	13	20	97	65	2	0.25	5
R- 30%	—	7.06	13	20	97	57.87	2	0.25	5
R-40%	—	9.42	13	20	97	55.64	2	0.25	5
F-3%	2.04	—	13	20	97	62.64	2	0.25	5
F-4%	2.72	—	13	20	97	62	2	0.25	5

2.3 Specimen Testing configurations

Mixing was carried out in three stages; dry mixing for 1 minute, wet mixing for 2 minutes, and a final mix not less than 2 minutes. Concrete specimens were cast in standard steel molds. Cubes 150 x 150 x 150 mm were prepared to be tested under static compression. The obtained stress strain curves were then used to obtain the static modulus of elasticity. Indirect tensile test was applied on cylinders of 150 mm diameter and 300 mm height. Prisms of 200 x 200 x 50 mm were also prepared for the purpose of impact test. After 24 hours from mixing, the specimens were de-molded and cured in water tank for 28 days. All specimens were cast and treated under the same environmental conditions.

2.4 Impact Test Setup

Impact test was prepared for studying the behavior of solid clay brick masonry with the protective layers which are used for strengthening the masonry structures against impact loads.

Self-made impact instrument was fabricated, according to Charpy impact test idea as shown in Figure1 and Figure 2. The test was carried out by releasing the weight 27

N freely from a height of 750 mm repeatedly. For each specimen, the number of blows corresponding to initial crack and ultimate failure was recorded, respectively. The first number was identified by the appearance of the first visible hair crack and was denoted by the first-crack impact resistance (FC). The test was continued until a complete failure occurred where sufficient impact energy was applied to spread the cracks. The ultimate impact resistance (UR) was then represented by the total number of blows required to propagate cracks until complete failure.

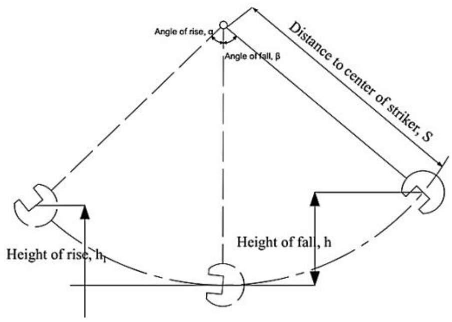


FIGURE 2. Charpy test free body diagram

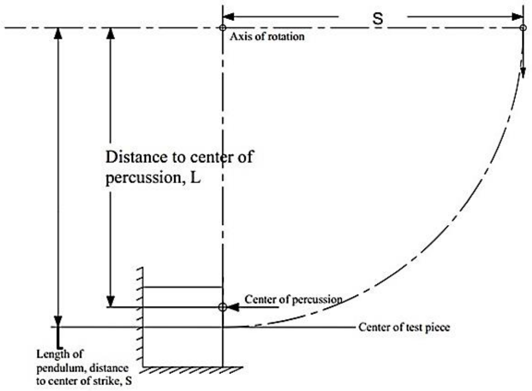


FIGURE 3. Free body diagram for the conducted test

2.4.1 Impact apparatus description

The apparatus consists of wall with 1 meter height and 7mm thickness, rod with 1 meter length divided into two small rods each one 0.5m length with different diameters 40mm and 20mm, base with 50cm width, 1m length, and 7mm thickness, and striker has weight 2.75kg can be increased as shown in Figure 4.

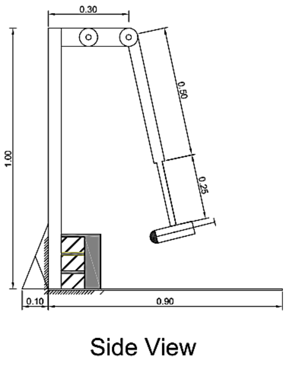


FIGURE 4. Schematic diagram for the used device, units in meter

2.4.2 Impact Specimens Preparation

1. Construct the masonry prisms for the test that consists of 3 courses high.
2. Wash the prisms before testing.
3. Put the prisms in the wooden molds.
4. Poure the protective layers mixes on prisms with 6 cm thickness and vibrate it well.
5. Let the layers setting and put the prisms on water for curing up to 28 days.
6. After 28 days, remove the prisms from water and let them dry.
7. Test the specimens as the described procedures.

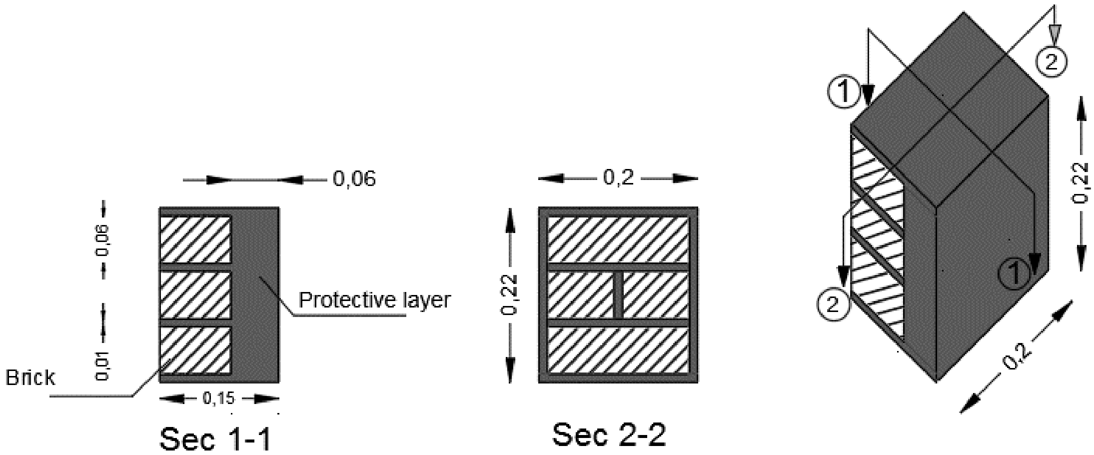


FIGURE 5. Tested Sample schematic diagram, units in meter

2.4.3 Impact Test Procedure

1. After preparing the masonry prisms for testing calibration and fixing the apparatus.
2. Set the length and angle of the rod for the test.
3. Fix the masonry prism on the apparatus.
4. Determine the required weight which achieved the required energy.

2.4.4 Impact Test steps

After the fixation of the masonry prism on the apparatus and adjustment of the length, weight, and angle of rod, the test is started. Rise the rod at 90° and let it fall free under its weight. This is repeated till the first crack appear and the number of blows is recorded. Continue dropping the rod on the prism to reach to the ultimate failure and write the number of blows.

3. RESULTS AND DISCUSSION

3.1 Hardened Properties

3.1.1 Compressive Strength

The 28-days compressive strength showed decrease with the increase of the percentage of rubber replacement especially when adding 20% fly ash. The compressive strength showed considerable decrease with the increase in rubber content. A reduction of about 74% was observed from 30% to 40% rubber content sand replacement. However, using admixtures affects the strength of each mix negatively. The decrease in the strength was caused by adding the fly ash except the mix with 4% fiber replacement.

To maintain the compressive strength requirements for such type of concrete, the mix design has to be adjusted for such type of strength loss. The compression stress-strain distribution varies according to the additives content, as shown in Figure 6.

TABLE 2. Compressive Strength for tested samples

Mix Name	0% Fly ash	20% Fly ash	0% Fly ash	20% Fly ash
	Compressive. Strength 7D (MPa)		Compressive. Strength 28D (MPa)	
Control	11.97	6.25	21.97	17.21
Fiber-3%	12.77	7.74	17.086	7.00
Fiber-4%	11.21	8.53	10.61	6.689
Rubber-30%	9.97	2.034	16.93	16.71
Rubber-40%	7.74	2.97	17.43	18.00

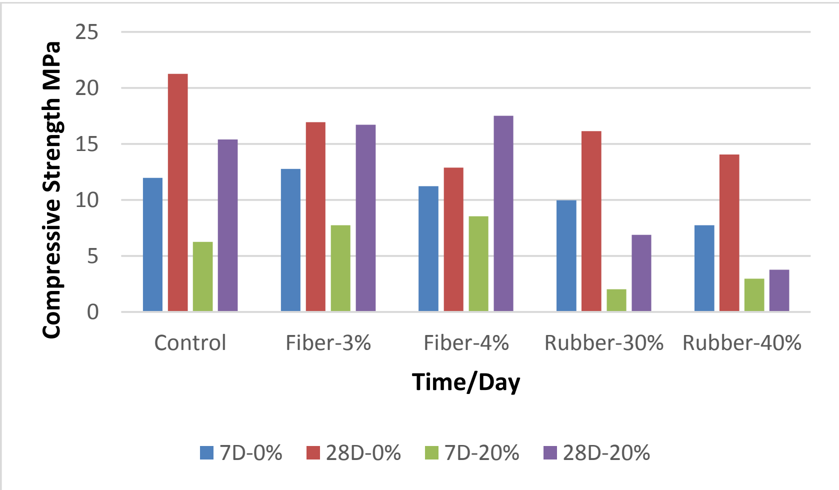


FIGURE 6. Compressive Strength comparison for 7D & 28D

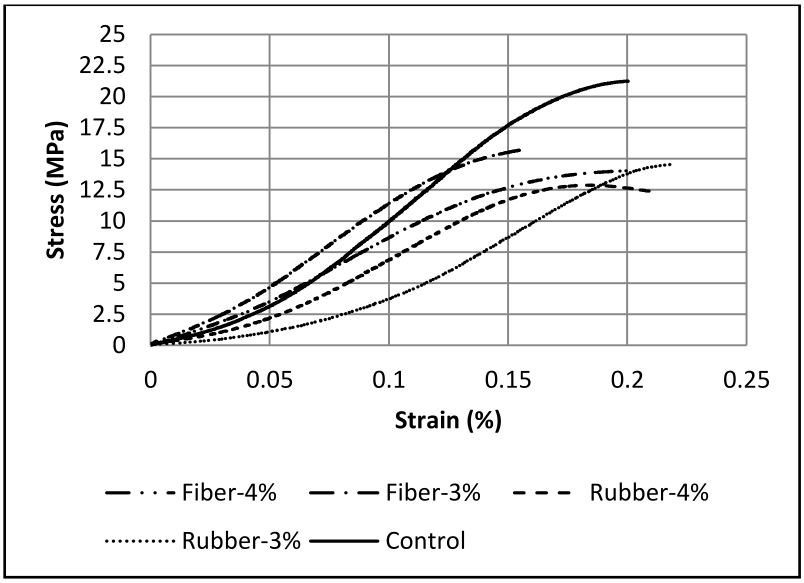


FIGURE 7. Stress-Strain curve at 28 days for 0% Fly Ash specimens

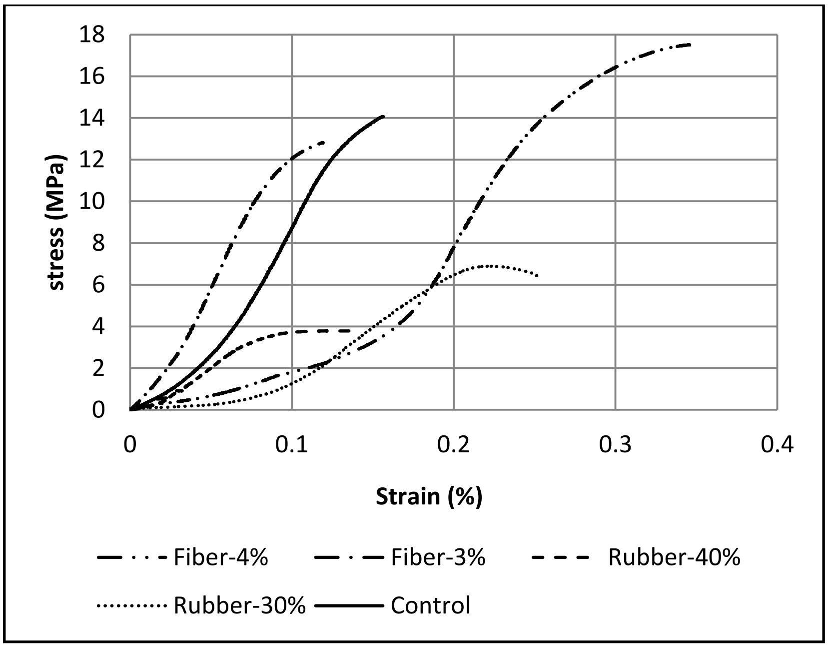


FIGURE 8. Stress-Strain curve at 28 days for 20% Fly Ash specimens

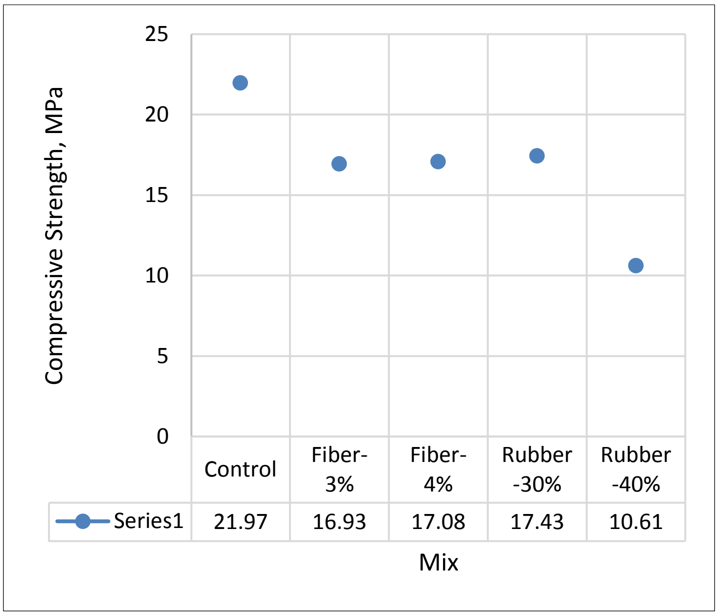


FIGURE 9-a. Average compressive Strength for 0% Fly Ash at 28 days

Figure 9-a represents the results of compressive strength of different mixes using different admixtures at 0% fly ash, adding fiber to the mix decrease the compressive strength by almost 20% while addition of rubber decreases the compression resistance by 50%.

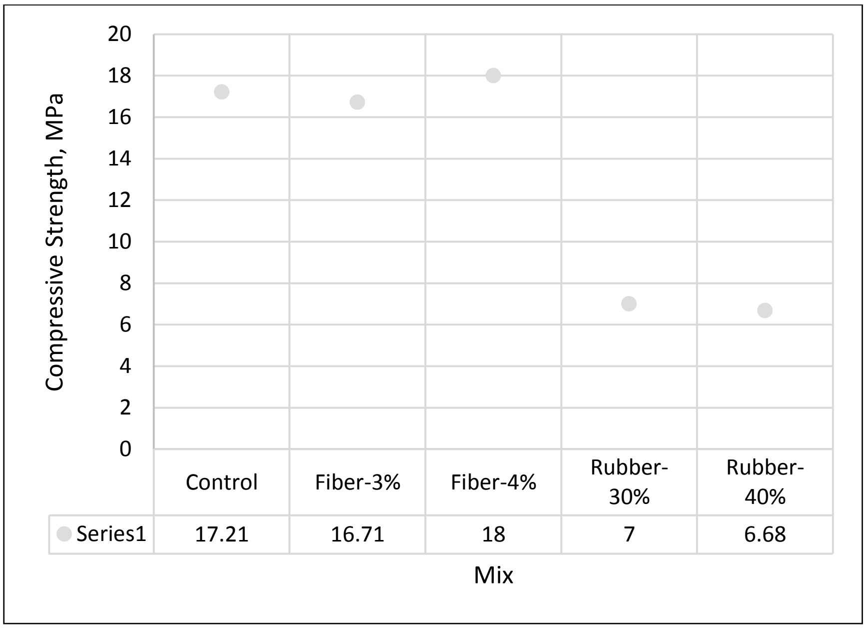


FIGURE 9-b. Average compressive Strength for 20% Fly Ash at 28 days

Figure 9-b represents the results of compressive strength of different mixes using different admixtures at 20% fly ash, adding fiber to the mix with 4% increase the compressive strength by almost 5% while addition of rubber decreases the resistance by37% as shown in Figure 9 and Table 2.

From previous figures, it is noticed that adding 20% fly ash to mixes decrease the compressive strength. However it is used to improve the quality and durability of their mixes, and improves concrete's workability, cohesiveness, finish, ultimate strength, and durability. The compressive strength was decreased by almost 80% for all mixes except fiber mix with 4%, it means that adding fly ash do not improve the behavior of mixes except for fiber with 4% mix, which increases the resistance by 25%.

3.1.2 Indirect Tensile Strength

The splitting tensile strength was conducted as per ASTM C307-03. The test showed considerable decrease in the indirect strength with the increase in rubber content.

TABLE 3. Tensile Strength for Tested Samples.

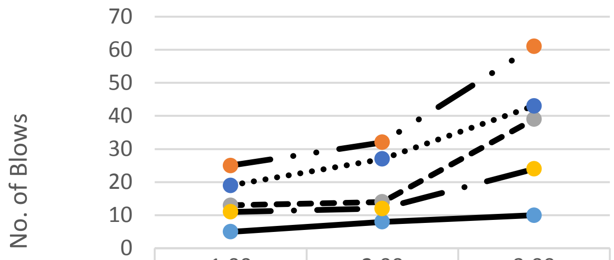
Mix Name	0% Fly ash	20% Fly ash	0% Fly ash	20% Fly ash
	Tensile strength 7D (MPa)		Tensile strength 28D (MPa)	
Control	4.32	3.04	6.17	4.82
Fiber-3%	6.28	4.80	8.97	6.84
Fiber-4%	5.83	3.84	8.33	7.33
Rubber-30%	2.10	2.07	3.45	3.68
Rubber-40%	3.42	1.79	4.63	3.20

4. IMPACT RESISTANCE

The first crack represents first sign of deterioration under Impact loading. The results show a wide range of first crack that vary from a specimen to another for same mix. The ultimate impact resistance followed the same trend of first crack. The number of blows resulting in the initiation of first crack is defined as (n_1), while the number of blows required for final fracture is defined (n_2) of all mixes, n1, n2 and the impact resistance performance, are shown in Figure 10, Figure 11, Figure 12, and Figure 13.

it is noticed that the results had a large scatter for the same mix, for example in control mix without fly ash the first crack occurred after 5 blows for one sample, while occurred after 10 blows for other sample for the same mix. For rubber 30% the scatter increased while the sample cracked after 5 blows and other after 61 blows. On this trend, the failure had the same scatter for example, the control mix sample cracked after 7 blows, while it had another sample cracked after 14 blows on the other.

Despite 20% dosage of fly ash is used but it is noticed that the same matter there is a scatter between the results, for instance the control mix has sample cracked after 8 blows, while other sample cracked after 10 blows for the same mix. For rubber 40% the scatter increased where the sample cracked after 36 blows and the other after 66 blows. On this trend, the failure has the same scatter for example, the rubber 40% mix has sample cracked after 44 blows while it has another sample cracked after 79 blows. Therefore, the abnormal values were excluded.

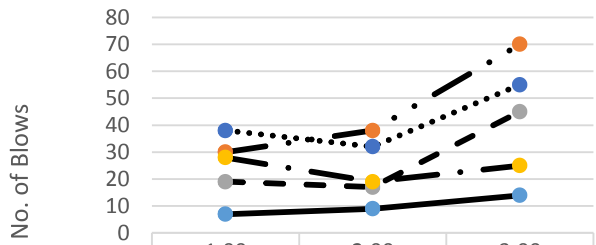


	1.00	2.00	3.00
Control	5	8	10
Rubber 30%	25	32	61
Rubber 40%	13	14	39
Fiber 3%	11	12	24
Fiber 4%	19	27	43

FIGURE 10. No. of impact blows inducing First Crack for 0% Fly Ash

Figure 10 represents the results of impact resistance of different mixes using different admixtures at 0% fly ash, adding rubber to the mix increases the impact resistance, while the control mix has the lowest impact resistance as shown in Figure 10.

Moreover, figure 10 illustrates that rubber mix with 30% is the best mix in terms of impact load resistance.

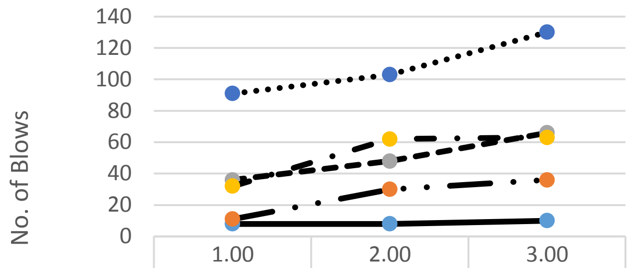


	1.00	2.00	3.00
Control	7	9	14
Rubber 30%	30	38	70
Rubber 40%	19	17	45
Fiber 3%	28	19	25
Fiber 4%	38	32	55

FIGURE 11. No. of impact blows causing failure for 0% Fly Ash

Figure 11 represents the results of impact resistance of different mixes using different admixtures at 20% fly ash, adding rubber to the mix increases the impact resistance by almost 460%.

The obtained results illustrate that rubber mix with 30% percentage is the best mix in terms of impact load resistance

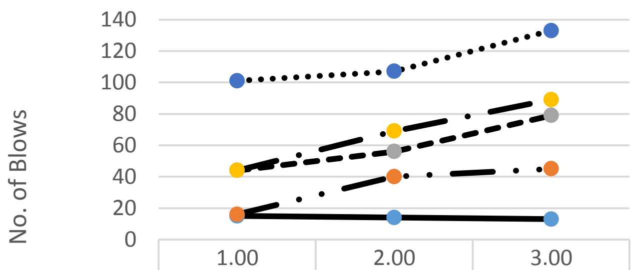


	1.00	2.00	3.00
Control	8	8	10
Rubber 30%	11	30	36
Rubber 40%	36	48	66
Fiber 3%	32	62	63
Fiber 4%	91	103	130

FIGURE 12. No. of impact blows inducing First Crack for 20% Fly Ash

Figure 12 represents the results of impact resistance of different mixes using different admixtures at 0% fly ash, adding fiber to the mix increase the impact resistance by 1200%.

The fiber mix with 4% percentage is the best mix in terms of impact load resistance.



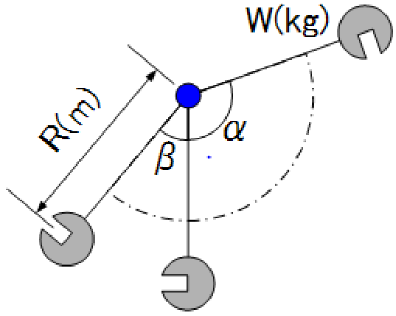
	1.00	2.00	3.00
Control	15	14	13
Rubber 30%	16	40	45
Rubber 40%	44	56	79
Fiber 3%	44	69	89
Fiber 4%	101	107	133

FIGURE 13. No. of impact blows causing failure for 20% Fly Ash

Figure 13 represents the results of impact resistance of different mixes using different admixtures at 0% fly ash, adding fiber to the mix increases the impact resistance by almost 812%.

The fiber mix with 4% percentage is the best mix in terms of impact load resistance.

The absorbed impact energy is calculated from energy equation that determine the absorbed energy for 1 blow then the value of energy multiples in the number of blows. The value of absorbed energy for one blow equal 33.83 joule. Shown in Figure, 14 Where, E: Energy, W: Mass of hammer, α: Angle of fall, β: Angles at the end of the swing, R: Length, g: Gravitational acceleration, and L: Energy Loss.



$$E(J) = WgR(\cos\beta - \cos\alpha) - L$$

FIGURE 14. Absorbed Energy Formula

TABLE 4. Absorbed Impact Energy-0% Fly Ash.

Sample ID	1'st crack		Failure	
Control	n1	Energy	n2	Energy
P-1	10	338.3	14	473.62
P-2	8	270.64	9	304.47
P-3	5	169.15	7	236.81
Rubber 30%				
R-1	25	845.75	30	1014.9
R-2	32	1082.56	38	1285.54
R-4	61	2063.63	70	2368.1
Rubber 40%				
R-1	14	473.62	17	575.11
R-2	13	439.79	19	642.77
R-4	39	1319.37	45	1522.35
Fiber 3%				
F-2	11	372.13	28	947.24
F-3	24	811.92	25	845.75
F-5	12	405.96	19	642.77
Fiber 4%				
F-1	27	913.41	32	1082.56
F-2	43	1454.69	55	1860.65
F-4	19	642.77	38	1285.54

Table 4, represents the absorbed impact energy for different mixes at 0% fly ash, adding rubber by 30% to the mix increases the ability of mix to resist impact load, while Table 5, represents the absorbed impact energy for different mixes at 20% fly ash, adding fiber by 4% to the mix increases the ability of mix to resist impact load.

TABLE 5. Absorbed Impact Energy-20% Fly Ash.

Sample ID	1'st crack		Failure	
Control	n1	Energy	n2	Energy
P-2	10	338.3	13	439.79
P-3	8	270.64	14	473.62
P-4	8	270.64	15	507.45
Rubber 30%				
R-1	30	1014.9	40	1353.2
R-3	36	1217.88	45	1522.35
R-4	11	372.13	16	541.28
Rubber 40%				
R-2	48	1623.84	56	1894.48
R-3	66	2232.78	79	2672.57
R-4	36	1217.88	44	1488.52
Fiber 3%				
F-1	63	2131.29	86	2909.38
F-2	62	2097.46	69	2334.27
F-6	32	1082.56	44	1488.52
Fiber 4%				
F-3	130	4397.9	133	4499.39
F-5	91	3078.53	101	3416.83
F-6	103	3484.49	107	3619.81

From the previous results, it represents that adding fiber by 4% is the best mix to resist impact load and improve the behavior of mix significantly by adding 20% fly ash, Table 00 represent the absorbed impact energy that show the ability of each mix to resist impact load that confirm that fiber 4% mix has the highest absorbed impact energy that translated to resistance of impact energy.

5. CONCLUSIONS

The current research introduces the use of additives in protective layers mixes. The impact resistance of such mix is investigated. The followings are among the main findings of this research:

1. Adding rubber to mix do not affect the compressive strength and impact resistance largely. The compressive strength decreases with increasing rubber content also the same effect on impact resistance with increasing rubber content the impact resistance decreases.
2. Adding fiber to mix affect the compressive strength and impact resistance significantly. The compressive strength increases with increasing fiber content especially with adding 20% fly ash also the same effect on impact resistance with increasing fiber content the impact resistance is obtained increases with adding 20% fly ash.
3. Adding 20% fly ash to mixes decreases the compressive strength in contrary with the tensile strength as it increases with addition of fly ash. The impact resistance increases after using 20% fly ash with the mix.
4. An appropriate fiber content should be determined for each mix to absorb energy.
5. Using 4% fiber and 20% fly ash is considered the best mix used to increase impact resistance at all with respect to all mixes.

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