An-Najah National University

Faculty of Engineering and Information Technology

Material Science Engineering

Graduation Project 2

Alternative concretes, sustainable resources and environmentally friendly products

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Abstract

In this project, we added hydrated lime and waste iron powder with a few percentages instead of cement as in the proportions shown (3%, 5%,7%, 10%,13% and 15%). The samples were mixed with electrical machine by mixing dry component of cement, sand, aggregate, hydrated lime and iron powder for four minutes to become a homogenous mix. Then water is added to initiate the reaction. After mixing the components with water, the mix was cast in molds to take its shape, before curing it in water path and testing it.

After making and curing cubes of concrete for 7 and 28-days testing was applied to specimens. This was to determine the compressive strength and water absorption to evaluate the effect of lime and waste iron powder on the concrete absorption and compression strength. We found that adding 5% of lime and 7% of iron powder give the best results. It enhances the compression strength for 7% of Fe powder added to cement, the compressive strength improves from 29.8 MPa to 37.8 MPa, and water absorption change from 4.89% to 2.56%. For lime it enhances the compression strength at 5% of replacement from 19.6 to 25MPa, but the water absorption increased from 7.22% to 7.31%.

1. Introduction

Ordinary Portland cement (OPC) is widely used all over the world, but not without environmental impact. In fact, it contributes about 8% of the global man-made CO_2. This is the second highest source after the energy sector. Cement industry contributes either to this emission directly by releasing CO_2 from the decomposition of calcium carbonate, which is the main ingredient for OPC manufacture, or indirectly through the production of energy needed for this manufacture. Therefore, reducing the amount of OPC used for concrete preparation is a milestone in reducing the overall production of CO_2 as a greenhouse gas.

In this project, we shall explore new concrete admixtures by attempting to replace OPC partially replacement binders used are lime and iron powder. We are particularly interested in adding powdered solid waste materials such as iron to construction materials to determine the impact of these wastes on the properties of construction materials. In addition, we shall focus on the behavior of the resulting binders and concretes with respect to water such as hydrophilic or hydrophobic reactions, water absorption. Permeability of concrete will be studies as function of porosity and sealing effects of certain additives. Another characteristic of concrete is its ability and capacity to fix carbon dioxide that will be explored, too. All final products shall be tested for their mechanical properties such as compressive and abrasion (friction) resistance.

Concrete is a composite material made of a mix of cement, water, sand, gravel. Some other material (additives) can be added to obtain certain properties, that harden into a super strong building material. The properties of the final product depend on the relative proportions of these components. So different mixes have different properties. For instance, for compression strength, every material in concrete has a special contribution.

First, cement is a fine powder material that one pound of contains 150 billion grains. Mixed with water, cement creates a paste that binds with sand, aggregate and reinforcing steel as it hardens.

Second, sand and aggregate (gravel), have a significant impact on the properties of the concrete as they form a mass of concrete, modify strength and stability.

Third, additive powdered or liquid material added to fresh concrete in small amounts to increase the durability of concrete, to control setting time or hardening. Concrete additive thus have different functions, depending on what to achieve. There are two type of it, chemical additive reduce the cost of construction, modify properties of hardened concrete, ensure quality of concrete during mixing, transporting, placing and curing, mineral additives make mixtures more economical, reduce permeability, increase strength, and influence other concrete properties.

Advantage of concrete

- The component of cement is available and cheap
- Concrete strength can be controlled by different the component
- The concrete is very durable
- Easy to form to any shape due to fluidity property
- Fire resistance concrete
- Concrete is insulator
- Concrete can withstand forces of wind and water
- Sound proofing material
- Can add different type of additives to enhance its property

Disadvantage of concrete

- The shrinkage of concrete which causes cracking
- Low tensile strength, and it is a brittle material
- Concrete has a porous structure
- Concrete contains low soluble salts, which affect its properties.

2. Literature review

Sand could be replaced by different type of waste material to enhance the property of fresh and hardening concrete such as workability, strength, compressive and tensile strength.

Krikar and Ibrahim [1] conducted a study on iron waste as a partial replacement of sand in concrete. The aim was to assess the possibility of adding iron waste as fine aggregate in different proportions (6%, 12%, 18%, 24%, and 30%) to enhance the strength of concrete. The mixing design was (1, 2.12, 2.37) to give 33MPa of compressive strength after 28 days of curing without any replacement of sand. Compressive strength and flexural tensile strength tests were conducted to determine the influence of iron waste on the strength of concrete. After mixing the concrete with different parentage showed that the best proportion is 12% replacement of sand with iron waste (15% more compressive strength and flexural tensile in 28 days than normal concrete).

Ghannam et al. [2] found that granite powder (GP) and iron powder (IP) are industrial byproduct that are generated from granite polishing and milling industry. It is a hazardous material to human health because they are airborne and can be easily inhaled. This study was conducted on waste granite and iron powder and the possibility to use it as a replacement of sand in concrete with these proportions (5%, 10%, and 20%) by weight and to observe the effects on compressive and flexural strength compared to other ratios. For (GP) it was observed that 10% replacement of sand was the most effective one and it enhances the compressive and flexural strength by 30% compared to normal concrete. It was observed that substitution of up to 20% weight of sand by (IP) replacement the result was an increase in compressive and flexural strength. Concrete mix that contained (GP and IP) showed good workability and fluidity similar to normal concrete mixes.

Largean el al. [3] studied the effect of ($Fe2O3$) on compressive strength, tensile strength, workability and porosity. Portland cement was partially replaced by (1.5%, 2.5%,3.5% and 5%) by weight of ferric oxide, respectively. They observed that the compressive strength was enhanced at 2.5%. However tensile strength was enhanced at 1.5%. The workability has decreased with the increase in the amount of ferric oxide, while the porosity has slightly decreased at 2.5% of sand replacement it decreased from 26.72% to 21.3%.

Ismail el al. [4] was found presented a summary of works conducted by other researchers or organizations. For example, he quoted from Dryden Aqua Company that tiny glass particles could be used as filtration media for purifying water. The colored glass (green or amber) have been ground into particles of less than a tenth of a millimeter, during this process a net negative electrical charge will be left on the particles surfaces, which enables them to attract grays. A second effect can occur in filters made from colored glass grains. Those filters can split oxygen molecules into single highly reactive oxygen, which is responsible for drawing microbes to the surface of the grains and killing them.

Wartman el al. [5] Glass is an indeterminate material with high silica content ($SiO2$), 72% of waste glass when crush to very fine powder (600 micron) reacts with alkali in cement & cementations product that help to contribute to the strength development. When glass is crunched to small scale it has a cementation property.

Abdallah el al. [6] conducted a study on the effect on concrete when sand is replaced by powdered glass, to see the effect of using crushed waste glass as fine aggregate replacement, to study compression, slump and water absorption, Replacement percentages were (0%, 5%, 15%, 20%) by weight of sand, the compression was enhanced by 5.28% when adding 20% of waste glass and the amount of water absorption decrease when increase the amount of waste glass, the value of slump will decrease with increase in glass added.

Taha el al. [7] state that replacement of course aggregate by crushed glass will effect the mechanical properties, due to lower adhesion and bonding strength between cement past and glass aggregate, due to smooth surface of aggregate.

Song, Ha-Won el al. [8] studies the effect of carbonation of concrete, During carbonation process they observed the CO_2 reacts with CaO and convert to $CaCO_3$, Due to this reaction the voids are filled because the volume of product $CaCO_3$ is lager than that of CaO particle, this decreases the permeability of concrete due to change in porosity.

TEPFERS [9] states that today it is possible in production to reach concrete compressive strength of up to 150 MPa, In laboratory Aalborg Cement, Denmark they have reached 300 MPa and French researchers have reached 800 MPa, in that case they have hardened the concrete at 200C and under pressure, It can be supposed that they have succeeded to reduce the gel and contraction porosity by pressing atoms with thermo vibrations into the micro pores of the structure, Basically they have applied nanotechnology for achieving this, The concrete technology is about to reduce the porosity of the concrete, In this way the concrete becomes both stronger and more environment resistant.

3. Experimental Work

3.1 Standard concrete mixture

The selected composition of the concrete in this study is B300 (1, 1.9, 2.7) kg and 90%w/c ratio. The main reason to select this composition is that it is the most popular in Palestine, it contains the main materials of concrete cement, sand, aggregate and water

3.1.1 Components of Standard mixture

1. Cement 3000 g
2. Sand 5700 g
3. Aggregate (18-25) 5100 g
4. Aggregate (7-17) 2700 g
5. Aggregate (1-6) 1800 g
6. Total Aggregate 9700 g
7. Water Cement ratio (w/c) 55%
8. Super (G7) 60 g

3.1.2 Mechanical testing of standard mixture

I. Compression at 7 days 22.2 (MPa)
II. Compression at 14 days 29.8 (MPa)
III. Water adsorption 4.90%

3.2 Basic material to make concrete

3.2.1 Cement (Portland cement)

Cement acts as a binder material that holds sand and aggregate to each other to give the final strength when it hardens. The cement in its wet form should coat the individual pieces of aggregate. Cement is approximately 10 to 15 %; more cement means that the spaces between aggregates are better filled. Consequently, more cement added, stronger concrete, the type of cement used is (42.5N) as shown in figure, the component of cement as Figure (2)

Figure 1: Cement powder

Figure 2: Main concrete component

3.2.2 **Aggregate**

Gravel or a coarse aggregate increases the failure strength of concrete. Makes concrete solid hard mass, and reduce the cost of concrete because coarse aggregate constitutes large part of the volume of finished concrete. In our project we are using three types of coarse aggregates: medium (18-25) 5.1 kg , small (7-17) 2.7 kg and very small (1-6) 1.8 kg.

3.2.3 **Sand**

Sand helps to make concrete free from voids, and helps to provide homogeneity to some extent. It helps in increasing the strength of concrete.

3.2.4 **Water**

Water is responsible for the reactions of cement phases or in the process called “setting”. Therefore, the strength of concrete depends on the water /cement ratio. More water is added than what chemical reactions require. The excessive water evaporates from cement glue and leaves pores behind, which weaken the concrete. More excessive water means higher water/cement ratio, results in weaker concrete.

3.2.5 Super

super plasticizers help to improve workability by maintaining the fluidity in concrete by releasing the water (from flock) which is entrapped during initial mixing. Retarders slows down the setting of concrete for example hydration process will take place slowly.

3.3 Waste material and new additive material

As disposal of iron wastes, by-products is a major problem in today’s world due to limited landfill space as well as its escalating prices for disposal, utilization of these wastes in concrete will not only provide economy but also help in reducing disposal problems.

We have used different waste materials in our project

3.3.1 Iron powder

We use a waste iron powder that is produced from grinding and cutting metals. The size of iron powder used varies from (30 and 60 micron). as shown in Figures 3 and 4.

Properties of iron powder:

- Reacts with CO_2.
- High strength and high hardness.
- Improve the wear resistance.

Figure 3: Sieve gradient *Figure 4: Result of screening*

3.3.2 Lime

Calcium hydroxide (traditionally called slaked lime) is an inorganic compound with the chemical formula $Ca(OH)_2$. It is a colorless crystal or white powder and is produced when quicklime (calcium oxide) is mixed, or slaked with water. It has many names including hydrated lime. It protects other metals from corrosion such as iron and steel by raising the pH and passivating their surface. Limewater turns milky in the presence of carbon dioxide due to formation of calcium carbonate, a process called carbonation

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Figure 5: Lime sample

3.4 Sample preparation

3.4.1 Instruments

Our project involves the preparation of concrete specimens that have a specified aggregate, cement, sand and new additive. The specimens were prepared and tested using many instruments, which must be always ready in advance to carry out the specimen mixing and test it, So, in this section, the instruments, are presented in sequence starting from the beginning to the end of test, as following scoop handle, digital balance, steel trays, water path, concrete molds, compression testing machine and furnace.

3.4.2 Sieving

Sieving is the process where the materials are separated into different particle size levels using a set of sieves. In this project sieving was used to separate iron powder. The size levels resulted ranges between 4.75 mm and 150 microns. The electrical shaker used to enhance sieving process. The set of sieves are placed on the shaker by order containing the material. They are electrically shacked separating the material to deferent particle size fractions, This process saved time and provided the potential of more accurate sieving.

By use iron powder of 3.45 kg the distribution of mass was as shown in table

Table 1: Mass of powder by size

Size of powder (mic)	Mass in (g)
700	587
450	1760
300	837
150	266

3.4.3 Mixing process

1. It was carried out by electrical mixing machine; The materials were weighed occurring to this mixing design relative to cement (1, 1.9, 2.7). For our study the cement=3kg sand=5.7kg aggregate=9.6 kg using electrical balance. The dry component (cement, sand, aggregate) of each mixture were initially mixed for 2 to 4 minutes until achieving a homogenous mix.
2. The water was added to other component, the concrete is mixed with all component in the mixer for at least three to four more minutes.

3.4.4 Casting process

3. The molds were cleaned and coated with oil to prevent adhesion of concrete before casting

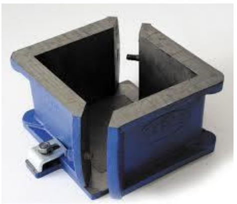

Figure 6: Curing mold

4. The concrete was placed in molds.

Figure 7: Setting and molding

5. The experiment work starts by cast cube for mix without any replacement of (iron powder and lime) these cubes are our reference to compare other product with.
6. The iron powder and lime were added as partial replacement of cement in these percentages (0%, 3%, 5%, 7% 10%, 13%, 15%) with constant water cement ratio at project one we used from 0.9% to 1.1% and we fixed it in project two to be 55%.

Table 2: Weigh for each component with iron powder replacement

	Cement(kg)	Iron powder(kg)	Sand(kg)	Aggregate(g)	Water cement ratio
Mix 0%	1.250	0	2.9	5	0.9
Mix 5%	1.187	0.0625	2.9	5	0.9
Mix 10%	1.125	0.125	2.9	5	0.9
Mix 15%	1.063	0.187	2.9	5	0.9

Table 3: Weigh for each component with lime powder replacement

	Cement (kg)	Hydrated lime (kg)	Sand (kg)	Aggregate (kg)	Water cement ratio
Mix 0%	1.250	0	2.9	5	0.9
Mix 5%	1.187	0.0625	2.9	5	0.9
Mix 10%	1.125	0.125	2.9	5	1
Mix 15%	1.063	0.187	2.9	5	1.1

Table 4: New mixing present by replace the cement by iron powder

	Cement (kg)	**Iron powder (kg)**	**Sand (kg)**	**Aggregate (kg)**	**Water cement ratio**	**Super to cement ratio**
Mix 0%	3	0	5.7	9.6	0.55	0.02
Mix 3%	2.91	0.09	5.7	9.6	0.55	0.02
Mix 5%	2.85	0.15	5.7	9.6	0.55	0.02
Mix 7%	2.79	0.21	5.7	9.6	0.55	0.02
Mix 10%	2.7	0.3	5.7	9.6	0.55	0.02
Mix 13%	2.61	0.39	5.7	9.6	0.55	0.02
Mix 15%	2.55	0.45	5.7	9.6	0.55	0.02

Table 5: New mixing present by adding iron powder

	Cement (kg)	**Iron powder (kg)**	**Sand (kg)**	**Aggregate (kg)**	**Water cement ratio**	**Super to cement ratio**
Mix 0%	3	0	5.7	9.6	0.55	0.02
Mix 3%	3	0.09	5.7	9.6	0.55	0.02
Mix 5%	3	0.15	5.7	9.6	0.55	0.02
Mix 7%	3	0.21	5.7	9.6	0.55	0.02
Mix 10%	3	0.3	5.7	9.6	0.55	0.02

7. The samples were shake for approximately 30 seconds to fill the void and to achieve good dispersion of course and fine material, as the cement slurry appeared on the top surface of the mold.

8. The top surfaces of the molds were leveled to make uniform and a label of information was added to each sample.

Figure 8: Setting for 24 hours

9. The samples were left in the iron mold for the first 24 hours at ambient condition.
10. After that they were removed from mold

Figure 9: Demolding

3.4.5 Curing

The specimens were placed in a water tank for 7 days to let the reaction take its place.

Figure 10: Curing in water path for 7 days

3.5 Methodology

3.5.1 Test of hardened concrete

There are two type of testing of hardened concrete, These are destructive and non-destructive tests. The destructive tests are compressive strength, flexural strength and tensile strength. Nondestructive test are water absorption, porosity, dry density and alkali silica test.

3.5.2 Compressive strength

This test is made to determine the amount of load that concrete can hold without any fracture, Waiting for 7 days to take the first specimens force with this percent range (60-70) % of the total strength and waiting 28 days to take the final specimens strength.

Figure 11: Compression machine

3.5.2.1 Procedure

1. The samples were curried for 7 days in water and left to dry before testing it.
2. The compression machine was cleaned from any contamination.
3. Cross section areas were measured for samples (unit should be in mm^2). and the weight of each sample was taken
4. The sample was placed in the middle of surface of the machine, to distribute the load on all the sample sides.
5. The piston was modified to be in touch with sample.
6. The machine was started to applied load on the sample.

7. The compression load was increased: By turning pressure-increasing valve clockwise, adjust the pressure on piston so that it matches concrete compression strength value. Apply the load gradually without shock.
8. The sample was fractured at its maximum load.
9. The absorbed load was recorded for all sample.
10. The compressive strength was calculated for all samples.

$$\boldsymbol{compresion\ strength = \frac{applied\ laod}{area} = \frac{ultimate\ load\ (N)}{mm^2}}$$

3.5.3 Water adsorption

The test is needed to measure the percentage of water absorbed by the concrete samples, and the porosity can be determined by this test too.

3.5.3.1 Procedure

1. After curing of samples in water for 7 days, as concrete takes final strength and after 28 days as the reaction stops, this test was repeated.
2. Concrete samples were placed in oven for 7 hours at 110C, the weight of samples was taken this process called dry concrete.
3. The sample were put in the water path for 48 hours.
4. Digital balance was use for weighting the samples according to the percentage of their size and masses after take from water path this process called is concrete wet.
5. Water absorption was calculated using this equation.

$$water\ absorption = \frac{weight\ of\ wet\ sample - weight\ of\ dry\ sample}{weight\ of\ dry\ sample} * 100\%$$

4. Result and dissociation

Table 6: Compression strength after 7 days

Sample	Weight of sample (g)	7days compressive test (KNa)	7 days compressive test (MPa)
Standard	2261	126	12.6
5%lime	2364	186	18.6
10%lime	2010	50	5
15%lime	2071	57	5.7
5%Fe	2359	146	14.6
10%Fe	2329	118	11.8
15%Fe	2291	116	11.6

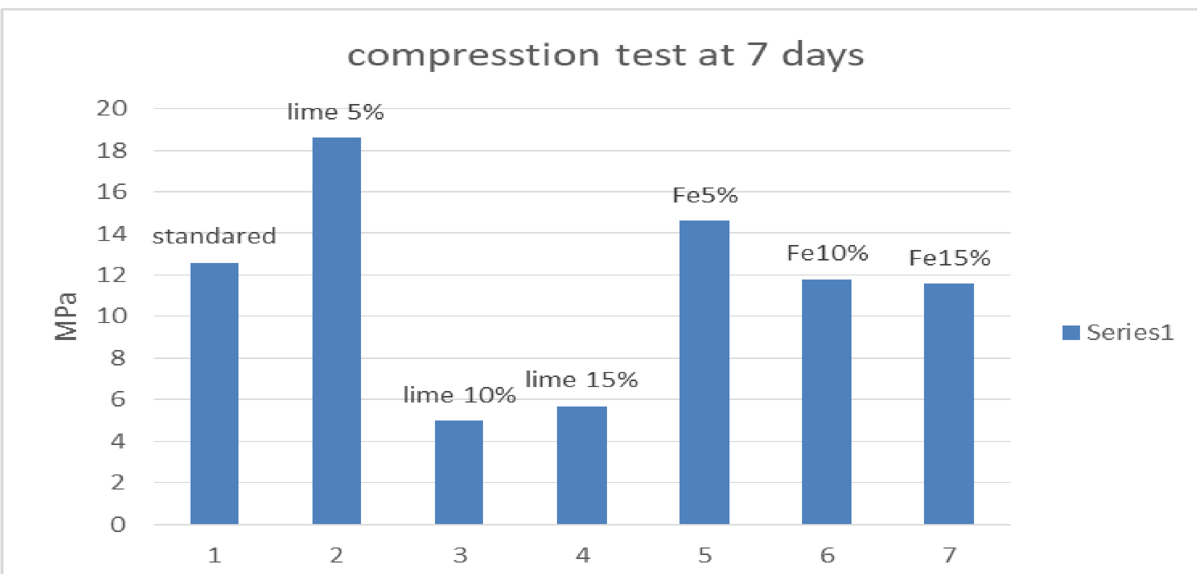

Figure 12: Compression strength after 7 days

Table 7: Compressive strength after 28 days

Sample	Weight of sample (g)	28 days compressive test (KNa)	28 days compressive test (MPa)
Standard	2166	196	19.6
5%lime	2198	250	25
10%lime	1953	130	13
15%lime	2063	64	6.4
5%Fe	2228	212	21.2
10%Fe	2187	170	17
15%Fe	2194	164	16.4

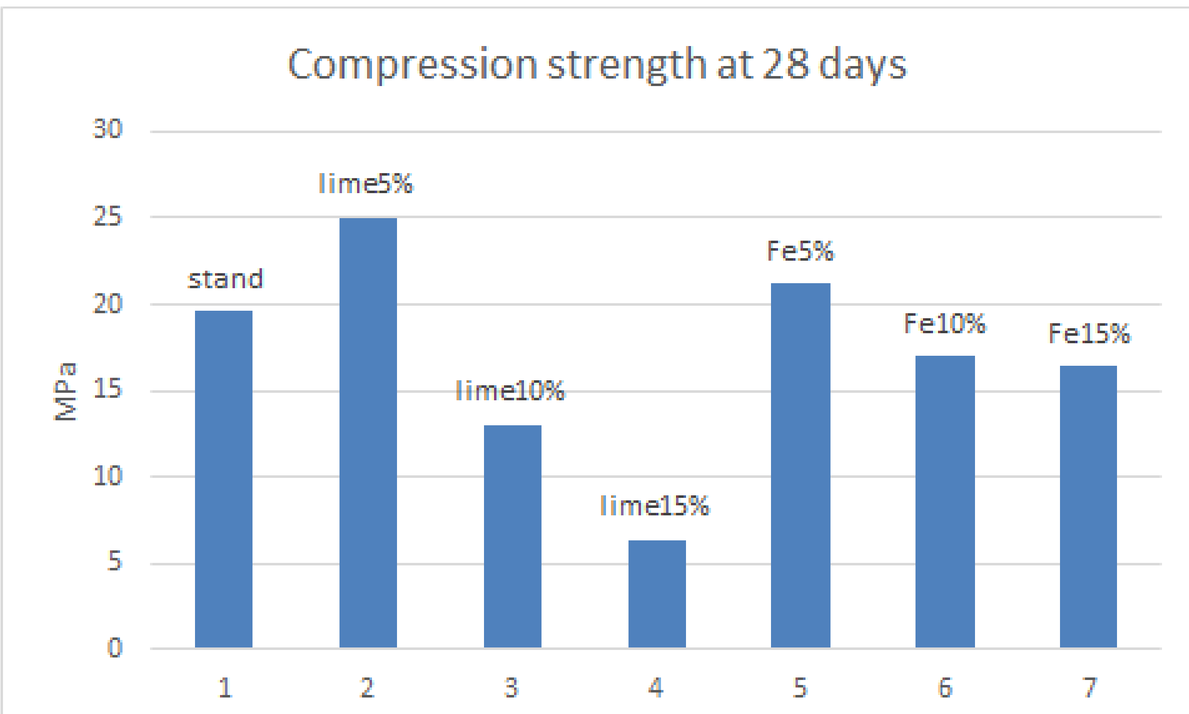

Figure 13: Compressive strength after 28 days

Table 8: Water absorption

	Weight of dry sample	Weight of wet sample	Water absorption %
Standard	2156	2324	7.228%
Lime 5%	2160	2318	7.314%
Lime 10%	1835	2050	11.700%
Lime 15%	2015	2253	10.918%
Fe 5%	2161	2313	7.030%
Fe 10%	2190	2350	7.305%
Fe 15%	2160	2338	8.240%

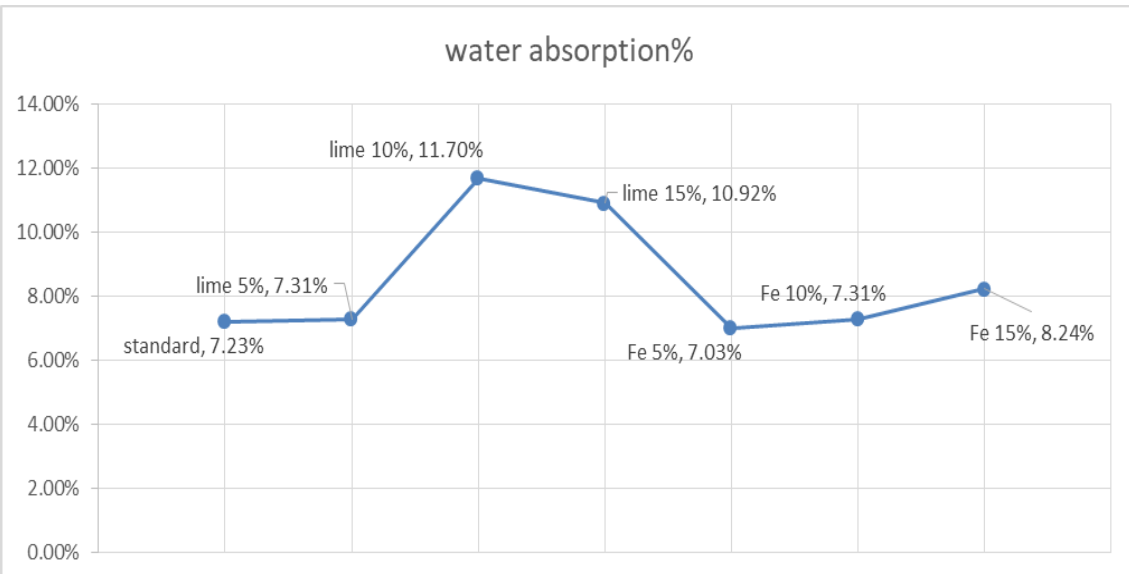

Figure 14: Water absorption for all samples after 28 days

➢ Our new result for using new mixing design in this experiment we replace the cement by iron power

Table 9: Compression test after 7 and 14 days

Sample	**Weight of sample**	**7 days compression test (MPa)**	**14 days compression test**
Standard	2378	22.2	29.8
Fe 3%	2254	21.8	28
Fe 5%	2409	20.4	27.4
Fe 7%	2335	18.5	25.2
Fe 10%	2408	16.7	21.4
Fe 13%	2484	14	19.8
Fe 15%	2409	11.6	16

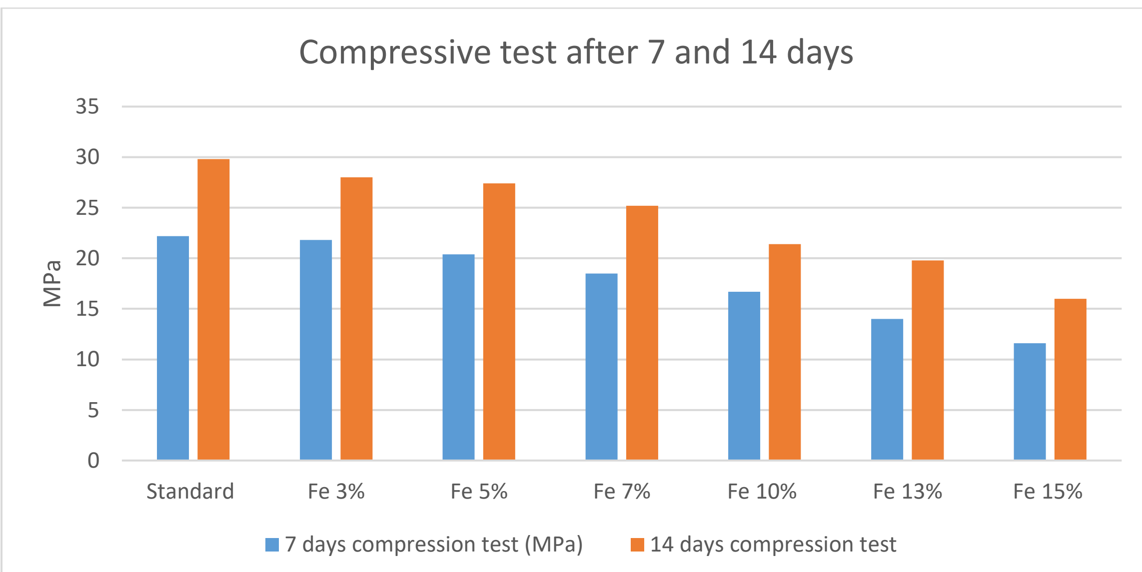

Figure 15: Compressive test after 7 and 14 days

- Our new result for using new mixing design in this experiment we added the iron powder to cement.

Table 10: Compression test for new mixes after 7 and 14 days

Sample	**Weight of sample**	**7 days compression test**	**14 days compression test**
Standard	2264	22.2	29.1
Fe 3%	2329	23.7	30.6
Fe 5%	2352	24.9	34.4
Fe 7%	2410	27.4	37.8
Fe 10%	2465	26	34.2

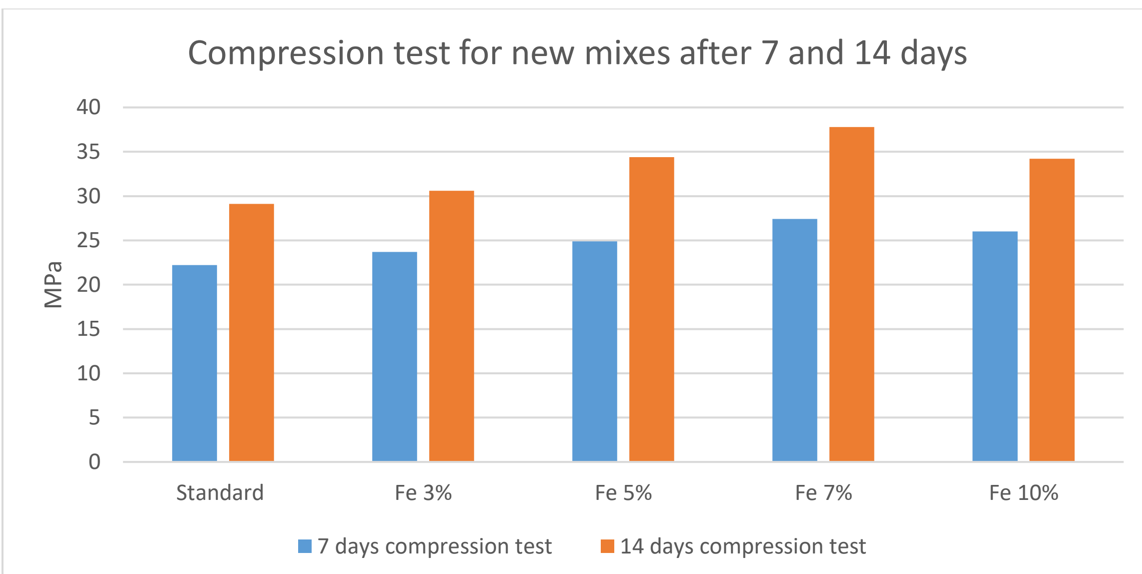

Figure 16: Compression test for new mixes after 7 and 14 days

- Water absorption of best result of compression strength which is adding iron powder to cement

Table 11: Water absorption for best result

Sample	**Weight of dry sample**	**Weight of wet sample**	**absorption test (%)**
Standard	2257	2368	4.89%
Fe 3%	2307	2398	3.97%
Fe 5%	2365	2453	3.70%
Fe 7%	2474	2538	2.56%
Fe 10%	2314	2394	3.47%

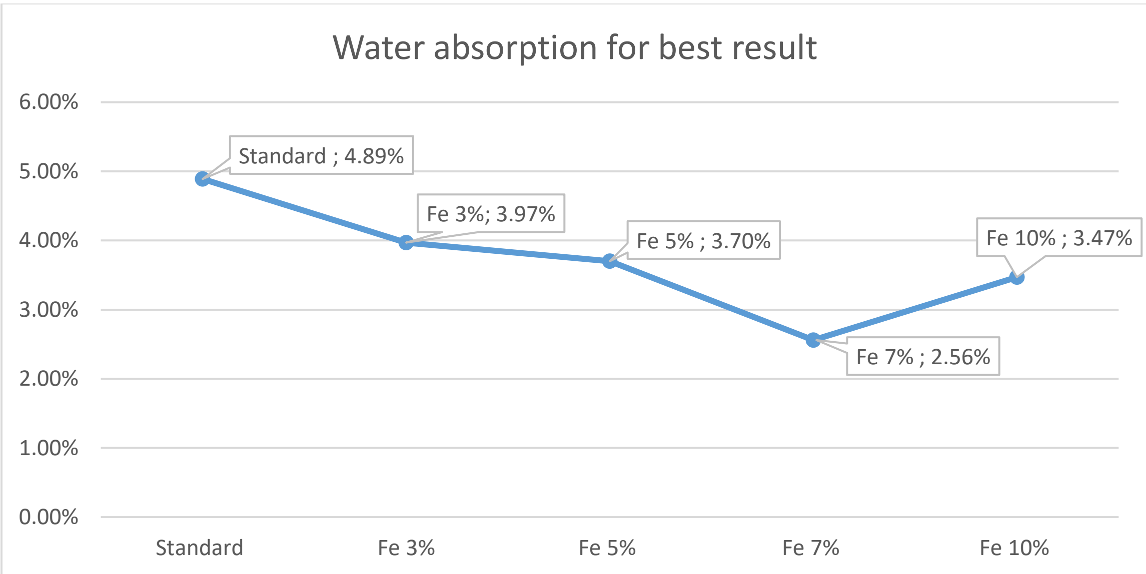

Figure 17: Water absorption for best result

- The best value of add iron powder to cement was 7% of weight of cement and we get the best compression strength and water absorption, and we get if we remove cement and replace it with iron powder the strength and most property will decrease.

5. Conclusion

Our standard sample was 22.2MPa after 7day of compression test and 29.8 MPa at 14 days and water absorption 4.89%. So we will compare all the results with it, Some samples that contain different additives enhance the compression strength and other additive reduce it, We make our sample with added Fe powder in these percentages (3%,5%,7%,13%, 10%, 15%), The best result was observed is for lime 5% which is 18.6 MPa at 7 days and 25MPa at 28 day but the water absorption has increases which is 7.3%, For Fe 7% the compression strength at 7 days was 27.4 MPa and 37.8 MPa at 14 days, After taking results from the water absorption test, the difference between them was measured, and then we could calculate the percentage of water absorption, We have noticed that at 7% the absorption of water was reduced by 50%, then above 7% the water absorption started to increase, this is actually good, because at high percentage of iron powder in concrete, the strength is lower, because even the concrete contents are weakly connected to each other.

6. Constraints and limitations

Unfortunately, we faced many obstacles in this semester; it began with the illness of the lab director which delayed our working in the lab and preparation and testing of samples until the Civil Engineering Department have hired a new lab director. After working for a week, we faced another obstacle which was the covid-19 pandemic that led to the lock down of the university. All our efforts were in vain because we couldn't test the samples and have the results until we started our work again in June. But we couldn't complete our work on the samples because of the lack of time and the renewed lock down of the university in June because covide-19.

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