

PREDICTION THE EFFICIENCY OF CHEMICAL PRECIPITATION AND COAGULATION FOR MERCURY REMOVAL FROM WASTEWATER ⁺

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Abstract :

Mercury is one of contaminating elements for environment being a heavy metal that discharged from many chemical industries, such as Al- Furat State Company for Chemical Industries, where it is used as a catalyst in mercury cells to produce caustic soda NaOH, leading to the introduction of some concentrations of mercury with wastewater discharged from the process plant.

The presence of toxic heavy metals in industrial discharge wastewater has become a matter of environmental concern and certainly, these metals have negative side effects on humans and on aquatic ecosystems.

The outcomes of this research showed that the most effective conditions for the efficient removal of mercury from wastewater by using of precipitation and coagulation method are within, pH range (7-8), and ambient temperatures with 1 hour resident time for each precipitation and coagulation processes. The approach of treatment includes only one filtration process at the end of coagulation process.

The dosage of Na₂S (the precipitated material) has an effective role for the treatment process, which is characterized as inexpensive and easy.

According to the presented results, an efficiency of (99%) for mercury removing can be achieved by this method.

Keywords: Industrial wastewater, mercury removal, chemical precipitation and coagulation.

تقييم كفاءة الترسيب الكيماوي والتخثير في ازالة الزئبق من مياه الصرف

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مضر عبد الوهاب راغب

المستخلص :

الزئبق هو واحد من العناصر الملوثة للبيئة، ويترشح مع مياه الصرف التابعة للكثير من الصناعات الكيماوية، مثال على ذلك، شركة الفرات العامة، حيث يستخدم كعامل مساعد في الخلايا الزئبقية المستخدمة لإنتاج هيدروكسيد الصوديوم، مما يؤدي إلى طرح بعض التراكمات من الزئبق مع مياه الصرف الصحي للشركة.

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لقد أصبح وجود المعادن الثقيلة السامة في مياه الصرف الصناعي من دواعي القلق البيئي. وبالتأكيد فإن لهذه المعادن الآثار السلبية على الإنسان وعلى النظام البيئي المائي. وأظهرت نتائج هذا البحث أن الظروف الأكثر فعالية للأزالة المتوازنة للزئبق من مياه الصرف الصناعي باستخدام طريقة الترسيب الكيماوي والتخثير تكون ضمن مدى الدالة الحامضية (7-8) ودرجة حرارة الجو وساعة زمن انتظار لكلا عمليتي الترسيب الكيماوي والتخثير. مع إجراء ترشيح واحد في نهاية عملية التخثير. وكذلك وضحت هذه الدراسة أن جرعة Na_2S (المادة المرسبة) لها الدور الفعال في عملية المعالجة والتي تتصف بكونها غير مكلفة وسهلة التنفيذ. ووفقاً للنتائج المقدمة يمكن تحقيق كفاءة أزالة للزئبق تقدر بـ (99%) من خلال هذه الإجراءات. الكلمات المفتاحية: مياه الصرف الصناعي ، ازالة الزئبق ، الترسيب الكيماوي والتخثير.

Introduction :

The presence of heavy metals including mercury in urban and industrial wastewater is considered one of the main causes of water and soil pollution. The toxicity of heavy metals on living organisms has been documented, so the presence of high concentrations in industrial wastewater is not only environmentally important, but also strongly reduces microbial activity and diversity of these organisms [1].

The development in the methods of wastewater treatment has rapidly increased to suit with the advanced development of other fields, and the statements of industrial wastewater varied from one chemical industry to another and may differ as well from time to time and this of course will pay researchers to adopt the best technologies for the treatment of industrial wastewater, with the focus on factories that discharge wastewater to the rivers and water drainages, which is without doubt will affect the specifications of water with respect to national and international standards.

Chlorine units, manufacturing of batteries and paints are the most units which discharge mercury with the effluents of chemical industries [2].

The main reason for using mercury in Al-Furat State Company is to produce caustic soda (sodium hydroxide) and chlorine from the electrolysis process using the unit of electrochemical hydrolysis (electrolysis unit), which represents the generating unit for caustic soda by mercury cells. It is the first method used to produce chlorine, caustic soda, hydrogen gas by electrolytic hydrolysis of sodium chloride solution in the electrolytic cells [3].

In this unit, a set of horizontal mercury cells consist of two parts; the main section is the upper broad part and is called the primary cell or electrolyser, while the second part of the cell is a narrow part, which is called the secondary cell or decomposer, and these cells are linked with mercury pump on one hand and with special connections on the other hand. Titanium or graphite anode is placed above mercury cathode, while sodium chloride solution where passed between them with the presence of electrical current. Mercury cathode gathers sodium ions (dissolved ions) from brine to form sodium amalgam, while chlorine gas is released at titanium anode. Then, the amalgam is transferred to a decomposer and reacted with water to produce sodium hydroxide solution, hydrogen gas and mercury which is returned to the electrolytic cell.

All these steps will lead to introduce some mercury concentrations in the water coming out of this unit as a result of a loss of this metal by the mercury cell. The working temperature is

up to (70–90 °C), and this will increase the rates of mercury evaporation added to on-going maintenance work which leads to deposit of mercury in special traps outside the electrolysis unit [3].

The official laboratory confirmed that the wastewater of the company is one of the mercury pollution sources, were the amount of mercury used as a reaction catalyst for the purposes of the production process while the offset quantity of mercury to the electrical decomposition cell depends on the rate of production and this is attributed to loss of mercury due to damage of the cells [3].

This fact was confirmed by the report of the office of research and development, U.S. Environmental Protection Agency (EPA), which confirmed that the most released industrial mercury, comes from the unit of chlorine and caustic soda production [4].

Today, 60% of the European chlorine production results from electrolysis decomposition cells by the so called amalgam process, which is based on electrolytic dissociation of concentrated sodium or potassium chloride solutions with mercury as the cathode of the electrolysis cell. Wastewaters from this process are characterized by high rates of mercury and salt concentrations, but the European Union plans to phase out their use by 2010, while Japan already has replaced most mercury cells, because of incidents of mercury poisoning [5].

There are several techniques used to remove mercury salts from wastewater including chemical precipitation, conventional coagulation, reverse osmosis, ion exchange and adsorption method (activated carbon adsorption) [6].

The precipitation method (a process converts soluble metal compounds into relatively insoluble metal compounds through the addition of precipitating agents, such as: Sodium sulfide (Na_2S) is probably the most common used method for removing of metals from aqueous solutions; it is based on the fact that some metal salts are insoluble in water [7].

A previous study showed that using of chemical precipitation in wastewater treatment with heavy metals less than (1 ppm) can be removed effectively 100% by sedimentation and using lime, were which has a good activity for removing of low concentrations of heavy metals by the formation of calcium compounds with low solubility in water [8].

Actually, chemical precipitation is used to reduce dissolved heavy metals concentrations in water and convert it to un-dissolved molecules with the ability of precipitating it.

The degree of solubility depends on the values of (pH). Generally, most of heavy metals have good solving rates between (pH, 8–11), were, many materials used for turning these metals into salts and precipitate it. At the same time, these materials can change pH values of the solution. Sodium Sulfide, Na_2S , is the most common used material to precipitate inorganic mercury from wastewater to produce un-dissolved mercury sulfide with easy to remove by filtration, and this process is combined with pH adjustment and flocculation followed by solids separation (filtration). This method is effective with high mercury concentrations with (99.9%) removing efficiency and is achieved with pH near (8.5) [9].

This fact is indicated by another study which confirmed that the precipitation method by using sulfide is the best way to remove mercury under basic medium, followed by filtration process with the use of certain salts such as iron salts as coagulant materials (coagulation treatment), to improve the efficiency of treatment [10]. While, another study illustrated that the best conditions for this reaction is induced under near neutral pH (7–9), with positive correlation factor between sulfide concentrations and precipitated metal [11].

Coagulation treatment can be considered as one of methods for wastewater treatment which is used to remove the stability of colloidal particles by adding special chemical substances and is

followed by slow mixing technique to enhance the assembling of colloidal particles, which have already been stability removed. With respect to mercury treatment, some colloidal particles of mercury are still suspended in wastewater and cannot be removed in a deposition, and then, it should be collected from fine particles to large particles. This process is achieved by the addition of coagulants to wastewater. Salts of aluminum ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$), and iron salts such as ferric chloride (FeCl_3), ferric sulfate ($\text{Fe}_2(\text{SO}_4)_3$), and ferrous sulfate (FeSO_4) are very effective for this purpose [9].

The main aim of this research is to study the efficiency of mercury isolation from wastewater of Al-Furat State Company for Chemical Industries, by using chemical precipitation with the addition of sodium sulfide as a precipitant and ferric chloride as coagulant. Also, this study will investigate the effect of precipitant concentration with pH and temperature effects on removing efficiency with filtration effect after precipitation and coagulation processes.

Experimental Work :

Materials :

The following materials were used in the presented work:

- Sodium sulfide ($\text{Na}_2\text{S} \cdot \text{H}_2\text{O}$, 60%).
- Ferric chloride (FeCl_3 , 38%, produced in Al-Furat State Company).
- Caustic soda (NaOH 33%, produced in Al-Furat State Company).
- Hydrochloric acid (HCl , 32%, produced in Al-Furat State Company).

Equipment :

- Baker 500 ml.
- Funnel.
- Pipet.
- Glass rod.
- Water bath (OLS 200 , Refrigerated immersion , Cooler , CS200G , "Grant Sciutific "
- PH-meter "Inolab PH level 1"
- Mechanical stirrer "JANKE &KUNKEL" RW 14H

Methods :

Samples were taken from industrial wastewater of caustic soda production unit of Al-Furat State Company to estimate the efficiency of mercury removing by chemical precipitation and coagulation processes.

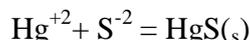
Sodium sulfide is used for precipitation of inorganic mercury and ferric chloride for coagulation process of suspended particles, and followed by process of separating the fine particles of mercury. All the collected samples were sent to Ibn-Sina Company to determine the concentration of mercury using Atomic Absorption A.A. 680 Type (Shimadzu).

Several samples were examined before any treatment and found that the average concentration of mercury (after the mercury trap) is (23.57 ppm) and this was adopted in the calculations.

The treatment process stages of wastewater were as follows:

1– Regulation of pH.

2–Deposition using Na_2S , where it is added to samples of wastewater to convert the soluble mercury to the relatively insoluble mercury sulfide form, which is separated easily by filter paper.



In this study, chemical additive (Na_2S) has been added to water samples collected from the effluent of the unit production of caustic soda in order to determine the efficiency of mercury isolation in the water.

3 – Coagulation by adding FeCl_3 .

4 – Filtration Stage.

According to this procedure, the adjustment of pH and flocculation are combined and followed by solids separation (e.g. gravity settling, filtration). Along the course of treatment, sulfide precipitant is added to the wastewater in a stirred reaction vessel and soluble mercury is precipitated as mercury sulfide.

The precipitated solid HgS was conducted through gravity settling and flocculation with chemical coagulant.

The laboratory work was classified to a series of experiments, as follows:

Group A :

This group studied the effect of (Na_2S) concentration on the efficiency of mercury isolation as single treatment procedure; several samples of wastewater were prepared with (100 ml). pH was measured (10.5) and then several concentrations of (Na_2S) were added (1, 2, 3, and 4 drops) under concentrations of (2.25, 4.5, 6.75, and 9 g/l) respectively. Then, the solution is mixed for five minutes and filtering of the sludge formed by using filter paper after waiting time of 15 minutes. The treated water samples were tested to measure the concentration of remaining mercury.

Group B :

This group studied the effect of (Na_2S) concentration on the efficiency of mercury treatment with fixing of pH value for all samples and using the process of coagulation (adding of FeCl_3) after the precipitation reaction.

In this set, another way for the procedure treatment was adopted by using larger concentrations of Na_2S . Five samples (5, 6, 7, 8, and 9, Table 2) of wastewater were prepared with (4, 6, 8, 10, and 12 drops) under concentrations of (9.0, 13.5, 18.0, 22.5, and 27.5 g/l) respectively of (Na_2S) with pH of (10.5) and (100 ml). Then, pH of these samples is moderated to (7.66) by the addition of one drop of HCl (32%) and waiting for an hour until sedimentation reaction is accomplished. Then, FeCl_3 coagulant with concentration of (41%) by (2 drops) was added with mixing for five minutes to ensure that the collection of suspended particles in the solution was achieved and then it was left for one hour to complete the process of flocculation. Finally, the filtrate was examined.

Group C :

This group studied the effect of pH sample on the efficiency of treatment before the addition of the precipitated material. Four samples of (10, 11, 12, and 13, Table 3) were prepared with (100 ml) under different pH values of (5.89, 7.66, 10.4 and 12.2) respectively with concentration of Na₂S (8 drops, optimum concentration). The solution is mixed for five minutes and left for one hour for sedimentation and coagulation processes.

Group D :

This group studied the effect of sludge separation from solution after the addition of Na₂S. Sample (14, Table 4) was prepared and the initial filtration was done after one hour to observe whether there was an impact on the course of treatment under pH of (8.5) and temperature of (13°C, using water-bath). The secondary filtration was done after one hour to complete the process of flocculation by the addition of FeCl₃ (2 drops).

Group E :

Through the previous experiments, it was observed that the addition of Na₂S caused an increase in pH values between (11–12.5). For this reason, this group studied the effect of pH. Samples (15, 16, and 17, Table 5) with (100 ml) and temperature within (13°C, using water-bath) were prepared with variable pH (8.39, 7.55, and 9.8) respectively, and adjust the pH value after the addition of Na₂S (8 drops) by (8.5, 10.1, and 9.87) respectively. Then it is followed the same previous procedure.

Group F :

This group studied the effect of temperature on the deposition process, were, sample (18) was prepared under pH (8.63) with temperature ranged between (28–32 °C) during the deposition process. The previous steps of treatment were achieved in the same manner of group B.

Discussion :

With respect to group A and according to the presented results in Table (1), were several concentrations of (Na₂S) has been used under (pH=10.5, T=18°C, vol.=100 ml), it can be concluded that the concentration of mercury in sediment decreased with the increasing of precipitate concentration material. The results obtained for this group observed that the best removing efficiency of mercury reached (35%) at 4 drops of Na₂S. This result did not match the standard specifications, which could be attributable to the basic reaction medium with the effect of sludge filtration within 15 minutes. This behavior can be followed up in Figure (1). The formation of some chips and small particles that did not precipitate in the solution was easily noticed. Therefore, it is suggested to use FeCl₃ (coagulant material) in the second group. FeCl₃ promotes the compilation of colloidal and suspended particles of mercury which cannot be removed in a chemical sedimentation unless it is converted into large particles to facilitate their deposition.

For group B, and according to Table (2), better results were obtained than group (A), where it can easily follow up the impact of Na_2S deposited concentration on mercury remaining concentration in the filtrate. It can be seen that the best concentration for the treatment is (18 g/l) of Na_2S which corresponds to (8 drops) where it shows the dark black and dense sludge as compared with the rest of additions. This is a good evidence of an increase in the formation of (HgS) compound as a result of the reaction. In the other hand, it can be seen that the addition of (10, and 12 drops) of Na_2S showed a clear deviation in the rates of sediment formed with rising in mercury concentration,. Seemingly, this can be attributed to an increase in the proportion of Na_2S in the solution which led to dominate of reverse reaction toward the dissociation of sludge and return of Na_2S formation again in the solution. This was observed during the experiments by catching the color of precipitate, where the black color became lighter compared to other additions. This behavior can be seen in Figure (2).

Along the course of experiments, it has been observed that the better concentration of coagulants material was (2 drops) of FeCl_3 , where the increase in the number of added drops showed the appearance of orange color in solution. This indicates the decrease of FeCl_3 isolation efficiency and then it was adopted to use (2 drops) of FeCl_3 for the coagulation process.

Group (C) focused on the studying of pH effect, where it was observed that the best medium for the precipitation reaction was under pH range (7 – 8), as indicated in Table (3).

Figure (3) shows the behavior and the effect of pH of a sample before adding Na_2S solution which deposited material on the remaining mercury in the filtrate. The increasing of mercury concentration can be observed with the increase of pH. This was demonstrated by a previous study which confirmed that the precipitation efficiency declines significantly at pH above 9 [9].

According to the presented results of Table (3), an efficiency of (99%) for mercury removal can be achieved through this procedure.

The reviewed literature reported that a pH near neutral range is the most appropriate for the removal of mercury by the precipitation method with regard to minimizing sulfide dosage [9]. For initial mercury levels, in excess of 10 mg/L of sulfide precipitation can achieve (99.9 %) removal. Optimum pH of 8.5 has been suggested, and precipitation efficiency declines significantly at pH above 9 [9].

For group (C) experiments, it can be clearly demonstrated that the process of coagulation in strong acid and base mediums were less efficient than in the moderate medium (pH = 7.66), where the gels layer formed in the solution is not clearly observed in the initial mediums, especially in strong acid medium (10.5, 12.2), while the clarity of the solution can be seen in the moderate medium. This is a good evidence for the coagulation efficiency in this medium as indicated in the results of Table (3).

In the fourth group (D), the impact of sludge separation has been studied from the solution after the process of precipitation using optimal conditions of (pH = 8.5, 8 drops of Na_2S). It was expected to reach low concentrations of remaining mercury in the treated water, but the results proved the opposite, where less quantity of sediment in the solution with more concentration of mercury in the filtrate was found. This can be attributed to the process of sludge separating from the solution after the end of sedimentation reaction which led to reduce the efficiency of coagulants material. The first filtration process makes a reverse action by lifting the suspended molecules and then affected the efficiency of coagulant material and this was clearly observed through the test where the solution became light orange in its color. This is a good evidence for the presence of large concentration of coagulant in the solution, which finally led to the largest

mercury concentration in the filtrate after the process of flocculation as compared with the course of treatment using only final filtrate process.

It can be seen that mercury remaining concentration in the filtrate, Table (4) has reached a concentration of (0.508 ppm) which is greater than what was obtained in most of third group (C), Table (3). This observation can be attributed to the effect of the addition of Na_2S which increased pH value to reach 12.1 (strong base solution).

In group (E), modifying and controlling pH after the addition of Na_2S was studied. The obtained results, Table (5) showed that the best result was conducted after adjusting of pH solution to (8.5) where mercury concentration of (0.392 ppm) was obtained, which demonstrates the best ability of sedimentation reaction under those circumstances.

All the previous groups of experiments were conducted under temperatures ranging from (13–18 °C) using cold water bath and therefore, group (F), focused on temperature impact on the course of treatment under a temperature range between (28–32 °C).

The results of Table (6) confirm that the high temperatures have a negative impact on the course of treatment where it resulted in very fine sediments, with brown color. The process of coagulation has not clearly separated the colloidal layer from the solution which produced higher mercury concentration in the filtrate. The increasing of temperature between (28–32 °C) may reduce the efficiency of precipitation and coagulation processes by cracking gelatinous substance formed with disintegration of the sediment and finally increasing mercury in the filtrate. Then, it is very significantly observed from this experiment that the appreciable rate of removal can be achieved at an ambient temperature.

Conclusion :

1. This paper has established that the removal of mercury by the precipitation and coagulation methods by using Na_2S as precipitating material and FeCl_3 as coagulant material are highly effective, inexpensive and very easy to operate.
2. The concentration of mercury in the sediment decreased with the increasing of precipitate concentration material.
3. The results showed that the best removing efficiency of mercury reached (99%) at 4 drops of Na_2S (9.0 g / l).
4. It has been observed that the optimum concentration of coagulants material was (2 drops) of FeCl_3 (3.0 g / l).
5. It was observed that the best medium for the precipitation reaction was under pH range (7 – 8) (near neutral range).
6. It can be clearly demonstrated that the process of coagulation in strong acid and base medium were less efficient than in the moderate medium (pH = 7.66).
7. With respect to the process of sediment filtration after the precipitation reaction, less efficiency of precipitation of mercury was found as compared with the sediment filtration after the end of coagulation process.
8. The appreciable rate of mercury removal can be achieved under ambient temperature (up to 28°C).
9. An approximate efficiency of (99 %) mercury removal in the course of treatment can be achieved according to the presented results, where for an effluent stream containing 50 ppm of mercury as maximum concentration; it can be purified to 0.5 ppm, with operating conditions at pH = 7.66 and at ambient temperature with one hour of contact time for precipitation and coagulation processes.

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Tables :**Table (1): Group (A)**

Sample no.	Temp. C°	Vol. ml	Sample pH	Na ₂ S addition drops	Concentration Na ₂ S (g/l)	Waiting time, min.	Concentration Hg (ppm)
1	18	100	10.5	1	2.25	15	21.2
2	18	100	10.5	2	4.5	15	18.5
3	18	100	10.5	3	6.75	15	18.08
4	18	100	10.5	4	9.0	15	15.32

Table (2): Group (B)

Sample no.	Temp. C°	Vol. ml	Sample pH	Moderated pH	Na ₂ S addition drops	Concentration Na ₂ S (g/l)	FeCl ₃ drops	Waiting time, min.	Appearance	Hg (ppm)
5	18	100	10.5	7.66	4	9.0	2	60	Little black	0.622
6	18	100	10.5	7.66	6	13.5	2	60	Little black	0.584
7	18	100	10.5	7.66	8	18.0	2	60	Dark black	0.31
8	18	100	10.5	7.66	10	22.5	2	60	Dark black	0.432
9	18	100	10.5	7.66	12	17.5	2	60	Little black	0.476

Table (3): Group (C)

Sample no.	Temp. C°	Vol. ml	Sample pH	Na ₂ S addition drops	Concentration Na ₂ S (g/l)	FeCl ₃ drops	Waiting time, min.	Hg (ppm)
10	17	100	5.89	8	18.0	2	60	0.335
11	17	100	7.66	8	18.0	2	60	0.225
12	17	100	10.5	8	18.0	2	60	0.45
13	17	100	12.2	8	18.0	2	60	0.66

Table (4): Group (D)

Sample no.	Temp. C°	Vol. ml	pH before addition	Na ₂ S addition drops	pH after addition	Concentration Na ₂ S (g/l)	FeCl ₃ drops	Waiting time, min.	Hg (ppm)
14	13	100	8.5	8	12.1	18.0	2	60	0.508

Table (5): Group (E)

Sample no.	Temp. C°	Vol. ml	pH before addition	pH after addition	Fixed pH	Na ₂ S addition drops	Concentration Na ₂ S (g/l)	FeCl ₃ drops	Waiting time, min.	Hg (ppm)
15	13	100	8.39	11.9	8.5	8	18.0	2	60	0.392
16	13	100	7.55	11.1	10.1	8	18.0	2	60	0.669
17	13	100	9.8	12.4	9.87	8	18.0	2	60	0.456

Table (6): Group (F)

Sample no.	Temp. C°	Vol. ml	pH before addition	pH after addition	Na ₂ S addition drops	Concentration Na ₂ S (g/l)	FeCl ₃ drops	Waiting time, min.	Hg (ppm)
18	28-32	100	8.63	12	8	18.0	2	60	2.04

Figures :

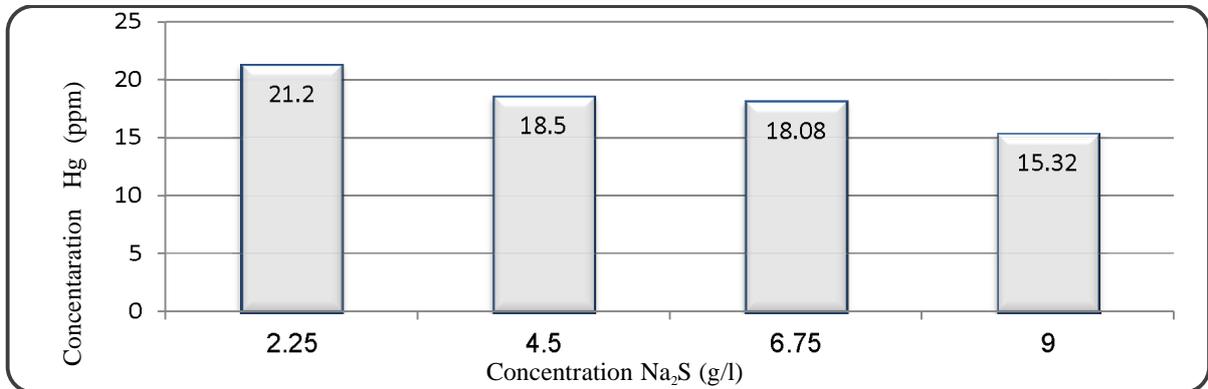


Figure (1): Effect of Na₂S addition on the removal of Hg.

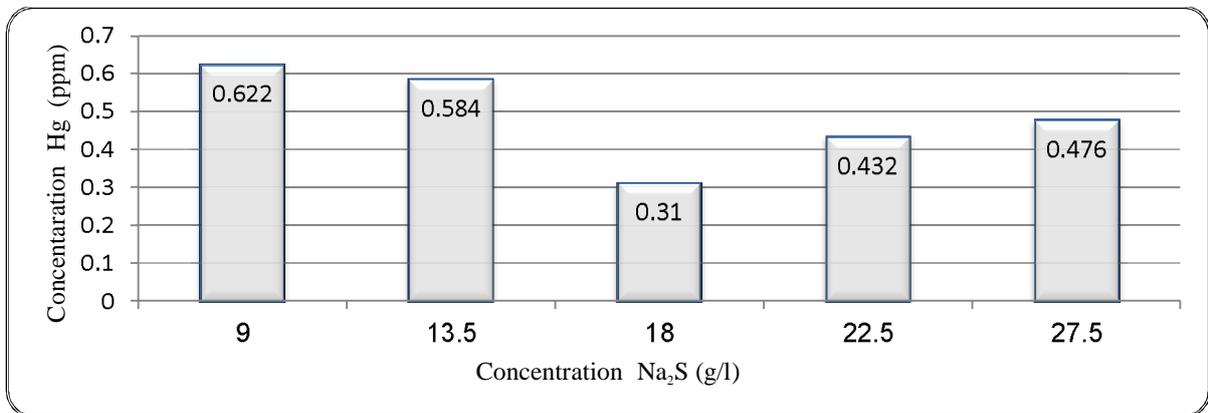


Figure (2): Effect of Na₂S and FeCl₃ addition on the removal of Hg.

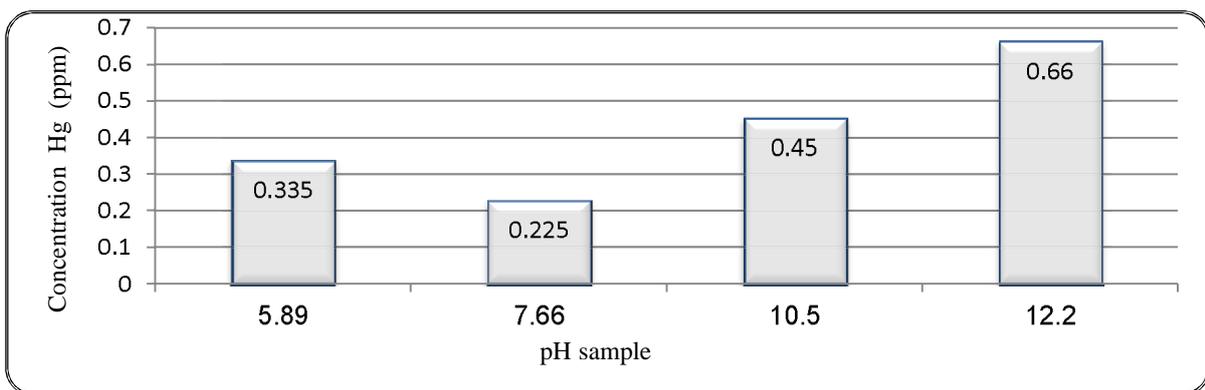


Figure (3): Effect of pH on the removal of Hg.

THE STUDY OF FACTORS AFFECTING THE STRENGTH OF AERATED CONCRETE MORTAR ⁺

Eithar Thanon Dawood *

Abstract :

This study was conducted to examine the properties of aerated concrete using different percentages of aluminum powder (0.05,0.1,0.2, 0.25, 0.3, 0.35 and 0.4%) based on weight of cement with a mixed proportion of 1:2.75 (cement: sand ratio by weight) and using 0.1 % of the aluminum powder mixed with different cement /sand mixed proportions of 1:1.6, 1:1.8, 1:2, 1:2.2 and 1:2.4, respectively. The experimental tests included density, compressive and flexural strength. The results show that as the amount of aluminum powder increases, the density, compressive and flexural strengths would decrease. Besides, the use of aluminum powder as 0.05% would optimize the production of lightweight mortar provided that sand to cement ratio is reduced.

Keywords : Aluminum powder, aerated mortar, lightweight

دراسة العوامل المؤثرة على مقاومة مونة الخرسانة المهواة

إيثار ذنون داود

المستخلص :

هذه الدراسة تتناول فحص خصائص المونة المهواة باستخدام نسب مختلفة من مسحوق الألمنيوم. تم استخدام نسب مختلفة من هذا المسحوق 0.05 و 0.1 و 0.2 و 0.25 و 0.3 و 0.35 و 0.4 كنسبة من وزن السمنت مع نسبة خلط 1:2.75 سمنت/رمل وكذلك استخدام نسبة 0.1 من مسحوق الألمنيوم مع نسب مختلفة من السمنت/الرمل وهي 1:1.6 و 1:1.8 و 1:2 و 1:2.2 و 1:2.4 على التوالي. الفحوصات تضمنت فحص الكثافة ومقاومة الانضغاط والانحناء. النتائج بينت بان زيادة مسحوق الألمنيوم يقلل الكثافة ومقاومة الانضغاط والانحناء. بالإضافة الى ذلك فان استخدام نسب 0.1 او 0.05 من مسحوق الألمنيوم هي نسب مثالية للحصول على مونة خفيفة الوزن عندما يتم تقليل نسبة الرمل الى السمنت.

1. Introduction :

Aerated concrete or mortar is classified as lightweight material, where the airvoids are entrapped in the mortar matrix by means of a suitable aerating agent. The prominent advantage of aerated concrete is that of its lightweight nature, automatically making it economical for the

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design of structural aspects such as columns and foundation. The porosity also provides a high degree of thermal insulation and less material consumption. By appropriate method of production, aerated concrete with a wide range of density ($300-1800 \text{ kg/m}^3$) can be obtained, at the same time offering flexibility in manufacturing products for specific applications (structural, partition and

insulation grades) [1,2]. Based on the pore-formed, air-entraining method (gas concrete – gas-forming) chemicals are mixed into lime or cement mortar during the liquid or plastic stage, resulting in an increase in volume of a porous structure.

Among the aluminum powder, hydrogen peroxide bleaching powder and calcium carbide liberating hydrogen, oxygen and acetylene, the aluminum powder is the most commonly-used aerating agent. The effectiveness of aluminum powder in the cementing process is influenced by its fineness, purity and alkalinity of cement, along with the means taken to prevent the escape of gas before the hardening of mortar [3].

The introduction of pores in the cement matrix is achieved through mechanical means either by the pre-formed foaming (foaming agent mixed with a part of mixing water) or the in-situ foaming (foaming agent mixed with the mortar). The method of pore-formation influences the microstructure, and thus its properties. The material structure of aerated concrete is characterized by its solid micro-porous matrix and macro-pores, the macro pores are formed due to the expansion of the mass caused by aeration and the micro-pores appear in the walls between the macro-pores [3-5].

The ratio of water to cementitious materials is related to the amount of aeration obtained and this enables the density to be determined. For a given density, water-cement ratio increases with the proportion of sand. For Autoclave Aerated Concrete (AAC) with pozzolans, water-solids ratio appears to be more important than the water-cementitious ratio, irrespective of the method of pore-formation [6].

As many physical properties of aerated concrete depend on the density ($300-1800 \text{ kg/m}^3$), it is essential that its properties qualify with density. While specifying the density, the moisture condition (i.e., oven-dry condition or at equilibrium with atmosphere) needs to be indicated.

The aerated concrete as delivered from the autoclave may be $15 \pm 25\%$ heavier than the oven-dry density of such concrete. However, this value can be as high as 45% for very low density aerated concrete [6].

The specimen's size and shape, method of pore-formation, direction of loading, age, water content, characteristics of ingredients used and method of curing are reported to influence the strength of aerated concrete [1,5]. The pore structure of the material and mechanical condition of pore shells has a marked influence on the compressive strength. Density reduction by the formation of large macro-pores is found to cause a significant strength reduction. Generally, the compressive strength increases in linear relation with the density [7-8].

2. Materials and mix proportions :

2.1. Materials :

The cement used in mortar mixtures was an ordinary Portland cement product of (Tasek Corporation Berhad). The chemical compositions of Ordinary Portland are given in Table 1.

The aluminum powder type Y250 was used as the gaseous agent to introduce the porosity within the mass of concrete mortar. Its properties are shown in Table 2.

The fine aggregate used is natural sand; with the fineness modulus of 2.86.

2.2 Mix proportions :

An approximated mortar composition is given in Table 3. The mixture is designed according to the absolute volume method given by ACI 211.2-98 [9]. In the beginning, the first seven mixtures (AL1-AL7) were prepared using the mix proportion 1:2.75/0.5 (cement: sand/water-cement ratio) with different percentages of aluminum powder (0.05 %, 0.1%, 0.2%, 0.25%, 0.3%, 0.35%, 0.4%) based on cement weight. The mixes (AL8-AL12) were prepared by changing the mix proportion of S/C (sand/cement) but maintaining the w/c to 0.45 and the aluminum powder of 0.1%. Subsequently, the aluminum powder was reduced to 0.05% and the w/c was maintained as in the previous case to prepare the other mixes (AL13-AL14). Using of 0.05% of aluminum powder is a trial to produce the aerated mortar from the least percentage of such powder.

3. Test methods :

Three 50mm cube samples were used for each mix for the density and compressive strength tests after water curing condition up to the age of test. The flow test for mixes was performed according to ASTM C230, while the test of fresh density were conducted directly after casting in cubes according to ASTM C567. The cube specimens were left in the molds for 24 hours at 20 °C. After demolding, the specimens were kept in water curing until the age of test. The test was conducted in saturated surface dry conditions for all specimens at various ages of test, according to ASTM C642. The test on the compressive strength at different ages was performed in accordance to ASTM C109. In addition, prismatic steel molds (40 × 40 × 160 mm) were used for the flexural strength test according to ASTM C348.

4. Results and Discussion :

4.1. Fresh Density & Hardened density :

Tables 3&4 show the results of the fresh and hardened density mortar for all mixes. The results show that the increase of aluminum powder in the aerated concrete mixes reduces the fresh and hardened density significantly as shown in Figure 1. In addition to that, it can be seen that the percentage of S/C (sand/cement) has affected the fresh and hardened density when the percentage of aluminum powder is retained at 0.1%. Figure 2 illustrates the relationship between S/C with the fresh density, where the increasing value of the sand content increases the fresh density as well as the hardened density. This behavior can be attributed to the interior voids in mortar which are resulting from the use of aluminum powder [10,11].

4.2. Compressive strength :

From Table 4, it can be concluded that the increase of aluminum powder affects the compressive strength due to the excess of porosity in the aerated mortar mix. In other words,

according to Tam & Lim, (1987) [12], the compressive strength correlates adversely to a/c ratio (air/cement ratio).

Meanwhile, as for the mixes AL1-AL7, the increase of aluminum powder of the same mixed proportion increases the amounts of voids in cement paste and this further leads to the decrease in compressive strength [13,14]. Figure 3, illustrates the correlation between aluminum powder and compressive strength, where the raising of the said powder from 0.05 % to 0.4% reduces the compressive strength for the same mixed proportion by about 72% (a drop from 31.4 MPa to 8.8 MPa).

On the other hand, Figure 4 shows that the increase of s/c ratio (sand/cement ratio) increases the compressive strength of the aerated mortar at a certain percentage of aluminum powder (0.1%), and this is also due to the reduction of air voids where the sand content has a crucial influence on the increase of volume of cement paste during expansion [14-16]. Moreover, the increase of the density leads to the increase of compressive strength of the aerated mortar as well [15-17]. The relation of compressive strength with density is found to be compatible whereby the increase of density will be accompanied by the increase of compressive strength. This relation is illustrated as in Figures 5,6 and 7. It can be noticed from Figure 7 that with fixed aluminum powder content, the increase for each of compressive strength and density may happen for the same causes related to the role of sand in the aerated concrete as listed above.

4.3. Flexural strength :

The flexural strengths of the aerated concrete mixes are shown in Table 4. The increase of compressive strength will increase the flexural strength for the aerated concrete, and it is also observed that the flexural strength at 28 days is about (20-25%) of the compressive strength of the same age. The Figures 8, 9, 10 & 11 illustrate the relation of compressive strength with the flexural strength at 7 and 28 days of water curing. Also, it is noticed that the factors which affect the compressive strength may also affect the flexural strength, although it needs to be said, at lesser extent. Thus, for the mixes AL1-AL7, it can be seen that the use of 0.4% of aluminum powder reduced the flexural strength of the aerated concrete by about 63% compared to aerated mortar produced by 0.05% aluminum powder.

5. Conclusions :

Tests have been conducted to study several properties of the aerated concrete using different percentages of aluminum powder with different mixed proportions using the same powder.

Some useful conclusions can be drawn from this study:

- 1- For a given mix proportion (cement: sand = 1:2.75), the increase of aluminum powder content reduces the density and hence the compressive and the flexural strengths. Thus, the reductions for such strengths were 72% and 63%, respectively as aluminum powder increased from 0.05% to 0.4%.
- 2- The increase in sand/cement ratio increases the density and compressive strength when the aluminum powder is maintained at 0.1%.
- 3- The compressive strength of aerated mortar produced by 0.1% of aluminum powder can be enhanced when S/C ratio is 2 or more.

6. Acknowledgement :

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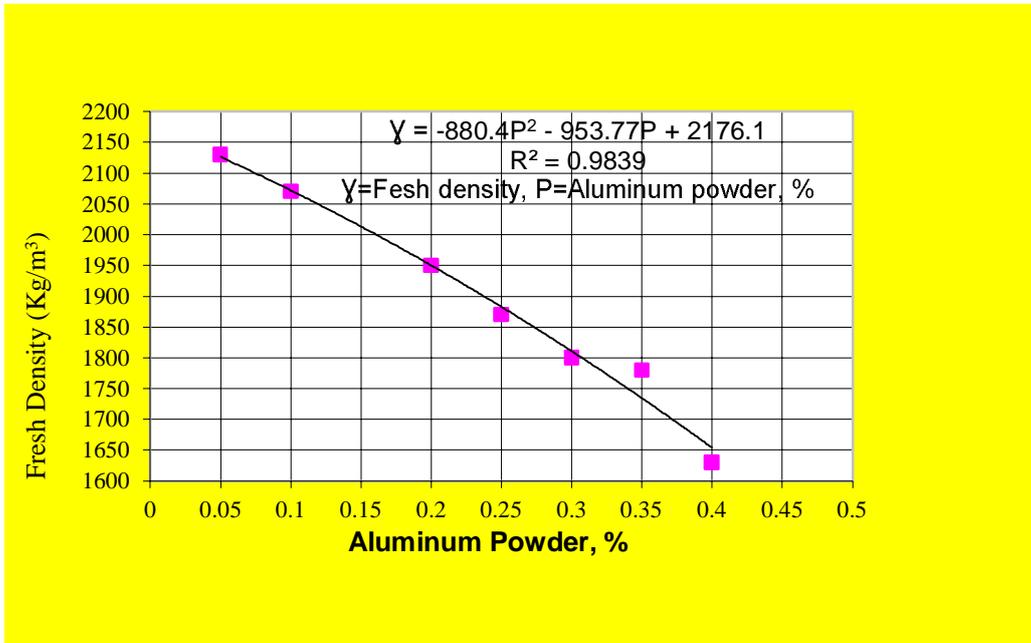


Figure (1): Correlation between Aluminum powder percentage and Fresh density for the Aerated mortar.

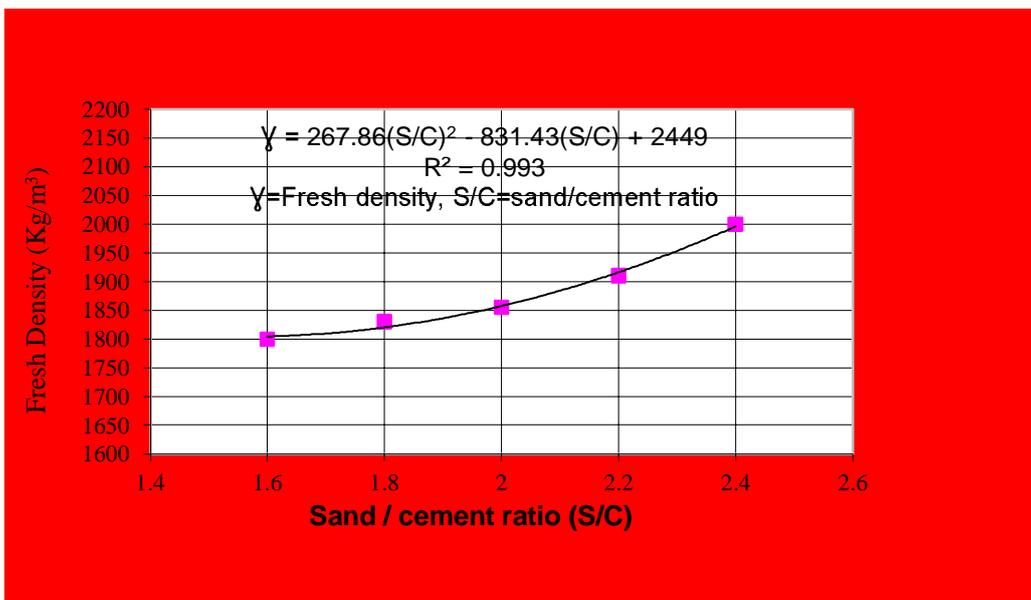


Figure (2): Correlation between sand/cement ratio (S/C) and Fresh density for the Aerated mortar with 0.1% AL. Powder

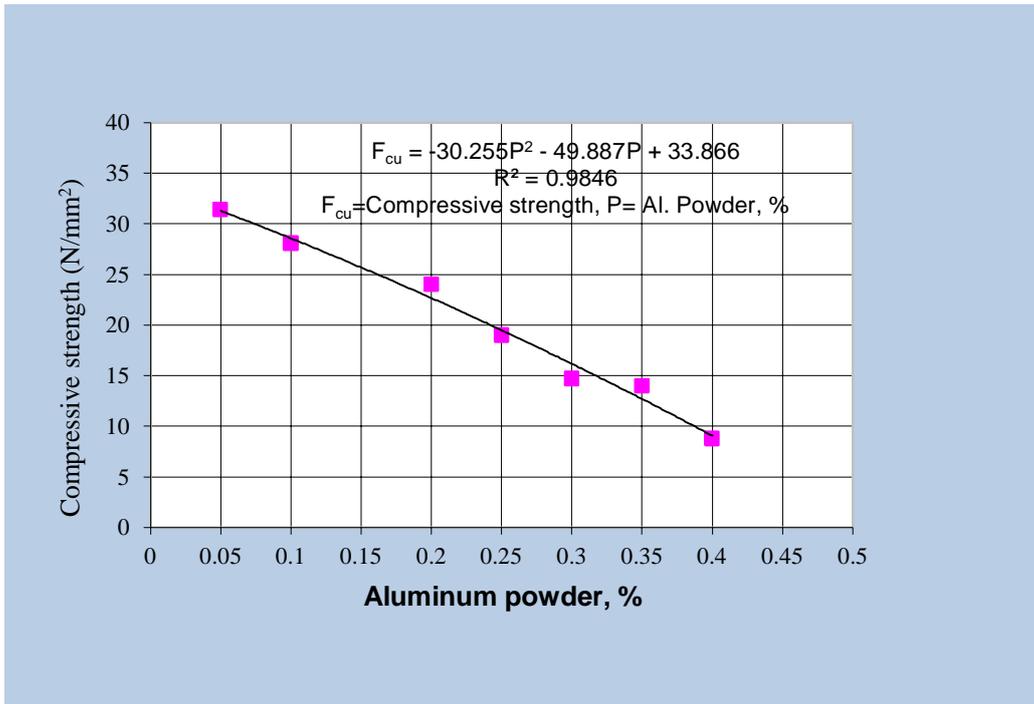


Figure (3): Correlation between Aluminum powder percentage and compressive strength of Aerated mortar at 28 days.

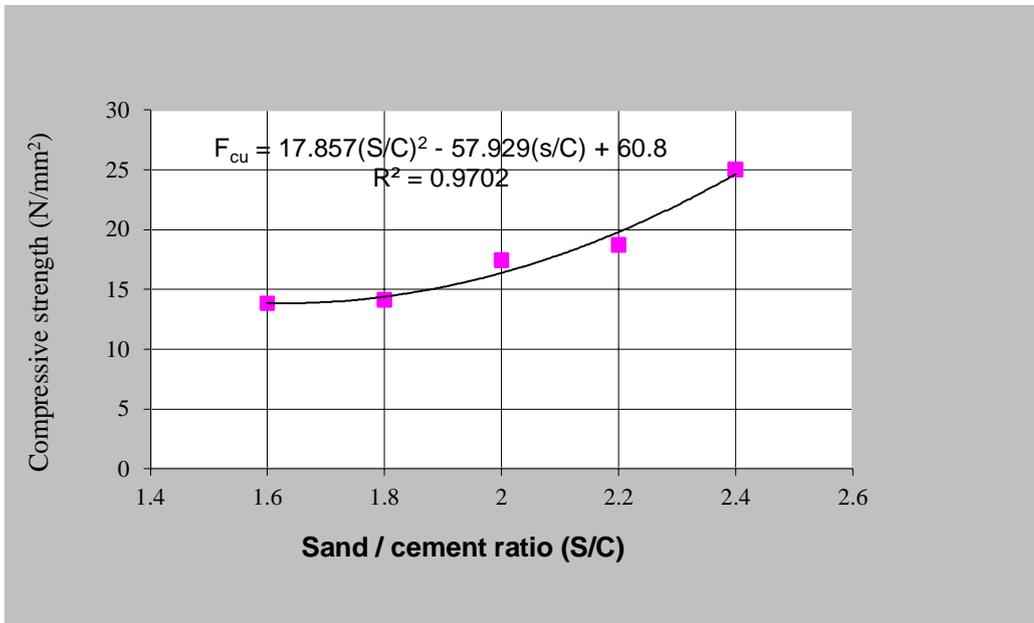


Figure (4): Correlation between sand/cement ratio and compressive strength for the aerated mortar with 0.1% AL Powder at 28 days.

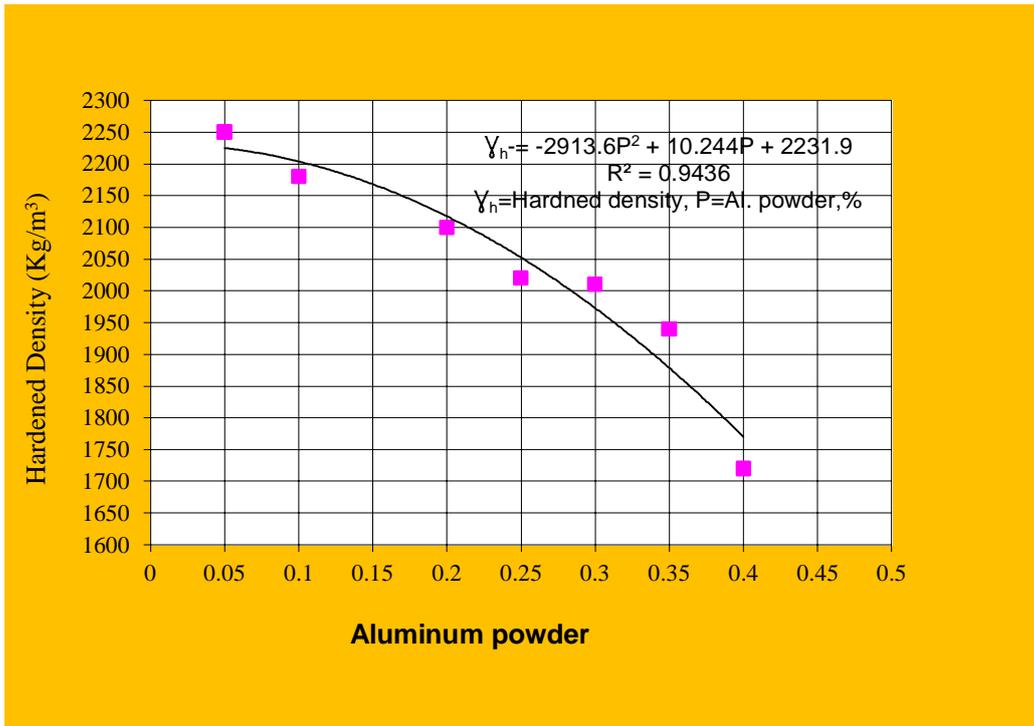


Figure (5): Correlation between Hardened density at 28 days with different Aluminum powder percentages

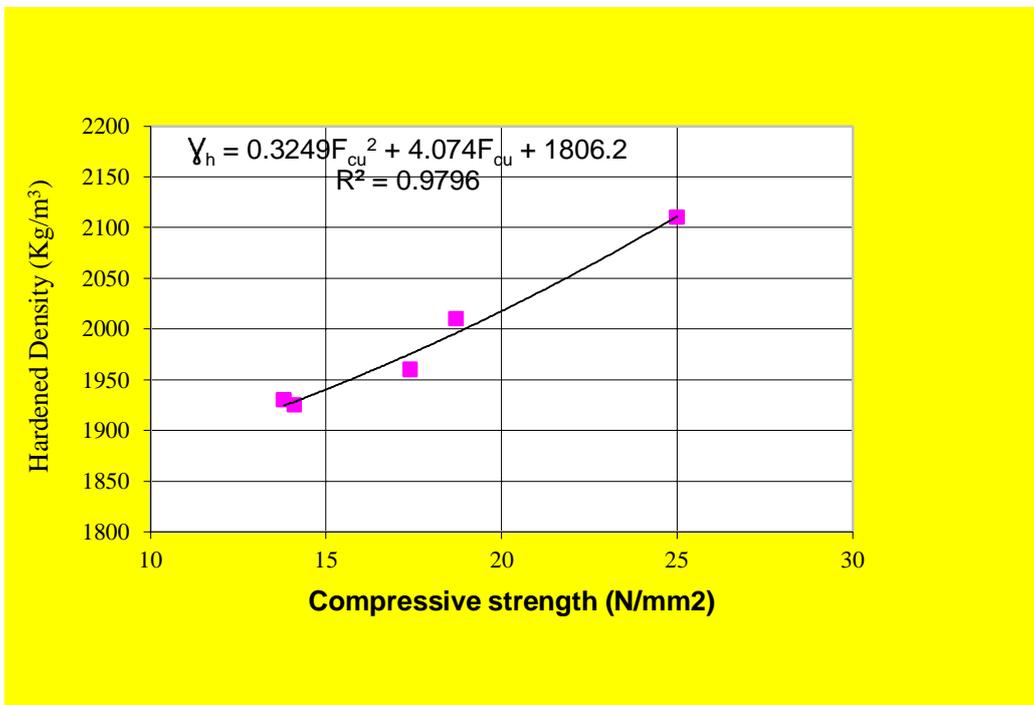


Figure (6): Correlation between Compressive strength and Hardened density at 28 days with Aluminum powder 0.1%.

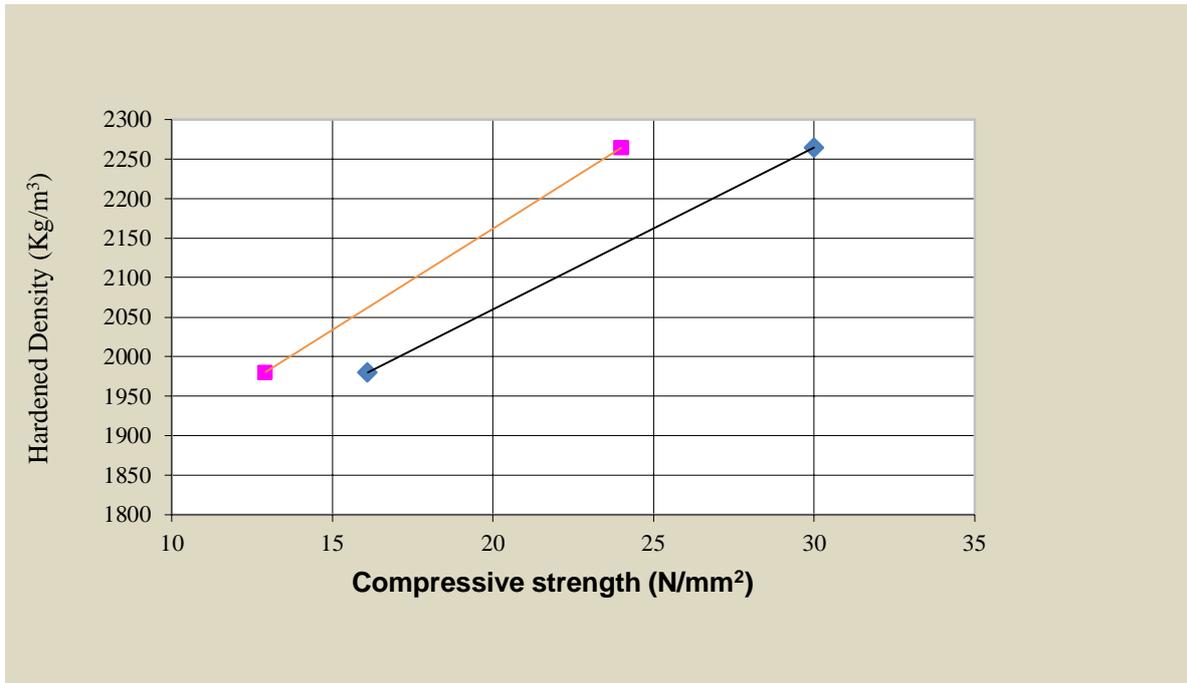


Figure (7): Correlation between Compressive strength and Hardened density at 7& 28days with Aluminum powder 0.05%.

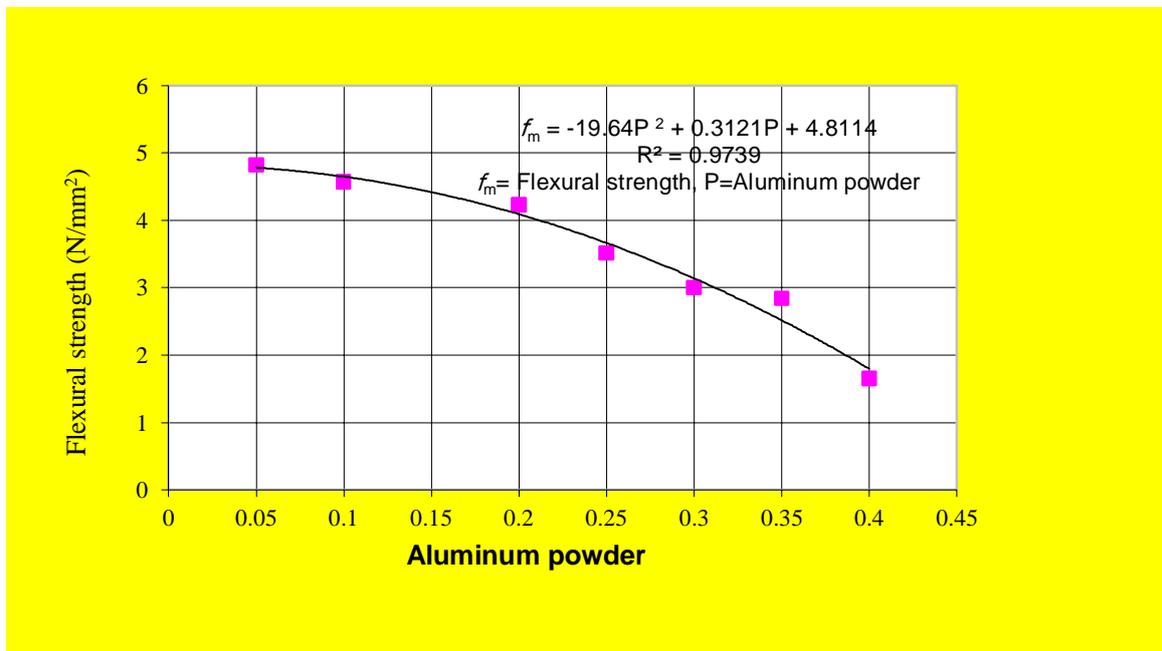


Figure (8): Correlation between Flexural strength at 7 days with different percentages of Aluminum powder 0.1 %

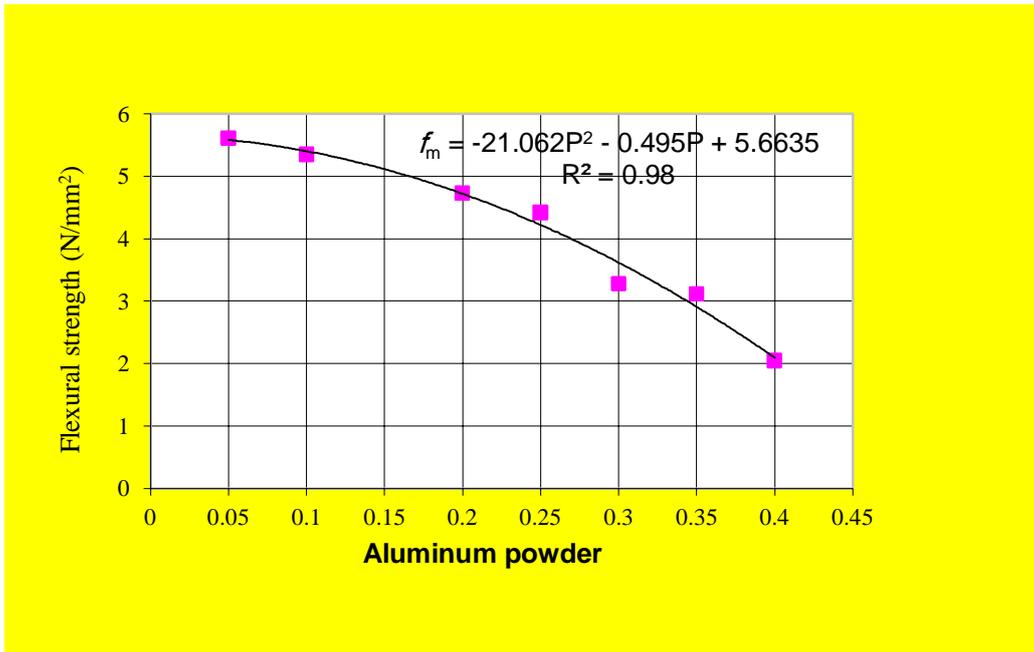


Figure (9): Correlation between Flexural strength at 28 days with different percentages of Aluminum powder 0.1 %

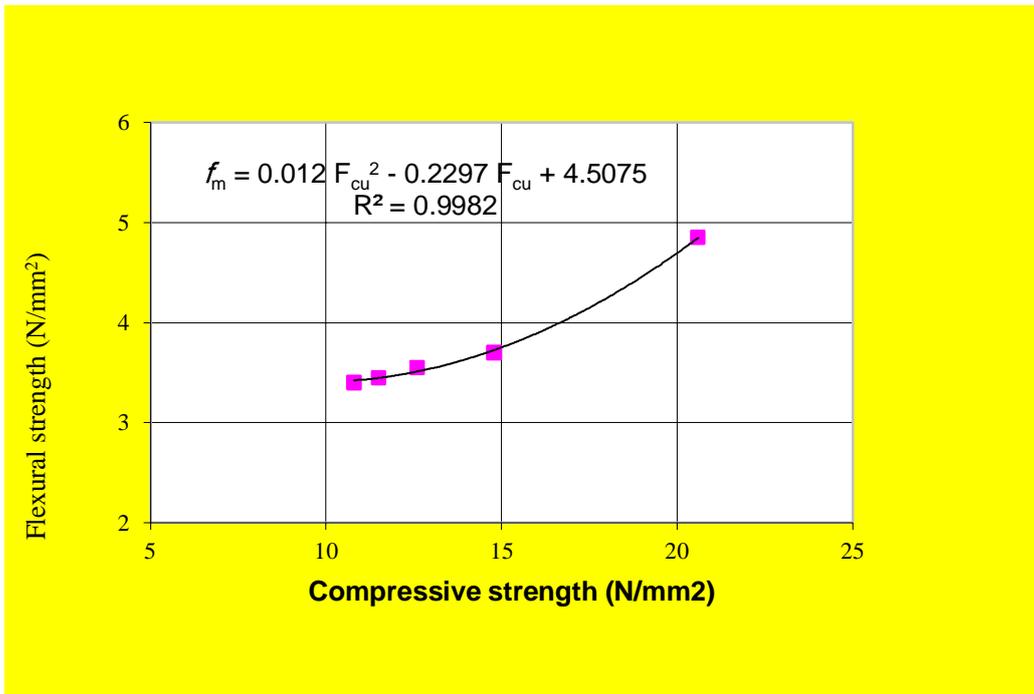


Figure (10): Correlation between Compressive strength and Flexural strength at 7 days with Aluminum powder 0.1 %.

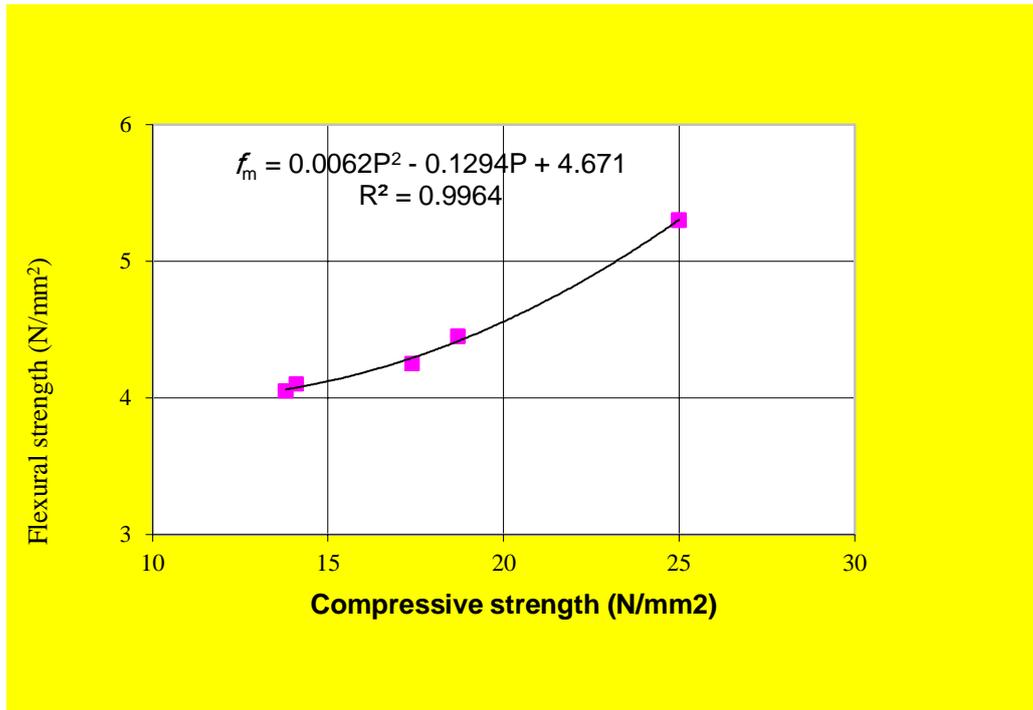


Figure (11): Correlation between Compressive strength and Flexural strength at 28 days with Aluminum powder 0.1%

Table (1): Chemical composition and physical properties of Ordinary Portland Cement

Constituent	Ordinary Portland Cement	Limit of Iraq specification No.5/1984
	% by weight	
Lime (CaO)	64.64	-
Silica (SiO ₂)	21.28	-
Alumina (Al ₂ O ₃)	5.60	--
Iron Oxide (Fe ₂ O ₃)	3.36	-
Magnesia (MgO)	2.06	≤5.0%
Sulphur Trioxide (SO ₃)	2.14	≥2.8%
N ₂ O	0.05	-
Loss of Ignition	0.64	≤4.0%
Lime saturation factor	0.92	
C ₃ S	52.82	
C ₂ S	21.45	
C ₃ A	9.16	
C ₄ AF	10.2	
Initial setting time (mins)	235	Min. 45 min.
Final setting time (mins)	290	Max. 600 mins
Fineness (Blain m ² /kg)	275	Min. 230

Table (2): Properties of aluminum powder*

Materials	Purity %	Apparent density (gm/m ³)	Melting Point (°C)	Boiling Point(°C)	Fineness (cm ² /g)
Aluminum Powder	99.7	0.15	620	2500	17000

*Tested by the manufacture

Table (3): Aerated Mortar Mixes

Index	Cement Kg./m ³	Water Kg./m ³	W /C	AL %	Sand Kg./m ³	Flow %	Fresh Density Kg./m ³	Remarks
AL 1	450	225	0.5	0.05	1240	100	2130	1:2.75
AL 2	440	220	0.5	0.10	1210	105	2070	1:2.75
AL 3	430	215	0.5	0.20	1180	115	1950	1:2.75
AL4	420	210	0.5	0.25	1155	120	1870	1:2.75
AL5	410	205	0.5	0.30	1130	120	1800	1:2.75
AL6	400	200	0.5	0.35	1100	125	1780	1:2.75
AL7	390	195	0.5	0.40	1070	125	1630	1:2.75
AL8	590	265	0.45	0.10	945	80	1800	1:1.6
AL9	560	250	0.45	0.10	1010	80	1830	1:1.8
AL10	530	240	0.45	0.10	1060	90	1855	1:2.0
AL11	510	225	0.45	0.10	1120	90	1910	1:2.2
AL12	490	220	0.45	0.10	1175	100	2000	1:2.4
AL13	510	230	0.45	0.05	1225	90	2200	1:2.4
AL14	600	270	0.45	0.05	960	75	1910	1:1.6

Table (4): Physical and Mechanical Properties of Aerated Mortar Mixes

Index	Density Kg./m ³ 7days	Density Kg./m ³ 28days	Compressive strength (MPa) 7 days	Compressive strength (MPa) 28days	Flexural strength (MPa) 7 days	Flexural strength (MPa) 28 days
AL 1	2220	2250	22.1	31.4	4.82	5.61
AL 2	2160	2180	19.8	28.1	4.57	5.35
AL 3	2060	2100	16.1	24.0	4.23	4.73
AL 4	1980	2020	14.5	19.0	3.51	4.42
AL 5	1940	2010	9.5	14.7	3.0	3.28
AL6	1860	1940	9.0	14.0	2.84	3.12
AL 7	1700	1720	6.0	8.8	1.65	2.05
AL8	1845	1930	10.8	13.8	3.40	4.05
AL9	1835	1925	11.5	14.1	3.45	4.1
AL10	1930	1960	12.6	17.4	3.55	4.25
AL11	1950	2010	14.8	18.7	3.70	4.45
AL12	2070	2110	20.6	25.0	4.85	5.30
AL13	2250	2265	24.0	30.0	4.90	5.72
AL14	1950	1980	12.9	16.1	3.16	3.88