

An Experimental Study on the Possibility of Demolition of Destroyed Concrete Buildings with Different Types of Acid

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Abstract

With the increase of environmental damage, especially in the Arab region as a result of wars in the past years and the destruction of infrastructure, engineers are concentrating more on reducing adverse environmental influences. In this study, the effect of three types of acids on the concrete properties, the corrosion progresses, chemical reaction rate and the penetration of the acid to the concrete were tested. The types of acids used in this research are Nitric, Sulfuric and Hydrochloric acids. It has been adopted to make holes in concrete cubes before submerging them with acid solutions to determine the penetration and chemical reaction rate by observation, all the solutions were ready to be poured in the holes using 2 cubes of concrete for each of the 8 solutions which have different concentrations of acids. The results indicated that the rate of chemical reactions are not the same for the acids which they have different concentrations. The Nitric acid is more corrosive and reactive since the concrete absorbed 100 mL in 330 minutes through a contact area of 23 cm². Nitric acid has reduced the compression strength by 37% and the mass loss is 21%.

Keywords: Acids Attack, Nitric, Hydrochloric, Sulfuric, Chemical reaction

1. INTRODUCTION

Urban and industrial developments in recent decades have been accompanied by significant increases in the need to demolish old buildings [Koushkbashi, 2019]. In addition, catastrophes, wars, and earthquakes are the reasons that make the demolition inevitable. Demolition can be defined as the dismantling; de-construction; wrecking; knocking; cutting or pulling down of any structure, building, plant, edifice [Dbpgdnz, 2019, Al Adday, 2019]. Demolition waste as well as construction waste constitutes the largest volume of municipal waste requiring high transportation and landfill running costs [Sallal R. Abid., 2018; Najib N. Gerges.2018]. Statistics indicate that developed countries suffer from spending big budgets on the maintenance, repair and demolition of infrastructure, where spending up to 50% in the EU, and 35-45% in UK [Gardner, 2018]. The large budgets in this field are due to the desire of human to search to meet his

basic needs in the new housing that is less expensive and better environmentally [Arowojolu, 2019]. However, one of the challenges facing the civil engineer is the choice of demolition process. For example, old processes, the structure was typically dismantled by manual hammer [Parnav, 2015]. Demolition of buildings in the traditional process (pulling down a building with a backhoe) often produces noise, dust, undesirable vibrations of adjacent buildings and water pollution. For the modern technology which relied on the dismantling of the construction parts in a manner that is contrary to the stages of construction and thus can reduce the environmental damage, this method called a deconstruction or green demolition [Schultmann, 2008]. On the other hand, there are several other methods of demolition, from blasting methods, ball and crane, pusher arm, deliberate collapse, wire pulling, to a hydrodemolition [Anumba et al, 2003; Aazdak, 2008; Awad, 2020]. Green demolition procedure has more time and higher budget than conventional demolition [Bradley and Timothy, 2018]. But, these methods have several advantages, including recover waste materials for recycling, the ecological health of the community, and a safe work environment [Usman et al, 2013]. Concrete is used in bridges, rigid pavement, dams, residential buildings and so on. Concrete is a combination of paste and coarse, fine, and filler aggregates, where the water and Portland cement make up the paste. Hydration is the process by which cement reacts chemically, the paste toughens and increases strength to create a solid body known as concrete [PCA, 2002, Fatima Alsaleh, 2019]. But after casting the concrete, it is necessary to curing, it is necessary to complete internal reactions in cement paste [Saffar., 2019, Al Adday & Awad, 2019]. Concrete has been used broadly in construction engineering because of its long durability, low cost, and high strength [Saleh A, 2015, Al Adday, 2020]. With these benefits, however, it has its most significant weaknesses, such as low tensile resistance, shrinkage and subsequent cracks, low resistance for fire, particularly at temperatures above 500 °C, and alkaline property [Changlin Zhou, 2018; Aleksandar Nikolov 2017]. Its alkalinity nature of Portland cement makes it susceptible to attack acid [Attiogbe and Rizkalla, 1988]. As for the durability of concrete, it is much affected by sulfates, salt, acid solutions, freezing and thawing. [Changlin Zhou., 2019], where durability, workability, strength are the three main

properties of concrete [Behnam Vakhshouri, 2015].

To know how acid attacks the concrete, it is necessary to identify the mechanism by which the reactions are made, where calcium hydroxide (Ca (OH) 2) is a typically by-product of process of cement hydration that can be expressed as equation (1) [Concrete pH Testing Problems and Solutions, 2015].

Calcium Silicate + Water → Calcium Silicate Hydrate
(C-S-H) + Calcium Hydroxide (Ca(OH)₂)

……Eq (1)

The reaction between the portion of Ca (OH)₂ and an acid which yields a Calcium salt (highly solvable) this process is called acid attack, the simple reaction is presented in equation (2).

Acid + Calcium Hydroxide → Calcium Salt + Water

……Eq (2)

A more destructive situation of acid attack happens as soon as concrete is attacked by sulfuric acid. The Stages of Ca(OH)₂ dissolution are done in two ways. The first stage begins in the cement paste when the reaction of both acid and Ca(OH)₂. The second stage starts the reaction of C-S-H with acid, this stage will not occur until completely Ca(OH)₂ is consumed. The dissolution of the C-S-H in this case, serious structural deterioration can be caused to the concrete [Acid Attack – Mechanism, 2017].

Many studies have been done over many years to investigate the effect of adding admixtures to increase the physical and mechanical properties of concrete [Alfoul. 2019]. But in the literature review here, it will focus on what materials are most effective on concrete erosion. A study conducted in 1988 by Attiogbe and Rizkalla pointed out that the effect of concentration ratios of different types of acid on the concrete properties is significant, where nitric, hydraulic, and sulfuric acids were used to examine the possibility of using acids in construction demolition. In 2005, both Kawai and Shinmi researched the use of acid in cement mixtures. In this study, the surface corrosion of the concrete was measured when exposed to SA, where concrete samples were submerged in several content of SA, and then the thickness of the area corroded by SA were determine. Also, deteriorated concrete areas were investigates with an XRD. The results of this study presented that the proportion of concrete deterioration produced by SA attack mainly depends on the pH of SA solutions. As well, it also showed that the depth of the damaged concrete is somewhat proportional to the duration of exposure to SA attack. Another investigation about acid attack achieved by Barbhuiya and Kumala in 2017. Five concrete specimens were cast. The first specimen was a control blend with 100% OC. The other mixtures contained OC with a variable proportions of fly ash (FA) and ultra-fine of fly ash (UFFA). An examinations were performed to influence acid attack on the concrete behavior, where sulphuric and nitric

acid were used. The tests showed that losses value of compressive strength concrete were the lowest in which 30% FA and 10% UFFA as replaced content of total cement. This modified concrete mixture also displayed the lowest loss of mass when exposed to such an acid attack. The results show that acid attacks led to a decrease of compressive strength of concrete and weight loss. A recent study completed in 2019 by Xujian Lin and others. They measured the surface corrosion of concrete samples under the influence of bio-sulfuric acid (BSA), they made a comparison between two types of concrete mixes, one alkaline active concrete (AAC) and the ordinary concrete (OC). Investigational results revealed that the thickness, hardness and permeability of the corrosion surface of OC are noticeably larger than AAC. Furthermore, the bacterial influence on corrosion surface of AAC is larger than that of OC. corrosion surface track of BSA smaller than that of OC. Consequently, the AAC has corrosion resistance to influence BSA higher than that of OC.

2. RESEARCH OBJECTIVES

With the frightening and unexpected masses of demolished buildings in the Arab region, the main challenge for engineers is to find new and innovative demolition techniques. In this study, a new techniques have been adapted to dismantle and destroy concrete structures by exposing them to quantities of chemical solutions. The following process was implemented to examine the effect of three types of acid attack on the concrete: Nitric, Sulfuric and Hydrochloric acids. First, measure the penetration of acid to the concrete using different concentrations of acid and the concrete. Second, determine the most destructive attack of the concrete among the above mentioned acid. Third, conclude the decrease of compression strength of concrete. It has been adopted to make holes in concrete cubes before submerging them with acid solutions.

3. MATERIALS PROPERTIES AND PROCEDURES.

The details of the material information, investigational program, examination procedures and apparatus have been provided in this study. And then analyze the results of the investigational program have been presented. For illustrate an influence of acid attack on concrete surface deterioration, weight loss, thickness change, the concrete samples are casted based on ASTM C39-05. The concentrations of acids that have been used in this study are shown below:

1. Hydrochloric Acid: 36%.
2. Nitric Acid: 36, 50 and 69%.
3. Sulfuric Acid: 36, 50, 80 and 99%.

There are two types of acids that are available in the market, commercial grade and lab grade. In this study only commercial grade acids have been used even though the commercial grade acids have impurities. Where the total number of acids solutions were used are 8 solutions. The

reasons for using commercial-grade acids are:

1. A realistic simulation of practical demolition is needed since the objective of this study is to use acids in demolition processes which require many liters of acids. Thus, it is not economical to use lab-grade acids.
2. Commercial-grade acids have slightly more impurities.
3. Lab-grade acids are used for laboratory experiments to pursue accurate and precise results.

Dilution of Acids. Different concentrations have been used to compare all acids at one possible concentration, for example: it was possible to have 36% concentration from the three acids. Volume dilution have been carried out to reduce the concentrated acids to get the desired concentrations by using the relation: $C_1V_1 = C_2V_2$; where C1: Concentration of stock solution; V1: Volume of stock solution needed to make the new solution.C2: Final concentration of new solution;V2: Volume of distilled water. All acids have been diluted with distilled water in the lab using the following equipment and apparatus: Pycnometer; Flask; Volumetric pipette with pump; Funnel; Beaker.

Concrete Cubes. The concrete cubes of (15 X 15 x 15 cm) and (10 X 10 x 10 cm) are brought ready from Kingdom Concrete to have a more uniform concrete mix than a mix that can be prepared in the concrete laboratory. The concrete cubes have an average compressive strength at 7 day and 28 days of 25.5 MPa and 34.6 MPa, respectively. Table (1) below shows the compressive strength of 6 cubes at 7 and 28 days. While table (2) shows the characteristics of the hole in the cubes as shown in Figure (1) below.

Table 1: Average Compressive Strength

At 7 Days Age		At 28 Days Age	
Cube No.	Compressive Strength (MPa)	Cube No.	Compressive Strength (MPa)
1	25.1	1	34.5
2	25.4	2	34.4
3	25.2	3	33.9
Average	25.2	Average	34.6

Table 2: The Characteristics of the Hole.

Depth	Area(Wall + Base)	Volume
7 cm	23 cm ²	5.5 mL

Prior to preparing the acid solutions, the concrete cubes are wet cured for 7 days. They are also taken out of water to dry for 7 days, they are dried to determine the penetration of acids inside the cubes. The (15 X 15 x15 cm) cubes are also drilled using a drill press to have uniform holes figure (1). The drilling process starts with drilling using 6 mm bits, then, 8mm bits and at the end 10 mm bits. Masonry bits are used in the process; Figure (2). Also, water is poured on the bits while drill not to overheat. The depth of the hole is 7 cm with a diameter of 1 cm. The volume of the groove is 5.5 cm³. The characteristics of the hole are shown in the table (2), figure (2) and (3) show masonry drill bits and drilled cube.

Mortar Cubes. These cubes of (5 X 5 X 5 cm) have been prepared to measure the compressive strength after full submersion in acids for 1 hour time. The cubes had been wet cured for 7 days and then have been taken out to dry for 3 days. The mix design that is used in making the cubes is shows in the table (3). The water content of the mix design is 33% or 200 mL for each 600 g of sand and cement. Figure 4 shows a (5X 5 X 5 cm) cube.

Penetration and Chemical Reaction Rate. To determine the penetration and chemical reaction rate by observation, all the solutions where ready to be poured in the holes using 2 cubes of concrete for each of the 8 solution which have different concentrations of acids. The volume of the hole is 5.5 mL. However, only 3 mL of acid is poured in in the beginning to avoid spillage and splashing because the reaction between acid and concrete generate bubbles and vapors. When the reaction ends and concrete absorbs the acid, more acid is poured in. The volume of the poured-in acid is recorded every 30 minutes. 100 mL was the maximum volume to be poured in as an assumption. The test would be stopped when one of the acids reach 100 mL. Afterwards, the cubes are broken using a compressive strength machine and a hammer to measure the penetration.

Compressive Strength of (5 X 5 X 5 cm) - Mortar Cubes. After getting the results from the penetration and chemical reaction rate methods. It was found that Hydrochloric acid (36% concentration) and Nitric acid (69% concentration) are the most reactive acids with concrete. Thus, two cubes are submerged in each of the two acids for one hour. The mass of each cube is measured before and after submersion. Then, the compressive strength is measure by the compressive strength machine. The results are compared to the compressive strength of same cubes but without any chemical treatment.

4. RESULTS, CALCULATIONS AND DISCUSSION.

The rate of chemical reactions (represented by acids consumption by time) is not the same for the acids which they have different concentrations. The most reactive acids are Hydrochloric acid (HCL - 36% concentration) and Nitric acid (HNO₃ - 69% concentration) but Nitric acid is more corrosive and reactive since the concrete absorbed 100 mL in 330 minutes through a contact area of 23 cm². Concrete absorbed and reacted with only 37 ml of Hydrochloric acid. 27 mL for Nitric acid with a concentration of 36% and 21 mL for Nitric

acid with a concentration of 50%. The least reactive acid was the sulfuric acid since only 6 mL is poured in and surprisingly the reaction stopped after a few minutes. For the Sulfuric acid (H_2SO_4) case, the concrete did not absorb or react with the acid in hole, the sulfuric acid was not even absorbed by the concrete after 24 hours. Table (4) shows the volume of acids that are poured in in 330 minutes. Figure (5) shows the relation between time and the reaction of rate in terms of acids consumptions for the all acids solutions.



Fig. 5. 5 X 5 X 5 cm Mortar Cube after expose to acid



Fig. 1. Drill press



Fig. 2. Masonry drill bits

Table 3: Mortar Design Mix.

Material	Cement	Sand
Mass Percentage (%)	75	25



Fig. 3. Drilled Cube.



Fig. 4. 5X5X5 cm mortar

Table 4: Volume of Acids Poured In and the Rate of Reactions.

Minutes	Volume of Acids (mL)							
	HCl 36%	HNO ₃ 36%	H ₂ SO ₄ 36%	HNO ₃ 50%	H ₂ SO ₄ 50%	HNO ₃ 69%	H ₂ SO ₄ 80%	H ₂ SO ₄ 99%
0	3	3	3	3	3	3	3	3
30	6	6		6		6		
60	9	9		9		9		
90	12	12		12		15		
120	15	15		15		21		
150	18	18		18		28		
180	21	21		21		36		
210	25	24				45		
240	31	27				60		
270	37					78		
300						90		
330						100		

As shown in Fig. 6, the reaction rate of Nitric acid (69% concentration) is faster because of its corrosive nature. For instance, at 240 minutes, the concrete reacted with 60 mL of Nitric acid (69% concentration) while only with 27 mL of Hydrochloric acid (36% concentration) after which the reaction stopped. It is very important to know that the concrete was able to react and absorb more Nitric acid (69% concentration) but 100 mL was the maximum volume for this methodology.

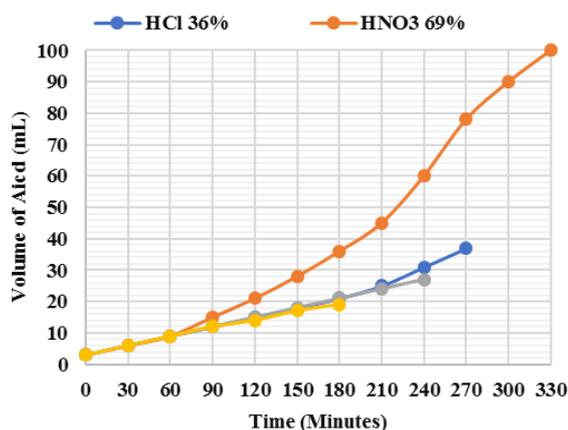


Fig. 6. Relation between time and acids volumes consumed (reaction rate) - (HCL 36%, HNO₃ 69%, HNO₃ 36% and HNO₃ 50%).

Penetration. The penetration is measured after breaking the cubes by the compressive strength machine, the cubes are furthermore broken by a hammer into smaller particles to measure the penetration. The penetration for Nitric acid (69% concentration) and Hydrochloric acid (36% concentration) is the same and almost uniform along the depth and around circumference of the cube. The Penetration for the Hydrochloric acid (36% concentration) is 1 cm and the same amount for Nitric acid (69% concentration). However, for Nitric acid (69% concentration) case the hole got wide the diameter which was increased to be 1.25 cm and the depth increased to 7.8 cm. Figure 7 is illustrated the penetration in inside the tested cubes.



Fig 7. Penetration of Nitric acid (69% concentration).

Compressive Strength of 5 cm X 5 cm Mortar Cubes. The submersed mortar cubes in acids (Hydrochloric and Nitric) resulted a reduction in mass and compressive strength. After full submersion of cubes in 300 mL of Hydrochloric (36%

concentration) acid for 1 hour, the compressive strength reduced by 26.5% on average for samples No. 3 & 4. Moreover, the average reduction in mass is 19.4%. For Nitric acid (69% concentration), the chemical attack reduced the compression strength by 37% for samples No. 5 & 6, and the mass reduction is 21%. Tables 5, 6, 7, 8 and 9 summarized these results.

Table 5. Compressive Strength of Mortar Cubes

Sample No.	Original Compressive Strength (MPa)
1	22.64
2	23.04
Average	22.84

Table 6. Compressive Strength of Mortar Cubes

Sample No.	Compressive Strength After Submersing in HCl (36%) (MPa)
3	17.17
4	16.35
Average	16.76

Table 7. Compressive Strength of Mortar Cubes after

Sample No.	Compressive Strength After Submersing in HNO ₃ (69%) (MPa)
5	14.46
6	14.25
Average	14.35

Table 8. Reduction in Compressive Strength after Submersion

Average Compressive Strength (MPa)	Average Compressive Strength After Submersing in HCl (36%) (MPa)	Average Compressive Strength After Submersing in HNO ₃ (69%)
22.84	16.76	14.35

Figures 8 and 9, show a visual illustration of the average compressive strength (MPa) for the ordinary sample and those submersed with HCL 36% and HNO₃ 69% before and after the tests. It is clear from figures that the average compressive strengths are decreased from the 22.84 MPa for original sample comparing to 16.76 and 14.35 MPa in cases of the submersions of the samples in HCL 36% and HNO₃ 60% acids, respectively.

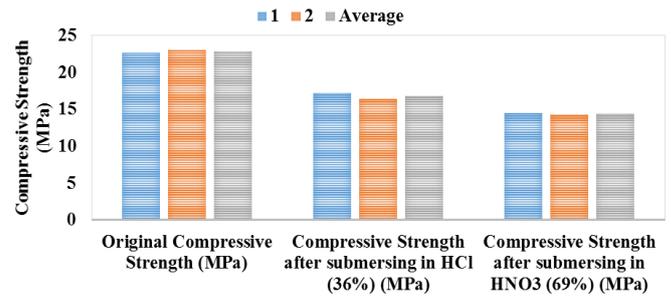
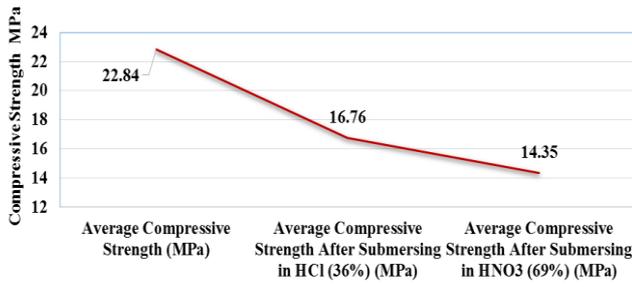


Fig. 8. Visual Illustration of Compressive Strength Reduction

Fig. 9. Visual Illustration of Compressive Strength Before and After Submersion

Table 9. Compressive Strength Before and After Submersion

Sample No.	Original Mass (g)	Mass after submersing in HCl (36%) (g)	Sample No.	Original Mass (g)	Mass after submersing in HNO ₃ (69%) (g)
1	237.6	189.3	1	239.6	187.9
2	231.2	188.7	2	232.4	185.3
Average	234.4	189.0	Average	235.9	186.6
Reduction		19.4 %	Reduction		21.0 %

For one hour of immersion, Nitric acid (69% concentration) resulted more reduction mass than the Hydrochloric acid (36% concentration) which comply with the results of table 4, that shows for the same time elapsed for Nitric acid (69% concentration) which has a more reaction rate than the Hydrochloric acid (36% concentration). Therefore, Nitric acid (69% concentration) has a bigger reduction of compressive strength. These effect leads that the samples loss of their mass. Figures 10 and 11 below show the mass reductions of the samples tested by using Hydrochloric acid (36%) and Nitric acid (69%). It is clear that there is big difference between the mass lost in case of Hydrochloric acid (36% concentration) with the case of using Nitric acid of (69% concentration).

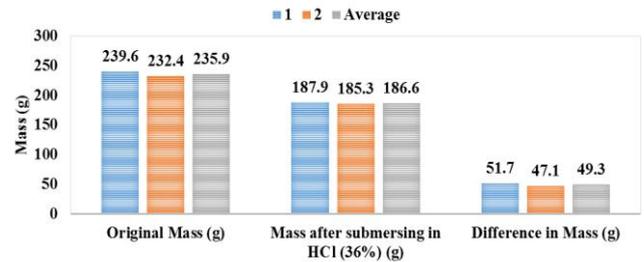


Fig. 11. Masses Before and After Submersion in Nitric Acid (69%).

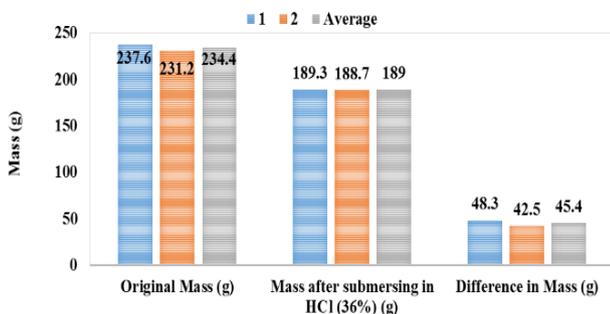


Fig.10. Visual Illustration of Masses Before and After Submersion in Hydrochloric Acid (36%).

5. CONCLUSION

This research was carried out to illustrate the effect of the attack of acid types on the concrete properties as well as the definition of the rate of chemical reactions, amount of absorption of the concrete, penetration that occurs as a result of that effect and the concentration of acid solution required. This study gave a set of results and conclusions which can be summarized by the followings; (1) The rate of chemical reactions is not the same for the acids which they have different concentrations. The Nitric acid is more corrosive and reactive since the concrete absorbed 100 mL in 330 minutes through a contact area of 23 cm². The least reactive acid was the sulfuric acid since only 6 mL is poured in and surprisingly the reaction stopped after a few minutes. (2) The penetration in the sample for the Hydrochloric acid (36% concentration) is 1 cm and the same depth was obtained in case of Nitric acid (69% concentration). However, for Nitric acid (69% concentration) case the hole got wide the diameter

which was increased to be 1.25 cm and the depth increased to 7.8 cm. (3) After full submersion of cubes in 300 mL of Hydrochloric (36% concentration) acid for 1 hour, the compressive strength reduced by 26.5% on average, the average reduction in mass is 19.4%. (4) For Nitric acid (69% concentration), the chemical attack reduced the compression strength by 37% for samples No. 5 & 6, and the mass reduction is 21%.

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