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# Durability of RC Pipes Made of Geopolymer Concrete Materials Subjected to Aggressive Corrosive Media

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***Abstract:*** *Infrastructure deterioration is one of the major problems which require applying several procedures such as maintenance of elements, substitution of parts of system and repair damages in water collection system or waste water collection system. Subsequently, it is necessary limiting the corrosion of water and waste water pipes embedded in aggressive media. In the present paper, the effect of aggressive media (Magnesium Sulfate and Chloride) on the corrosion rate and flexural capacity of RC pipes has been studied. Also, the effect of accelerated corrosion periods on the corrosion rate and flexural capacity of RC pipes has been considered. Different parameters including thickness of pipes (50mm and 100mm), concentration of aggressive media, accelerated corrosion setup period, mix compositions of concrete, and reinforcement details have been studied by testing eighteen concrete pipes. The tested RC pipes have been divided on three groups according to concrete type: geopolymer concrete with mix binder contains 90% slag and 10% red mud (GPCB), geopolymer concretewith mix binder contains 63% slag, 27% fly ash, and 10% red mud (GPCC), and Ordinary Portland Cement concrete (OPC) concrete. Linear polarization techniques have been applied on steel bars extracted from pipes after accelerated corrosion setup and loading test by putting it in tap water. A loading test has been performed on these pipes to obtain their flexural capacity and the corresponding deflection at mid-span (vertical) and mid-height (horizontal). Compressive strengths have been determined at 28 days and at test day.The test results showed clearly that most important features of geopolymer concrete are amelioration mechanical properties of concrete in water and aggressive media attack. The highest increase in compressive strength has been recorded in case of (GPCB) pipes in water curing case by percentage 84% at test day compared to compressive strength at 28 day. The reduction in peak load increased with the accelerated corrosion setup and aggressive media as a result of the deterioration in steel bars in case of OPC pipes only. Anincreaseof the peak load has been noticed for GPCB and GPCC pipes despite of the accelerated corrosion setup and aggressive media. This is can be attributed mainly due to the high compressive strength and corrosion resistance of geopolymer pipes compared with OPC pipes*

***Key Words:*** *Geopolymer Concrete, RC Pipes, Flexure test, Steel Corrosion*.

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## I. Introduction

Infrastructures are usually exposedto high aggressive media attackfrom the ground water and waste water collection system. Thus, it was necessary to innovate a new construction material which is characterized by high durability under aggressive media attackrather than the ordinary Portland cement. Ordinary Portland cement hasdisadvantages asdeterioration under aggressive media attack,environment pollution from gas emission during cement industry, and high cost.On the other hand, geopolymer binder canbe used in concrete as a construction material or in mortar as a rehabilitation material in waste-water and water pipes. It has many advantagessuch as it is an environmentally pollution free material, its high strength, low cost,and resistant to aggressive media attack.

Precast Concrete pipes are commonly used in water supply system and waste-water collection systemsand they are generally used these dayseither in low or high pressure. Concrete pipes carrying wastewaterusually examine corrosion, and deterioration under aggressive media. Plain concrete pipes are made for low pressure, and Reinforced Concrete RC pipes are made for high pressure. The main disadvantages of these pipes are their heavy weight which results in transportation difficulties and the lack of an easy repair technique for them.

For RC pipes, the fabrication process of steel cage reinforcement consumes significant effort and time during processing. In order to resist anticipated loads, the pipe may have up to three welded reinforcement cages. The number of welded reinforcement cages depends on multiple parameters such as pipe diameter, pipe wall thickness and, required strength [1]. Uniform constraint function and the resistance of deformation ability of drainage pipescan be provided by using double spiral stirrups on internal concrete [2]. Earth pressures usually affect the pipes and produce transverse bending moments in pipe walls. As a result, the circumferential reinforcement is needed to resist the resulted bending moments in concrete pipes as illustrated in Fig (1). Pipes behave as rectangular reinforced concrete sections under the effect of transversal bending moments. In order to promote the service life of these pipes in aggressive sewer environment and to reduce their maintenance requirements, the cover thickness of pipes must be increased. So, using one layer of steel reinforcement in pipe designis better than using two layers to increase cover thickness for the single reinforcement layer[3].

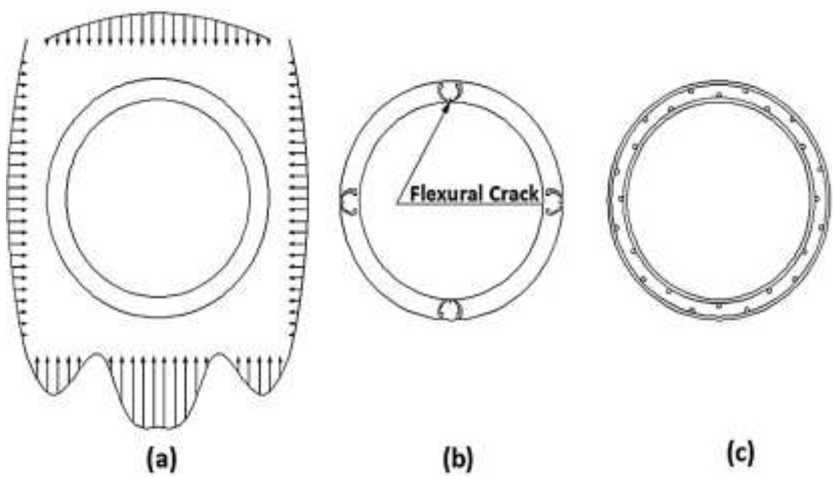


**Fig. (1):**Concrete pipe: (a) external loads, (b) flexural cracks, and (c) reinforcement system.

Corrosion is an electrochemical process that takes place for the embedded reinforcing steel in concrete. The function of the surface of the corroding steel is mixed electrode that is a composite of the anode and the cathode electrically connected through a body of steel itself, upon which coupled anodic and cathodic reactions take place.Corrosion of steel in concrete structures is affected bythe availability of oxygen and moisture at the rebar level, relative humidity and temperature, carbonation and entry of acidic gaseous pollutants to rebar level,chloride ions reaching to the rebar level either through the concrete ingredients or from the external environment, aggregate size and grading, construction practice, cover over reinforcing steel, cement composition, impurities in aggregate,impurities in mixing, and curing water[4-5]. Several researchers studied corrosion in reinforced concrete RC elements such as slabs and beams [6-7].

On the other hand, accelerated corrosion setup is a setup aiming at accelerating the corrosion process of the reinforcing steel connecting it directly to an electric current for specific period and putting concrete element in wet media. Corrosion rate of metal is the speed at which any metal in a specific environment deteriorates. It also can be defined as the amount of corrosion loss per year in thickness. The speed or rate of deterioration depends on the environmental conditions and the type and condition of the metal under reference. By applying accelerated corrosion test on RC beams, statistical parameters of maximum pit-depths distribution of corroded steel in RC elements was recorded. Then, it was concluded that the less detrimental of pitting corrosion on flexural and shear capacity of a RC beam is less than the effect of general corrosion [8]. Surrounding concrete of corroded steel bar under applying direct current in case of artificial corrosion process would not bear from remarkable expansive force accompanying steel rusting like in natural corrosion case[9-10]. Both yield strength and ultimate strength did not examine appreciable changes counter to ductility under tensile test of mild and high tensile steel after accelerated corrosion test. As a result of bond degradation, bending stiffness decreased under high degree of rebar corrosion in either mild steel case or high tensile steel case [9].Concrete cover cracking and spalling, stirrups cutting, bond loss between the corroded rebar and the surrounding concrete and reduction in the cross sectional area of the corroded rebar affect mainly the residual load carrying capacity of concrete elements subjected to corrosion. During loadingcorroded concrete elements, there are eccentricities in loads as a result to corrosion and random deterioration of steel in elementsthus there is a decrease in load capacities of corroded elements [10].

Several researches were carried out aiming at mapping out the various mechanisms which control the process of steel corrosion in concrete.Schematic models were carried out in order to illustrate the process of corrosion where the service life was divided into a period of initiation and a period of propagation.The time up to the initiation of the corrosion process was determined by the flow of penetrating substances into the concrete cover and by the threshold concentration for corrosion to start [11].Another experimental study on RC structures was conducted to study the effect of different concentrations of HClon the corrosion rate and flexural capacity of RC slabs.It was found that exposure to one-month and three-month accelerated corrosion decrease the bar diameter by 20% and 49%, respectively [12].

Geopolymer concrete is produced by the reaction of an alkaline liquid with a source material that is rich in silica and alumina such as slag, fly ash, red mud, silica fume, …etc. Geopolymer binder is usedas paste, mortar, and concrete in many investigations that aimed to propose a new material with higher resistance to aggressive media attack. Failure modes characterized by splitting, shear, central cracking and conical type of failure of geopolymer mortar specimens were observed and thegeopolymer mortar specimens was classified as a brittle material [13]. Geopolymer concrete can be used in many applications such as precast unitswhere it is more environmental friendly and economical than ordinary cement concrete [14]. Workability of geopolymer concrete was better than that of OPC concrete of the same grade. Itdemands amount of water and binder less than OPC concrete for the same workabilitylevel and compressive strength at 28 days [15]. After exposing to sulfate attack such as magnesium sulfate, the change in length of geopolymer concrete is less than that of OPC the concrete by 0.1% [16].

However, the geopolymer as aconcrete is not yet used in pipes industry in Egypt although thegeopolymer mortar was used as a coating to corroded pipes in order to prevent the increase the corrosion in pipes. This mortar was used as a spray which forms a crystalline structural solution for with high resistance to acids and surface durability. It cures fast which permits the pipe to be rehabilitated quickly. Furthermore, it is resistant to environmental effects such as heat and cold [17].

The objective of the present study is to experimentally investigate the effect of geopolymerconcrete on the flexure behavior of RC pipes compared to OPC concrete.To do so, an experimental program of Twenty-onegeopolymer concrete mixes containing sodium based activators combinations under the effect of different binder compositionshas been carried out. Different parametershave been accounted for such as thickness of pipes (50mm and 100mm), concentration of aggressive media, accelerated corrosion setup period, mix compositions of concrete and reinforcement details.In this study, one layer of reinforcement steel has been used in order to produce pipes resisting to highly aggressive media by increasing the cover thickness of the pipes.The accelerated corrosion setup has been applied in order to keep steel bars in high degree of corrosion so the effect of corrosion on load capacity of the pipes can be measured.

This study gives lighton replacement OPC concrete by geopolymer concrete. The corrosion of the reinforcing steelis evaluated by estimating the reduction in the peak load of RC pipes and compressive strength after the corrosion process. The paper introduces the experimental program details containing the preparation of pipes forms, casting concrete and curing technique. The details of the accelerated corrosion setup technique and the flexure test setupare presented. Afterwards, the results obtained from the performed experimental program are presented and discussed.

## II. Experimental program

Twenty-one concrete pipes with 500 mm effective length and an internal diameter of 500mmhave been reinforced by a single mild steel mesh of 8mm diameter except for three pipes which have been kept un-reinforced. The pipes have been categorized into seven groups. the first two groups; A and B; have been casted using OPC concrete with wall thickness of 50 mm and 100 mm for group A and B; respectively. The second two groups have similar wall thickness to those of groups A and B but with different materials. These two groups; C and D, have been made of GPCB concrete in which the mix binder contains 90% slag and 10% red mud. The third two groups; E and F have the same wall thickness like the corresponding groups but have been made of GPCC concrete with 63% slag, 27% fly ash, and 10% red mud. The pipes of the last group; group G, have been made of OPC concrete with no reinforcement.For each group,threedifferent aggressive media conditions have been applied to the pipes in this group. Each pipe has been denoted by an identification name that represents the conditions at which the pipe has been exposed to. The letter “S” in the pipe name indicates that the specimen has been exposed to laboratory field condition without aggressive media or accelerated corrosion setup. The symbol “0%” in the pipe name indicates that the specimen has been filled with water without any aggressive media and has been exposed to accelerated corrosion setup for three months. While the symbol “10%” indicates that the specimen has been filled with aggressive media (10 % magnesium sulphate and 5% Chloride in mix water) and has been exposed to accelerated corrosion setup for three months.

### *2.1 Concrete Constituent Materials' Properties*

Typical chemical composition and physical characteristics are shown in Table (1) while Table (2) represents the mechanical properties of the used gravel and sand. Themain physical and mechanical properties of the used ordinary Portland cement are listed in Table (3).

**Table (1):** Chemical compositions of fly ash, GGBFS, red mud and cement

| Items | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | Cl- | L.O.L |
|---|---|---|---|---|---|---|---|---|---|---|
| Fly ash | 56.2 | 25.8 | 6.8 | 3.67 | 1.76 | 0.47 | 0.01 | 2.06 | 0.52 | 6 |
| GGBFS | 36.59 | 10.01 | 1.48 | 33.07 | 6.43 | 3.52 | 0.74 | 1.39 | 0.05 | 0.00 |
| Red mud | 73.05 | 13.41 | 6.35 | 1.35 | 1.46 | 0.74 | 0.91 | 1.62 | 0.18 | 0.95 |
| Cement | 18.5 | 5.24 | 5.9 | 60.9 | 1.1 | 1.5 | - | - | 0.002 | 0.80 |

**Table (2):**Main physical and mechanical properties of the used gravel and sand

| | |
|---|---|
| Gravel | |
| Unit Weight | 1.56 $t/m^3$ |
| Specific Gravity | 2.85 |
| Crushing value | 13.76% |
| Sand | |
| Unit Weight | 1.73 $t/m^3$ |
| Specific Gravity | 2.5 |

**Table (3):**Main physical and mechanical properties of the used ordinary Portland cement (CEM I) complying with ESS 4756-1/2013

| | |
|---|---|
| Initial setting time | Hrmin<br>2 5 |
| Final setting time | Hrmin<br>3 10 |
| Compressive strength at 3 days | 20 $N/mm^2$ |
| Compressive strength at 7 days | 28 $N/mm^2$ |

### *2.2 Reinforcing Steel Properties*

The used longitudinal and hoop reinforcements are mild steel plain bars of a nominal diameter 8mm. Table (4) shows the geometrical and the mechanical properties for the used reinforcement. The reinforcement arrangement is shown in Photo (1)

**Table (4):**Geometric and mechanical properties of the used high deformed and mild steel bars complying with ESS 262/2009

| Type of steel | Nominal bar diameter (mm) | Actual bar diameter (mm) | Actual cross sectional area ($mm^2$) | Yield stress ($N/mm^2$) | Ultimate strength ($N/mm^2$) | Elongation (%) |
|---|---|---|---|---|---|---|
| Mild steel | 8 | 7.7 | 47 | 303.3 | 460.2 | 25 |

**Photo (1):**Thetypical reinforcement of the pipes.

### *2.3 Concrete Mix, Casting and Curing of the Specimens*

The concrete mix has been designed to produce concrete with different compressive strengthsfor each group of the three concrete mix types OPC, GPCB and GPCC. Casting of samples has been carried out in wooden form after placing the reinforcement inside the form. The concrete has been mixed in a rotating mixer of 100 liters capacity and has been compacted using an electrical poker vibrator. Photos (2) and (3) show the stages of casting. The curing of the RC pipes has been carried out by putting the pipes in laboratory field in air curing as shown in Photo (4). Then, the specimens have been stored in the laboratory until applying of the accelerated corrosion setup. During casting specimens, four standard 150 mm cubes have been taken, compacted by electrical vibrator and cured for a week similar to the common practice in the Egyptian construction industry. In addition to, four mortar standard 50 mm cubes have been taken, compacted by electrical vibrator and cured in two cases; air and water curing.

**Photo (2):** Wooden mouldofpipes**.**

**Photo (3):** Concrete casting of pipes.

**Photo (4):**Curing of pipes**.**

***2.4 Accelerated Corrosion Setup (ACS)***

An accelerated corrosion setup has been performed to precipitatethe corrosion process in laboratory field in order to simulate the corrosion process in real field. Twelve concrete pipeshave been filled with water or aggressive media (10 % magnesium sulphate and 5% Chloride in mix water) as mentioned in Table (5). Every pipe has been filled with water or aggressive media has been worked as electrolyte. Stainless steel bars have been placed into the pipe and work as cathode while the reinforcing steel bars in the pipes act as anode.The current induced accelerated corrosion setup has been applied on eighteen pipes only. The samples have been filled with solutions for one month before connecting the Direct Current (DC) power supply with variable resistance with a rate of 1 mA/cm$^2$. The setup has been applied for three months.Figure (2) and photo (5) show the accelerated corrosion setup.

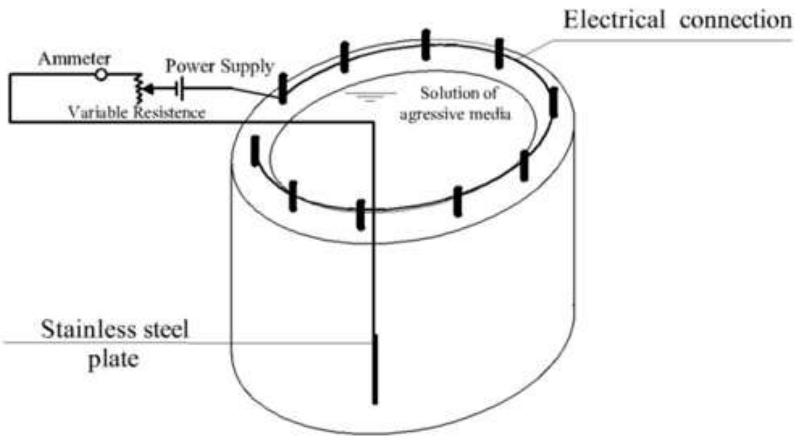


**Fig. (2):**Schematic representation of the accelerated corrosion setup.

**Photo (5):**Applying the accelerated test in the lab.

**Table (5)** main properties of the tested pipes

| Pipe No. | Groups | Pipes Indent. | Internal Diameter, Do (mm) | Wall Thickness, h (mm) | External Diameter, Df (mm) | Cage Area ($cm^2$/m) | Long. Reinf. | fcu* ($N/mm^2$) | Tensile strength ($N/mm^2$) | Solution aggression | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Accelerated corrosion period (month) | % magnesium sulphate in mix water | % Chloride in mix water |
| 1 | A | OPC50S | 500 | 50 | 600 | 6.0 | 10ϕ8 | 24.6 | 1.61 | ….. | ….. | ….. |
| 2 | | OPC50(0%) | 500 | 50 | 600 | 6.0 | 10ϕ8 | 24.6 | 1.61 | 3 | 0 | 0 |
| 3 | | OPC50(10%) | 500 | 50 | 600 | 6.0 | 10ϕ8 | 24.6 | 1.61 | 3 | 10 | 5 |
| 4 | B | OPC100S | 500 | 100 | 700 | 6.0 | 10ϕ8 | 24.6 | 1.61 | ….. | ….. | ….. |
| 5 | | OPC100(0%) | 500 | 100 | 700 | 6.0 | 10ϕ8 | 24.6 | 1.61 | 3 | 0 | 0 |
| 6 | | OPC100(10%) | 500 | 100 | 700 | 6.0 | 10ϕ8 | 24.6 | 1.61 | 3 | 10 | 5 |
| 7 | C | GPCB50S | 500 | 50 | 600 | 6.0 | 10ϕ8 | 32.0 | 2.7 | ….. | ….. | ….. |
| 8 | | GPCB50(0%) | 500 | 50 | 600 | 6.0 | 10ϕ8 | 32.0 | 2.7 | 3 | 0 | 0 |
| 9 | | GPCB50(10%) | 500 | 50 | 600 | 6.0 | 10ϕ8 | 32.0 | 2.7 | 3 | 10 | 5 |
| 10 | D | GPCB100S | 500 | 100 | 700 | 6.0 | 10ϕ8 | 32.0 | 2.7 | ….. | ….. | ….. |
| 11 | | GPCB100(0%) | 500 | 100 | 700 | 6.0 | 10ϕ8 | 32.0 | 2.7 | 3 | 0 | 0 |
| 12 | | GPCB100(10%) | 500 | 100 | 700 | 6.0 | 10ϕ8 | 32.0 | 2.7 | 3 | 10 | 5 |
| 13 | E | GPCC50S | 500 | 50 | 600 | 6.0 | 10ϕ8 | 22.2 | 1.46 | ….. | ….. | ….. |
| 14 | | GPCC50(0%) | 500 | 50 | 600 | 6.0 | 10ϕ8 | 22.2 | 1.46 | 3 | 0 | 0 |
| 15 | | GPCC50(10%) | 500 | 50 | 600 | 6.0 | 10ϕ8 | 22.2 | 1.46 | 3 | 10 | 5 |
| 16 | F | GPCC100S | 500 | 100 | 700 | 6.0 | 10ϕ8 | 22.2 | 1.46 | ….. | ….. | ….. |
| 17 | | GPCC100(0%) | 500 | 100 | 700 | 6.0 | 10ϕ8 | 22.2 | 1.46 | 3 | 0 | 0 |
| 18 | | GPCC100(10%) | 500 | 100 | 700 | 6.0 | 10ϕ8 | 22.2 | 1.46 | 3 | 10 | 5 |
| 19 | G | OPCP100(0%) | 500 | 100 | 700 | ……. | ……. | 24.6 | 1.61 | ….. | 0 | 0 |
| 20 | | OPCP100(10%) | 500 | 100 | 700 | ……. | ……. | 24.6 | 1.61 | ….. | 10 | 0 |
| 21 | | OPCP50(10%) | 500 | 50 | 600 | ……. | ……. | 24.6 | 1.61 | ….. | 10 | 0 |

* This value represents the average compressive strength obtained from the compression test performed for four cubes at the age of 28-day

### *2.5 Loading test setup*

After applying the accelerated corrosion test, the flexural test has been performed by a loading frame. The reaction frame used in the test program is 100.0 tons capacity and has a sufficient large stroke of 300 mm. During the loading test, strain measurements have been obtained by Linear Variable Displacement Transducer (LVDT) connected to data acquisition system. The stroke of the used LVDT is +/- 100 mm with 0.1mmsensitivity. The LVDTs have been located against the upper and the inner surface of the pipe attached to the supports and fixed to the longitudinal steel bar passing through the pipe in order to measure the deflection .Figure (3) shows a schematic representation of the loading test, and the supports' locations.

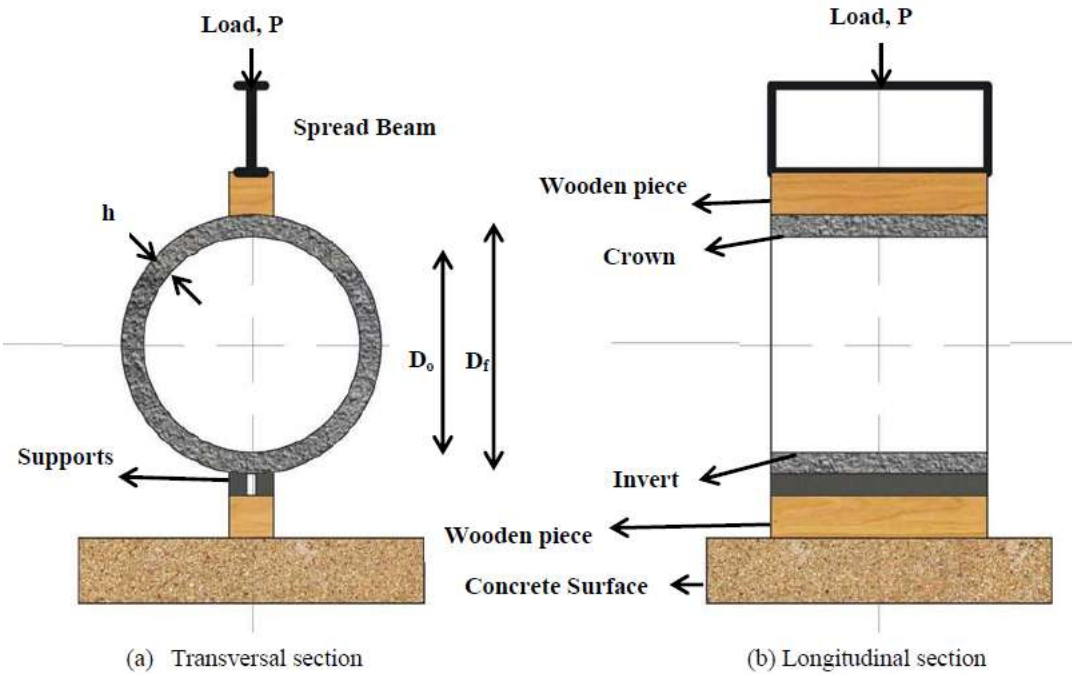


**Fig. (3):** Schematic representation pipe loading test setup.

## III. Experimental Results

Eighteen concrete pipes have been tested by the loading frame. The experimental investigation has been based on failure load, load-mid-span (vertical) deflection and load-mid-span (horizontal) deflection. The results of the pipes OPC50S, OPC50(0%), OPC50(10%), OPC100S, OPC100(0%) and OPC100(10%) have been compared to the results of pipes' samples GPCB and GPCC with the same condition of OPC samples.

### *3.1 Load-Vertical DeflectionRelationships*

The load-deflection relations for all the tested RC pipes are shown in Figures (4)to (7) where the vertical deflection is measured at the mid-span. The load-deflection relation for the reference pipes OPC50S, OPC50(0%), OPC50(10%), OPC100S, OPC100(0%) and OPC100(10%)are compared to those of the pipes samples GPCB and GPCC with the same condition of OPC samples.

Figure (4) shows the effect of aggressive media and accelerated corrosion setup on peak load and mid-span (vertical)displacements of the GPCB and OPC pipes with 50 mm wall thickness. The increase in the concrete compressive strength of pipes GPCB50S, GPCB50(0%) and GPCB50(10%) by 70%, 100% and 81%, increases the load carrying capacity of this pipe by 13%, 14% and, 36% compared with the control pipes OPC50S, OPC50(0%) and OPC50(10%), respectively. The verticaldeflection at failure for pipes GPCB50S and GPCB50(0%)is larger than that of pipes OPC50S and OPC50(0%),respectively while the deflection at failure for pipeGPCB50(10%) is less than that of pipe OPC50(10%).

Figure (5) shows the effect of aggressive media and accelerated corrosion setup on peak load and mid-span (vertical) displacements of the GPCC and OPC pipes with 50 mm wall thickness. The peak load of pipes GPCC50S and GPCC50(0%) is the same peak load of pipes OPC50S and OPC50(0%), respectively because the compressive strength of these pipes has the same compressive strength of pipes OPC50S and OPC50(0%), respectively. While the increase in the concrete compressive strength of pipe GPCC50(10%) by 3% increases the strength of this pipe by 29% compared with the control pipe OPC50(10%).Theverticaldeflection at failure for pipes GPCC50S, GPCC50(0%) and GPCC50(10%) is larger than that of pipes OPC50S, OPC50(0%) and OPC50(10%),respectively.

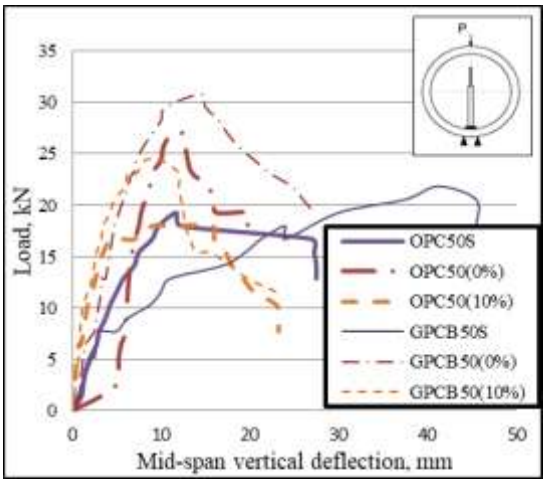


**Fig. (4):** Load-mid-span vertical deflection of samples GPCB50 and OPC50 with different aggressive media

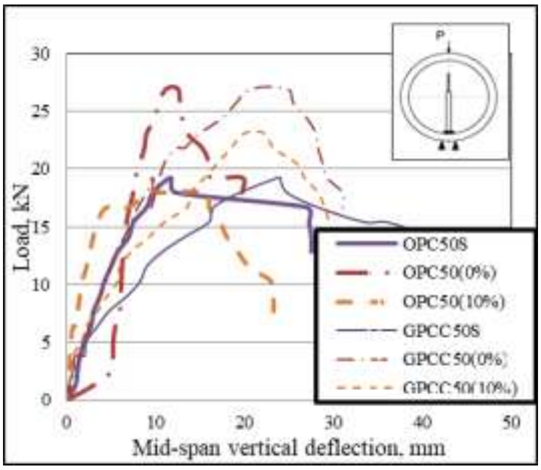


**Fig. (5):** Load-mid-span vertical deflection of samples GPCC50 and OPC50 with different aggressive media

From Figures (4) and (5), itcan be noticed that geopolymer pipes GPCB50 and GPCC50 in case of aggressive media (10% Magnesium Sulphate +5% Chloride) and applying ACS for three months have showed high corrosion resistance compared to sample OPC50 when subjected to the same conditions. Whereas, the sample OPC50 in the same conditions shows lower peak load value comparing to that of sample OPC50 in case of air curing and without applying ACS for three months. In addition, the specimen GPCB has the highest load capacityamong all the studied cases of all concrete mixes.

Figure (6) shows the effect of aggressive media and accelerated corrosion setup on the peak load and mid-span (vertical)displacements of the GPCB and OPC pipes with 100 mm wall thickness. According to this figure, increasing the concrete compressive strength of pipe GPCB100S by 70%, decreases the strength of this pipe by 28% compared with the control pipe OPC100S. This can be an indicator that air curing of geopolymer concrete has worse effect than that of cement concrete. The increase in the concrete compressive strength of pipes GPCB100(0%) and GPCB100(10%) by 100% and 81%, respectively, increases the load carrying capacity of this pipe by 46% and 10% compared to the control pipes OPC50(0%) and OPC50(10%), respectively. The vertical deflection at failure for pipes GPCB100(0%) and GPCB100(10%) is larger than that of pipes OPC100(0%) and OPC50(10%), respectivelywhile the deflection at failure for pipe GPCB100S is less than that of pipe OPC100S.

Figure (7) shows the effect of aggressive media and accelerated corrosion setup on the peak load and mid-span (vertical) displacements of the GPCC and OPC pipes with100 mm wall thickness. The decrease in the concrete compressive strength of pipe GPCC100S by 3% decreases the strength of this pipe by 69% compared to the control pipe OPC100S. This can be an indicator that air curing of geopolymer concrete has worse effect than that of cement concrete. Furthermore, the vertical deflection at failure for pipes GPCC100(0%) and GPCC100(10%) are larger than those of pipes OPC100(0%) and OPC10(10%), respectively while the deflection at failure for pipe GPCC100S is less than that of pipe OPC100S. Finally, from Figures (6) and (7), it can be realized that geopolymer concrete has high corrosion resistance compared to the specimens OPC in both cases of 50mm and 100 mm wall thickness in pipes.

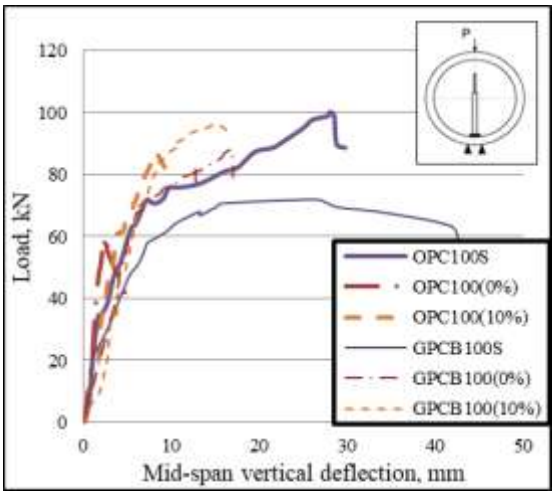


**Fig. (6):** Load-mid-span vertical deflection of samples GPCB100 and OPC100 with different aggressive media

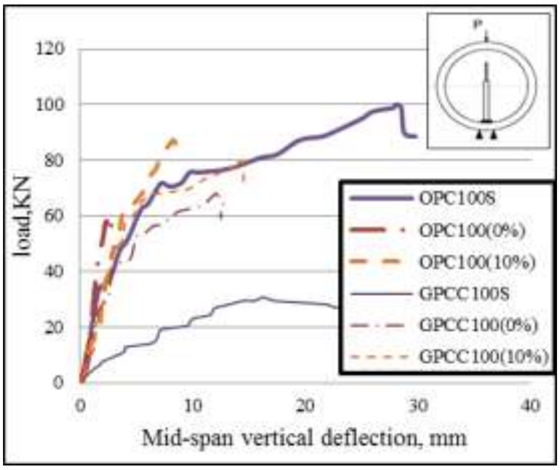


**Fig. (7):** Load-mid-span vertical deflection of samples GPCC100 and OPC100 with different aggressive media

***3.2Load-Horizontal Deflection Relationships***

Figures (8 to 11) show the load-deflection relations for all the tested RC pipes where the horizontal deflection is measured at the mid-height. The load-deflection relation for the reference pipes OPC50S, OPC50(0%), OPC50(10%), OPC100S, OPC100(0%) and OPC100(10%) are compared to those of the pipes samples GPCB and GPCC with the same exposure conditions of the corresponding OPC samples.

Figure (8) shows the effect of aggressive media and accelerated corrosion setup on the peak load and mid-height (horizontal) displacements of the GPCB and OPC pipes with 50 mm wall thickness. It can be seen that The horizontal deflection at failure for pipes GPCB50S and GPCB50(10%) is larger than that of pipes OPC50S and OPC50(10%), respectively while the deflection at failure for pipe GPCB50(0%) is almost the same as that of corresponding reference pipe OPC50(10%). The same conclusions can be noticed from Figure (9) where the effect of the aggressive media and the ACS on the peak load and the mid-height (horizontal) displacements of the GPCC and OPC pipes with 50 mm wall thickness have been shown. It can be seen that the horizontal deflection at failure for pipes GPCC50S and GPCC50(10%) is larger than that of pipes OPC50S and OPC50(10%), respectively while the deflection at failure for pipe GPCC50(0%) is the almost the same as that of the corresponding reference pipe OPC50(10%). According to these figures (8 and 9), it can be concluded that using the geopolymer concrete has resulted in better corrosion resistance and better behavior after corrosion comparing to the ordinary Portland cement concrete.

For the pipes of the 100mm wall thickness, Figure (10) shows the effect of aggressive media and accelerated corrosion setup on peak load and mid-height (horizontal) displacements of the GPCB and OPC pipes with 100 mm wall thickness. The horizontal deflection at failure for pipe GPCB100(0%) is larger than that of pipe OPC100(0%), respectively.While the deflection at failure for pipesGPCB100S and GPCB100(10%) is less than that of pipe OPC100S and OPC100(10%), respectively.Moreover, Figure (11) shows the effect of the aggressive media and the ACS on the peak load and the mid-height (horizontal) displacements of the GPCC and OPC pipes with 100 mm wall thickness. According to this figure, the horizontal deflection at failure for pipe GPCC100(0%) is larger than that of pipe OPC100(0%). While the deflection at failure for pipesGPCC100S and GPCC100(10%) is less than that of pipe OPC100S and OPC100(10%), respectively.

From figures (8) and (11), it can be realized that geopolymer concrete has high corrosion resistance compared to the specimens OPC in both cases of 50mm and 100 mm wall thicknesses in pipes as illustrated previously in figures (4) to (7).

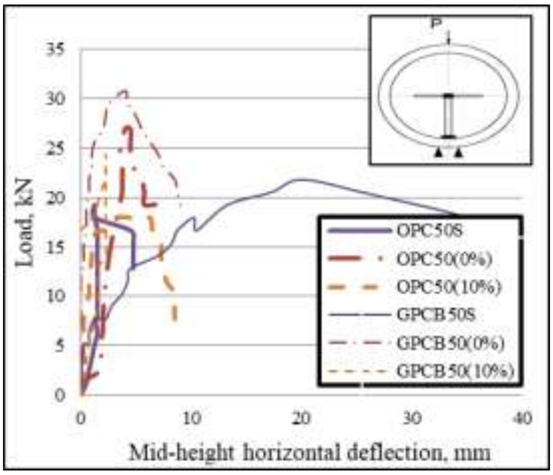


**Fig. (8):** Load-mid-height horizontal deflection of samples GPCB50 and OPC50 with different aggressive media

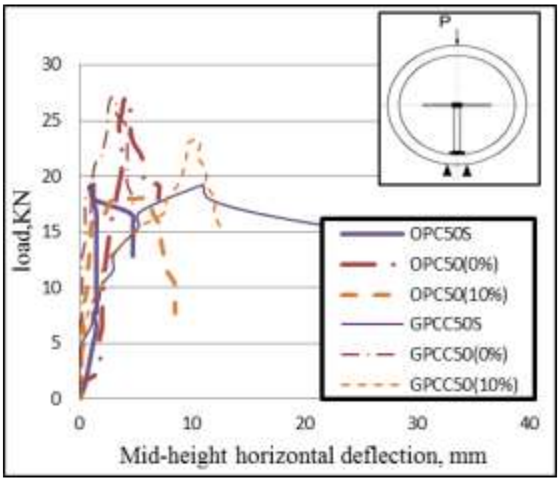


**Fig. (9):** Load-mid-height horizontal deflection of samples GPCC50 and OPC50 with different aggressive media

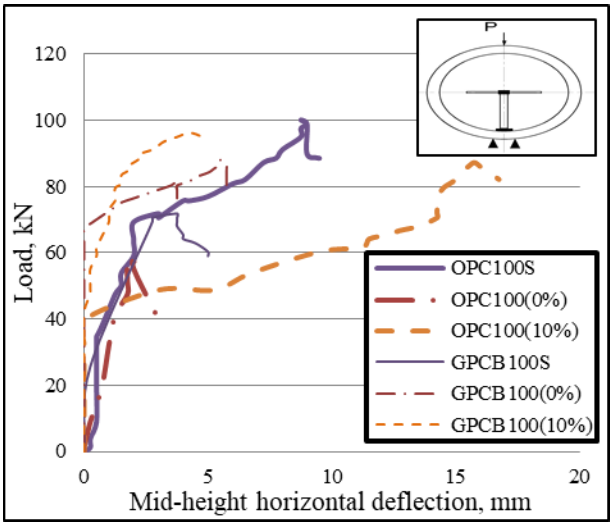


**Fig. (10):** Load-mid-height horizontal deflection of samples GPCB100 and OPC100 with different aggressive media

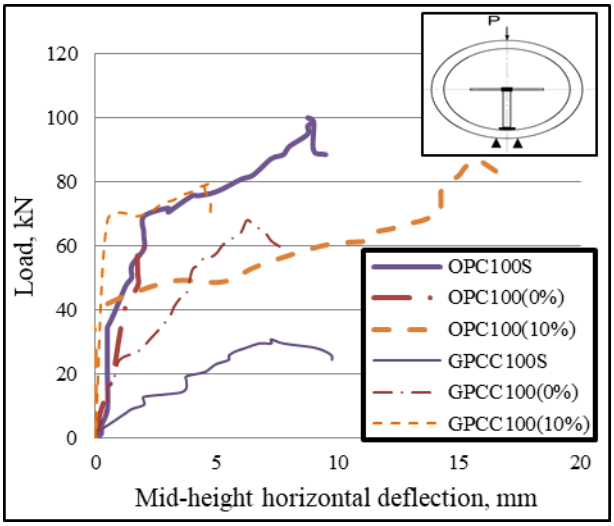


**Fig. (11):** Load-mid-height horizontal deflection of samples GPCC100 and OPC100 with different aggressive media

***3.3Compressive strength***

Figure (12) shows the compressive strength of the standard cubes which have been taken from the concrete mix of the tested RC pipes (GPCB, GPCC and OPC) in air at 7days, in air at 28 days, in water at 28 days, in air at test day (3 months), in water at test day (3 months) and in aggressive media (10% magnesium sulphate + 5% Chloride) at test day (3 months).The concrete cubes of the pipes OPC have showedhigher compressive strengths of 9%, 35% and 33% at test day (3 months) in case of air curing, water curing and, aggressive media (10% magnesium sulphate + 5% Chloride)comparing to the compressive strength of pipes OPC with air curing at 28 days. The increase in compressive strength of pipes GPCB reaches 26%, 84% and 46% at test day (3 months) in case of air curing, water curing and, aggressive media (10% magnesium sulphate + 5% Chloride), respectively,with reference to pipes GPCB in case of air curing at 28 days.The compressive strength of pipes GPCC increases at test day (3 months) in case of air curing, water curing and, aggressive media (10% magnesium sulphate + 5% Chloride) by a percentage of8%, 33% and 41%, respectively,with reference to pipes GPCC in case of air curing at 28 days.Itcan be seen that the sample SR(GPCB) has recorded the highest compressive strength in all samples for all cases. Samples SFR(GPCC) and OPC have the same compressive strength almost for all cases.

It can be also noticed that, water curing leads to higher compressive strength than that produced by air curing at age of 3 months. Compressive strength of sample SR(GPCB) and OPC show lower values in aggressive media than that in water at age 3 months. At variance, compressive strength of sample SFR(GPCC) shows higher values in aggressive media than that in water at age 3 month. Finally it can be noticed that although fly ash in binder decreases the compressive strength, it has a good behavior in resisting the aggressive media attack.

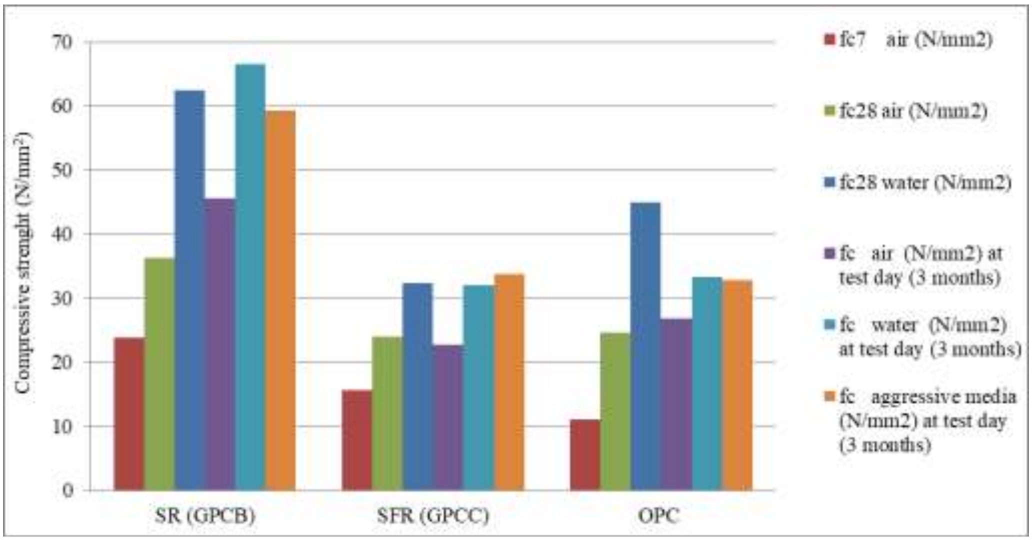


**Fig. (12):** Compressive strength of the concrete of the tested RC pipes.

## IV. Conclusions

Twenty-oneconcrete pipes were tested under different parameters which are thickness of pipes, concentration of aggressive media, accelerated corrosion setup period, mix compositions of concrete and reinforcement details. RC pipes divided on three groups according to concrete type:geopolymer concrete (GPCB), geopolymer concrete (GPCC) and OPC concrete. The reinforcing steel bars in the pipes worked as anode, stainless-steel plate acted as cathode, while, the aggressive media (10% magnesium sulphate + 5% Chloride) solution or water worked as electrolyte in the ACS. A Direct Current (DC) power supply and a variable resistance were utilized.The pipes were subjected to different curing methods: air curing, water curing and aggressive media (10% magnesium sulphate + 5% Chloride) curing. Compression tests were conducted for cubes subjected to the same environmental conditions of the pipes to obtain the compressive strength for each pipe. The pipes were tested under flexure and the load-deflection relation was recorded at mid-span both vertical and horizontal direction.

According to the experimental test, the following conclusion can be drawn:

1. All the tested GeopolymerConcrete pipes for (GPCB) possessed the highest compressive strength in comparison to that of GeopolymerConcrete pipes (GPCC) for all cases. However, the tested Ordinary Portland Cement pipes (OPC) showed approximately the same compressive strength results of GeopolymerConcrete pipes (GPCC).
2. For Ordinary Portland Cement concrete pipes (OPC) only, the reduction in peak load increases with using accelerated corrosion setup and aggressive media.This is can be explained due to the deterioration in steel bars and the constancyinconcrete compressive strength.
3. In general, GeopolymerConcrete pipes (GPCB),(GPCC) exhibited an increase in the peak load in spite of using accelerated corrosion setup and aggressive media.This is due to the most important features of geopolymer concrete in which its compressive strength enhanced with curing in water or aggressive media.
4. The percentage increase in the peak load for GeopolymerConcrete pipes (GPCB), (GPCC) exposed to accelerated corrosion setup is 46% and 29% respectively, compared to Ordinary Portland Cement Concrete pipes (OPC) having the same condition.
5. The compressive strength of the tested pipes, for all mixes types (GPCB), (GPCC) and (OPC), with aggressive media curing is higher than pipes with air curing. This is due to the fact of increasing the hydration rate in the presence of chloride and sulfate in water treatment.

6. In localized parts of pipes, there are random cracks, as result of permeability increase, which affect the peak load results. Accordingly, it is necessary using graded aggregates with small sizes and highly compacted concrete.

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