Mechanical properties and durability for concrete using waste heat resistance glass (Pyrex Type) as coarse aggregate

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Abstract. This study aims to investigate some mechanical properties along with durability against several severe environmental conditions of concrete using waste heat resistant glass (Pyrex glass) as a replacement of coarse aggregate with several replacement ratios. Study shows higher mechanical properties improvements by using this type of aggregate, compressive, tensile and flexural strengths were improved by 20%, 54% and 230% respectively by 75% replacement. Moreover, modulus of elasticity was also investigated, it was found that it is also increased from 2.3234 GPa for reference mixes to 2.8452 GPa for mixes with 75% aggregate replacement. The study also includes durability investigations against several severe environmentally conditions which are: acid attack and fire exposure, study shows significant improvement in resistance of Pyrex aggregate concrete against both sulphuric acid attack and fire exposure comparing with normal concrete.

1. Introduction
Concrete is the most important construction material, the use of waste materials as an aggregate in production of new concrete types could give several benefits for both construction and environment. Many types of waste materials used in production concrete such as: waste iron, marble, glass, ceramics, bricks, plastics, waste concrete..etc[1]–[6],these materials could be used in concrete as normal aggregates with several replacement percentages. In general, this use gives enhancing in mechanical properties, less cost of construction, and cleaner environment. Some investigations used waste glass as fine aggregate which give higher compressive strength of concrete until 30% of replacement[7],Higher flexural strength up to 20% replacement while expansion was recorded at 66% for fine aggregate[8]. Mechanical properties increased by using waste glass powder up to 20% for compressive strength and also increasing in flexural strength values by using waste glass[9]. Some investigations give improvement in compressive and flexural strength up to 15% replacement of waste glass with normal fine aggregates [10]. Using waste Pyrex glass or heat resistance glass as an aggregate in concrete is such new idea to use because its difficulties to reuse It could be useful to use waste heat resistance glass in concrete as coarse aggregate because it has significant physical and mechanical properties.
This research has two main aims; the first is to study the effect of using waste Pyrex glass as a coarse aggregate on mechanical properties of the concrete while the second aim is to investigate its durability of the new concrete against both acid attack and fire resistance.

2. Experimental program

2.1. Materials used
Ordinary Portland cement was used in all mixes type V (sulphate resisting cement), crushed rocks used in all mixes with 20 mm maximum size aggregate, while red natural sand was used as fine aggregate, the grading of coarse and fine aggregates shown in tables 1 and 2, and its confirming Iraqi standards[11], table 3 shows the grading of crushed heat resistant glass which is also meeting the Indian standards for 20 mm maximum size aggregate. Integral waterproofing admixture used in all mixes, the heat resistant glass used in study is a borosilicate glass which have the trade name (Pyrex glass) had the properties in table 4, it is used as coarse aggregate with different ratios of replacement: 0%, 25%, 50% and 100% replacement. The mix proportions in study were 1:1.5:2.5 (cement: sand: coarse aggregate), water/cement ratio was 0.3 in all mixes and the integral waterproof admixture used with 1.8% by weight of cement in all mixes. Figure 1 shows the crushed heat resistant glass as coarse aggregate.

![Figure 1. Heat resistant glass as coarse aggregate.](image)

2.2. Testing procedure:
All concrete specimens tested after 28 days of curing. Compressive strength values were the average of testing 3 cubes for each mix with dimensions of 100×100×100 mm.
Tensile strength was determined using indirect test, which is splitting tensile test for 100×200 mm cylinders. The value of tensile strength was obtained from the following equation:

$$F_t = \frac{2P}{\pi D L}$$

Where: $F_t$: tensile strength, $P$: Max load and $D$&$L$: Diameter and height of cylinder.

Flexural strength test was performed according to British standards[12], by using impact testing machine for compressive and flexural strength as shown in figure 2, third point type test was applied for prisms with dimensions of 100×100×400 mm. The flexural strength value obtained from below equation:

$$F_b = \frac{PL}{bd^2}$$

(2)
Where: $F_b$: the flexural strength of prism, $L$: clear length between supports, $P$: maximum load and $b$ and $d$: the width and depth of prism.

Figure 2. Flexural test for heat resistance glass (Pyrex) aggregate concrete.

As shown in figure 3, mechanical stress-strain gauges was attached on cylinder with 150×300mm, then it subjected to gradually increasing load in order to get the stress-strain relationship, this test was conducted according to ASTM–C-469 [13] to compute the modulus of elasticity.

Figure 3. Stress-strain test for concrete specimen

After finishing exploration the mechanical properties of the new concrete mixes, two sever environmentally conditions have also been investigated, the first condition is (a) Acid Attack while the other one is (b) heat exposing.

When concrete subjected to acid attack, many changes happened like: appearance, reduction in weight and compression strength, these changes were investigated in this study by making a comparison between reference and concrete with 75% replacement ratio—which gives the higher value of compression strength-. This process was carried out according to ASTM–C-267-01 [14]. The specimens were tested after 7, 14, 21, and 28 days of submerging in a 3% Sulphuric acid (H2SO4 Acid). Figure 4 shows two specimens after deterioration due to acid attack, the left specimen is the Pyrex concrete while the right one is the reference concrete. Figure 5 shows specimen during test it in compressive machine.
The second severe environmentally condition is fire exposing, fire resistance in this study was checked according to ASTM–E119 [15]. Basing on the spec., the temperature should be raised as illustrated in table 5, three specimens were tested for each mix for both 1 and for 2 hours in heating oven with maximum temperature of 927 and 1010 centigrade respectively, all specimens were weighted before and after getting out from heating oven, and all of them were tested to find their compression strength. Figure 5 shows the furnace oven with concrete specimens inside it, figure 6 (a) and (b) shows the same concrete specimen taking it out from the oven immediately and after 2 hours of room temperature cooling, respectively.

**Figure 4.** Concrete specimens after deterioration due to Acid effect -pyrex aggregate concrete cube to left reference concrete (to the right), and compressive strength test after acid effects.

**Figure 5.** Concrete specimens inside box resistance furnace during fire test.
Figure 6. Concrete specimen after 1 hour fire exposure, and compression test.

Table 1. Grading of fine aggregates confirm zone 3, Indian standards

| Sieve size | % passing by weight | Standards Specification (%passing) |
|------------|---------------------|-----------------------------------|
| 10 mm      | 100                 | 100                               |
| 4.75 mm    | 100                 | 90-100                            |
| 2.36 mm    | 94.1                | 85-100                            |
| 1.18 mm    | 92.6                | 75-100                            |
| 600 micron | 75.7                | 60-79                             |
| 300 micron | 13.9                | 12-40                             |
| 150 micron | 5.8                 | 0-10                              |

Table 2. Grading of coarse aggregate for crushed rocks aggregates

| Sieve size, (mm) | % passing by weight | Standards Specification (%passing) |
|------------------|---------------------|-----------------------------------|
| 40 mm            | 100                 | 100                               |
| 20 mm            | 97.3                | 95-100                            |
| 10 mm            | 29.6                | 25-35                             |
| 4.75 mm          | 3.1                 | 0-10                              |
### Table 3. Grading of coarse waste heat glass aggregate used in study

| Sieve size, (mm) | % passing by weight | Standards Specification (% passing) |
|-----------------|---------------------|------------------------------------|
| 40 mm           | 100                 | 100                                |
| 20 mm           | 95.2                | 95-100                             |
| 10 mm           | 27.1                | 25-35                              |
| 4.75 mm         | 1.3                 | 0 - 10                             |

### Table 4. Some properties of heat resistant glass (Borosilicate glass) used in the study

| Heat resistant glass - properties | Color, type | Maximum heat resistance | Bending strength | Tensile strength | Modulus of elasticity | Specific gravity | Poisson’s ratio |
|----------------------------------|-------------|-------------------------|------------------|-----------------|-----------------------|-----------------|----------------|
| Transparent color, Pyrex Glassware | Transparent color, Pyrex Glassware | 500 centigrade | 80 MPa (average) | 65 MPa | 64 000 MPa | 2.23 | 0.2 |

### Table 5 : ASTM-E119, Rising temperature as a function of time [15]

| Time (minutes) | ASTM-E119, Temperature in centigrade |
|----------------|--------------------------------------|
| 0              | 20                                   |
| 5              | 538                                  |
| 10             | 704                                  |
| 30             | 843                                  |
| 60             | 927                                  |
| 120            | 1010                                 |

### 3. Results and discussion

The mechanical properties for concrete with different ratios of course aggregate Pyrex glass replacement were all listed in table 6.

The compressive strength was increased with the increase of replacement ratio, the maximum increase was about 20% this increase was got at 75%, then, and it went back to 16% at 100% replacement. The same pattern was recognized for modulus of elasticity, it increased to 22% at 75% then decrease to 18% at 100% replacement ratio. This similarity could be attributed to the relationship between compressive strength and modulus of elasticity of concrete [16] [17], which is states that modulus of elasticity increasing by increase of compressive strength of concrete.

Unlike the behavior of compressive strength and modulus of elasticity, both tensile and flexural strengths were continued to increase until full replacement, which they reached to 57% and 226%, respectively, which is a very noticeable result.
In general, the increase in mechanical properties could be explained to the good bond of Pyrex with cement paste and also to its high mechanical properties as shown in Table 4. While the slight increase in some of them may be attributed to the irregular shape of Pyrex aggregate which is with higher content (100%) affected the compressive strength.

Although the mechanical properties of the new concrete were increased in general, its density was decreased slightly of about 3%, this reduction in density not affected on strength of concrete, on the contrary, less density concrete was coming with higher mechanical properties. This advantage could be attributed to the higher mechanical properties of Pyrex glass itself and also to its less specific gravity (about 2.23) comparing to conventional coarse aggregate used in reference mixes which has specific gravity about 2.65, this feature leads to reduction in density of new concrete and enlarging the strengths at the same time. And that’s due to less density of Pyrex comparing with natural aggregates and higher mechanical properties of Pyrex itself.

Acid attack on concrete is a major problem, especially when using concrete as foundation, in general, concrete have low resistance when it surrendered by an acidic environment, this fact was well noticed in this study, the reference mix suffering from weight reduction and losing in compressive strength when submerging in Sulphuric acid (3% concentrated). The weight reduction was about 16% and losses in compressive strength was very significant and found to be approximately 80%, however, the concrete with Pyrex as coarse aggregate showed more resistance than ordinary concrete, the weight loss was changing from 16% to 8.5% while the losses in compressive strength varied from 80 up to 61%, this change in behavior was predictable because of the high resistance of Pyrex glass against acids effects.

The main feature of Pyrex glass is heat resistance, according to this fact, it was very essential to check the change in behavior of concrete with Pyrex glass comparing with conventional concrete. Similarly, to acid attack, both changing in weight and compressive strength were examined for concrete after exposing to high temperature degrees. The percentage of enhancement against weight and strength losses was about 30% and 7%, respectively.

**Table 6. Mechanical properties of reference and waste Pyrex glass concrete mixes.**

| Replacement Ratio | Compressive strength, MPa | Tensile strength, MPa | Flexural strength, MPa | Modulus of elasticity, MPa | Density Kg/m3(Average) |
|-------------------|---------------------------|-----------------------|------------------------|---------------------------|-----------------------|
| 0% (Ref.)         | 36.91                     | 3.12                  | 4.06                   | 23234                     | 2382                  |
| 25%               | 40.64                     | 3.40                  | 5.63                   | 25416                     | 2357                  |
| 50%               | 43.49                     | 4.62                  | 6.92                   | 27920                     | 2346                  |
| 75%               | 44.35                     | 4.87                  | 8.78                   | 28452                     | 2328                  |
| 100%              | 43.10                     | 4.90                  | 9.21                   | 27403                     | 2307                  |

**Table 7. Reduction in weight (%) due to acid effects for Pyrex concrete and ordinary concrete mixes.**

| Submerging in Acid (days) | Replacement Ratio | 7 | 14 | 21 | 28 |
|---------------------------|-------------------|---|----|----|----|
| 0% (Ref.)                 | 8.76%             | 13.02% | 14.80% | 15.93% |
Table 8. Reduction in compressive strength due to acid effects for Pyrex concrete and ordinary concrete mixes.

| Mix type                           | Reduction in strength %, 7 days exposure | Reduction in strength %, 14 days exposure | Reduction in strength %, 21 days exposure | Reduction in strength %, 28 days exposure |
|------------------------------------|----------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| Reference                          | 46.15%                                 | 75.26%                                   | 78.12%                                   | 79.68%                                   |
| Pyrex aggregate concrete mix, 75%  | 37.33%                                 | 53.5%                                    | 59.18%                                   | 60.90%                                   |

Table 9. Reduction in weight due to fire exposure for normal and Pyrex aggregate concrete mixes.

| Mix type                              | 1 Hour exposure (927 C) | 2 Hours exposure (1010 C) |
|---------------------------------------|-------------------------|---------------------------|
| Reference                             | 12.15%                  | 14.87%                    |
| Pyrex concrete 75% Pyrex aggregate    | 7.43%                   | 11.39%                    |

Table 10. Reduction in compressive strength due to fire exposure for normal and Pyrex aggregate concrete mixes.

| Mix type                              | 1 Hour exposure (927 C) | 2 Hours expose (1010 C ) |
|---------------------------------------|-------------------------|--------------------------|
| Reference                             | 89.37%                  | 96.75%                   |
| Pyrex concrete 75% Pyrex aggregate    | 77.10%                  | 90.31%                   |

4. Conclusions

- The use of heat resistance glass as coarse aggregate in concrete increase compressive, tensile, flexural strength and modulus of elasticity.
- The optimum replacement percentage for compressive strength and modulus of elasticity was 75% while it was 100% for tensile and flexural strengths.
- Concrete with optimum replacement percentage (which is 75%) shows less deterioration against acid resistance comparing with normal concrete mixes.
- The use of Pyrex coarse aggregate in concrete increase its durability against exposing to high degrees of temperature.
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