Evaluation of the Dynamic Behavior of Green Concrete under Impact Load by Using CEB-FIP Code

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Abstract. Growing environmental pollution, rapid depletion of natural resources (virgin), need for larger areas of landfill and the increased cost of landfill are the factors that led to focus on the recycling of concrete and the demolition of waste in the new concrete. The principle of recycling for sustainable construction was adopted during the present study by recycling plastic and glass waste as an alternative to aggregates in concrete. Eight concrete mixes were tested, and production of green concrete with waste content of 35% and residual strength about 83% was achieved. The dynamic properties of green concrete under impact load were calculated. Dynamic properties are very useful in the design of civil structures exposed to impact loads such as a gas explosion, runways, etc. CEB-FIP Model code (2010) show the most inclusive forms for expecting the strain rate development of concrete. The dynamic of compressive and flexural calculated by CEB-FIP models under strain rates range $10^{-2}$ and $10^{0}$. This range used to predict dynamic loads in structures of civil engineering within the quasi-static strain level.

1. Introduction

Industrial processes are accompanying with large quantities of non-disintegrated solid waste. It produces hazardous impacts on the environment. Plastic and glass waste are of the most widespread and most pronounced.

The consumption of these substances in other creations is an equitable technique for shrinking their harmful influences. Wastes materials have to be considered as valued supplies just require appropriate management and application [1]. Concrete represents a significant in take advantage of these materials in construction. Obtaining aggregates for concrete and waste disposal from different activities is the current goal. Sustainability is currently a top priority in the construction industry [2]. Utilization of plastic wastes in place of coarse aggregate is characterized with lighter weight in appraisal to normal aggregates, in addition to its elevated crushing resistance [3]. The glass --in concrete- can lead to a reaction and its effectiveness increases by increasing alkali content and particle size to greater than 1 mm. Particles less than 1 mm reduce the occurrence of alkali-silica reaction with the possibility of diminishing their effectiveness by using metakaolin, fly ash, or GGBS [4]. If the glass was crushed to less than 75 μm, the effect of the alkali-silica reaction did not appear, and the durability properties were confirmed. Therefore, the possibility of using glass waste as fine aggregates in concrete and mortar has been identified [5]. The demand to know the impact resistance and dynamic properties of concrete is important in many applications such as: offshore platforms, aircraft impact, transportation facilities, gas explosion, etc. One of important structure is ground storage tank. It is contain many types of liquid such as water, oil, chemicals,…. etc. some of these liquid
classified as hazardous materials because any damage in tanks caused the catastrophic humanity and environment. These require the construction of structure nearby the tanks of storage to avoid the leakage in tanks as well as disasters failure. In many countries, a secondary containment as a bund wall was used. It is designed by BS EN 1992-3 [6]; this code is dealing with hydrostatic pressure. When failure catastrophic happened, the liquid material was escaped very quickly. In this case, the bund wall falls under dynamic load. The loading impact classified into two major types according to the level of deformation happening in impactor, hard and soft impacts. In the first type, the deformation of the impactor is very unimportant according to that occur in the target. While, in soft impact, both the target and impactor having the same significant deformations as fluid flow beating a bund wall. The various velocities is another property for impact loading. It determined by the performance of structure under impact loading. Othman, [7] was stated that the loading impact more than 40m/s, a local response occurred in structure because the period time of acting load is very short. It is very small to the typical period structure. When the speed was less than 40 m/s, the global responding and damage do not have time to affect. In structures of civil engineering occurring in the low velocity impact during dynamic accidental loading. When the strain rate is high in materials its mechanical characteristics are improved (i.e, increasing in compressive strength, flexural strength, and the Elastic Modulus) [8]. The increasing in strain rate depended on the type of load as shown in the table. 1

| Load case       | Strain rate (s\(^{-1}\)) |
|-----------------|--------------------------|
| Traffic         | 10\(^{-6}\) – 10\(^{-4}\) |
| Gas explosions  | 5×10\(^{-5}\) – 5×10\(^{-4}\) |
| Earthquake      | 5×10\(^{-3}\) – 5×10\(^{-1}\) |
| Pile driving    | 10\(^{-2}\) – 10\(^{0}\) |
| Aircraft impact | 5×10\(^{-2}\) – 2×10\(^{0}\) |
| Hard impact     | 10\(^{0}\) – 5×10\(^{1}\) |
| Hypervelocity impact | 10\(^{2}\) – 10\(^{6}\) |

There are many existing tests depended on the level of strain rate to estimate dynamic characteristics. The strain rate was range between 10\(^{-2}\) to 10\(^{0}\) for a hydraulic test machine. While it is up 10 s\(^{-1}\) for drop weight impact test machine. The peak strain rate limited by 10 s\(^{-1}\) to 10\(^{4}\) s\(^{-1}\) for Split Hopkinson Pressure Bar due to Ross et al, (1995) cited by [1]. It is feasible to employ codes in which formulae are obtained from investigational tests in the condition of an absence of appropriate experimental devices. CEB-FIP Model Code [9] comprises the most widespread forms for calculating the strain rate development of concrete. The dynamic characteristics for concrete covered up 120MPa and strain rate up 5×10\(^{2}\) s\(^{-1}\) for compressive as well as flexural [9]. This code is suitable for prediction for the impact loading of fluid flow to strain rate less than 3×10\(^{2}\) s\(^{-1}\).

This work estimates mechanical properties of green concrete made with the waste of plastic and glass of juices and soft drink bottles at conditions of quasi static, and goals to predict the dynamic properties under impact load of liquid flow by utilizing of CEB-FIP Model Code (2010).

2. Materials and Methods

2.1. Materials

2.1.1. Cement
Cement Type I (Ordinary Portland cement (O.P.C.)) was used to achieve the experimental program; this cement was in accordance with Iraqi specification (IQS No.5: 1984) [10].

2.1.2. Fine Aggregate
Natural sand was used. The gradation of this sand was found be positioned in the second zone within the Iraqi specification (IQS 45/1984) [11].
2.1.3. Coarse Aggregate
Coarse aggregate with max. size 20 mm from Badra and Jassan’s quarry was employed. Its gradation inside the ranges of Iraqi specification (IQS 45/1984) [10].

2.1.4. Waste Materials
Plastic wastes and glass wastes of bottles of juices and soft drinks were used as aggregate. They were formulated as follows:
- Plastic waste: Bottle caps were distorted approximately to fragments with a dimension of (10×10) mm to use as coarse aggregate, see Figure 1.
- Glass waste: The glass bottles were broken into small pieces that were passed from a 5 mm sieve to be used as an alternative to sand as in a Figure 2.

2.1.5. Water
Tap water was used in mixing and curing of all specimens.

2.2. Mix design
Concrete mixes were prepared according to British mix design method (B.S. 5328, Part 2:1991) [12]. The target strength was 30MPa at the age of 28 days. Table 2 displays reference mix proportions. Eight mixes were done with the following details:
- C00: the reference mix not including any adding of waste materials.
- CG10: the glass with 10%, was added as a replacement of sand volume.
- CG15: the glass with 15%, was added as a replacement of sand volume.
- CG20: the glass with 20%, was added as a replacement of sand volume.
- CP15: plastic bottle caps with 15% was added as a replacement of gravel volume.
- CP20: plastic bottle caps with 20% was added as a replacement of gravel volume.
- CP25: plastic bottle caps with 25%, was added as a replacement of gravel volume.
- CP20G15: plastic bottle caps with 20% as a replacement of gravel volume and the glass with 15% as a replacement of sand volume were added.

Table 2. Mix proportion.

| No. | w/c | Cement, Kg/m³ | Fine aggregate, Kg/m³ | Coarse aggregate, Kg/m³ | Slump, mm |
|-----|-----|---------------|-----------------------|------------------------|-----------|
| C00 | 0.5 | 340           | 515                   | 1385                    | 100       |

2.3 Mixing, casting, compaction, and curing
Materials for concrete mixes fitting to mix proportions were prepared, mixed manually, and then cast in the cleaned and oiled mould. The specimens comprise cubes, cylinders, and prisms. The compaction was done
by electrical vibration table. After 24±0.5 hrs., moulds were released and specimens were submerged in a curing tank, at laboratory temperature (22±2)ºC until testing age.

2.4 Tests

2.4.1. Compressive strength

Test machine with the maximum limit (2000 KN) was used to achieve the test according to (BS.1881: Part 116:1989) [13]. The average of three 100mm cubs for each mix was approved at 7 & 28 days ages.

2.4.2. Flexure strength

ASTM C 293-83 [14] method was followed in this test. (100×100×400) mm prisms were tested at age of 28 days. The average of two tests was adopted for each mix.

2.4.3. Modulus of elasticity

ASTM-C469-06 [15] was adopted to achieve this test using cylinders with 300mm height and 150mm diameter at age of 28 days.

3. CEB-FIP Model Code

Dynamic properties for concrete can be estimated by the Dynamic Increase Factor (DIF). The (DIF) defined by CEB-FIP code [9] as the ratio between dynamic strength and static strength. The mechanical properties for the dynamic state can be calculated from equations below [7]:

- Used for compressive strength
  \[
  DIF_{fc} = \frac{f_{cd}}{f_{c}} = \left( \frac{\dot{e}_c}{3 \times 10^{-6}} \right)^{0.014} \quad \text{for} \quad \dot{e}_c \leq 30 \text{ s}^{-1} \quad (1)
  \]
  \[
  DIF_{fc} = \frac{f_{cd}}{f_{c}} = 0.012 \left( \frac{\dot{e}_c}{3 \times 10^{-6}} \right)^{0.5} \quad \text{for} \quad 30 \leq \dot{e}_c \leq 300 \text{ s}^{-1} \quad (2)
  \]
- Used for flexural strength
  \[
  DIF_{fc} = \frac{f_{cd}}{f_{f}} = \left( \frac{\dot{e}_c}{3 \times 10^{-6}} \right)^{0.018} \quad \text{for} \quad \dot{e}_c \leq 10 \text{ s}^{-1} \quad (3)
  \]
  \[
  DIF_{fc} = \frac{f_{cd}}{f_{f}} = 0.0062 \left( \frac{\dot{e}_c}{3 \times 10^{-6}} \right)^{0.5} \quad \text{for} \quad 10 \leq \dot{e}_c \leq 300 \text{ s}^{-1} \quad (4)
  \]
- Used for modulus of elasticity
  \[
  DIF_{Ec} = \frac{E_{cd}}{E_{c}} = \left( \frac{\dot{e}_c}{3 \times 10^{-6}} \right)^{0.026} \quad \text{for} \quad 30 \leq \dot{e}_c \leq 300 \text{ s}^{-1} \quad (5)
  \]

Where

- $f_{cd}$ = the dynamic compressive strength corresponding to strain rate $\dot{e}_c$
- $f_{c}$ = the static compressive strength corresponding to the static strain
- $f_{cd}$ = the dynamic tensile strength corresponding to strain rate $\dot{e}_t$.
- $f_{t}$ = the static tensile strength corresponding to the static strain.
- $E_{cd}$ = the elastic modulus corresponding to strain rate of $\dot{e}_c$.
- $E_c$ = the elastic modulus corresponding to the reference static strain.

$f_{cd}, f_{t},$ and $E_c$ depended on quasi static rate as $30 \times 10^{-6}$, $1 \times 10^{-6}$, and $30 \times 10^{-6}$ respectively[7].

This paper deal with the impact of liquid flow. The strain, in this case, estimated limit is between $10^{-1}$ to $10^0$. Offshore platforms, aircraft impact, transportation facilities, gas explosion... etc are specified in this range of strain rate as shown in table 1.

4. Results and discussions

4.1 Static properties:

In Table 3 and figure 3, many notes can be collected, when plastic waste was used, the compressive strength was reduced. When using glass waste, the decrease in strength was shrunk at 28 days. While combining the two types of waste resulted in clear improvement in compressive strength (i.e, improved than cases of
separate use of waste). In mix CP20G15, the residual compressive strength was 76% and 83% with the entire percentage of wastes 35% at the age of 7 and 28 days, respectively. The performance of mixes strength is associated with the properties of the wastes that were used. Crushed glass has less abrasion resistance than natural sand, and plastic hardness is less than natural gravel [16].

Table 3. Compressive strength result

| No. | C00  | CG10 | CG15 | CG20 | CP15 | CP20 | CP25 | CP20G15 |
|-----|------|------|------|------|------|------|------|---------|
| Compressive strength MPa. 7 days | 24.98 | 16   | 19   | 15   | 13.79| 13.89| 13.11| 19      |
| Dynamic Compressive strength MPa. 7 days | 28.90 | 18.51| 21.98| 17.35| 15.96| 16.07| 15.17| 21.98   |
| Compressive strength MPa. 28 days | 31.01 | 23.72| 28.04| 22.08| 19.98| 20.11| 15.93| 25.68   |
| Dynamic Compressive strength MPa. 28 days | 35.88 | 27.44| 32.44| 25.55| 23.12| 23.27| 18.43| 29.71   |

Figure 3. The compressive strength result for static and dynamic strength with age 7 days and 28 days.

The behavior of flexural strengths is denoted in Table 4 and figure 4. The flexural strengths of the mixes containing the glass waste were the closest to the reference mix, while the greatest decrease in the strength was in the mixes containing plastic waste. When the two types of waste were mixed (i.e., CP20G15), the decrease was 50% of the reference mix. Therefore, it is possible to conclude that the addition of plastic waste has the greatest impact on the flexural strength and this may be due to the nature of the rigidity and limits of the flexibility of the material used [16].
Table 4. Flexural strength results

| No. | C00  | CG10 | CG15 | CG20 | CP15 | CP20 | CP25 | CP20G15 |
|-----|------|------|------|------|------|------|------|---------|
| Flexure strength MPa | 2.40 | 1.68 | 1.90 | 1.70 | 0.70 | 0.68 | 0.50 | 1.20    |
| Dynamic flexure strength MPa | 3.08 | 2.15 | 2.44 | 2.18 | 0.90 | 0.87 | 0.64 | 1.54    |

Figure 4. The flexure strength result for static and dynamic strength.

From observing Table 5 and figure 5, can be noticed that; in mixes containing plastic waste the modulus of elasticity values exceeded the mixes containing the glass waste but remained less than that of the reference mix. The modulus of elasticity values was decreased with the increase in the plastic ratio. The value of the elasticity of the mix containing the two types of waste (i.e, CP20G15) lies between the values of the mixes containing the plastic waste and the other containing the glass waste, and less than reference mix by about 3.99 GPa.

Table 5. Modulus of elasticity results.

| No. | C00  | CG10 | CG15 | CG20 | CP15 | CP20 | CP25 | CP20G15 |
|-----|------|------|------|------|------|------|------|---------|
| Modulus of elasticity MPa | 28  | 20.98 | 23.85 | 20 | 26.84 | 25.92 | 21.88 | 24.01 |
| Dynamic modulus of elasticity MPa | 40.10 | 30.05 | 34.16 | 28.64 | 38.44 | 37.12 | 31.34 | 34.39 |

4.2 Dynamic state

As mentioned earlier, this work deal with the impact of flow liquid. The strain, in this case, estimated to range between $10^{-1}$ to $10^{0}$. The (DIF) is equal to 1.16 for compressive strength. It is 1.282 for flexure strength. The (DIF) for Modules of elasticity is 1.43. The results of compressive strength, flexure strength, and modulus of elasticity in the dynamic state are tabled in table 2, table 3, and table 4 respectively. The predicted strength attained by CFB-FIP DIF forms for tension and compression is in concurrence with the experimental results of plain concrete depicted in [17] and [8] within the limit of the strain rate studied.
5. Conclusion
Based on the current study, the following points can be inferred:
1. It is possible to produce green concrete with 35% waste content and residual compressive strength of 76% and 83% at the age of 7 and 28 days, respectively.
2. The CEB-FIP Model (2010) DIFs are well suited to this type of green concrete results in both tension and compression as the formulas are close with other experimental studies. It is, therefore, possible to adopt this code to estimate dynamic characteristics within the quasi-static level as an alternative to practical tests, in which testing machines are often expensive, unavailable or specified at a maximum load rate.

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