Properties of Papercrete Concrete Containing Crushed Concrete Waste As Coarse Aggregate

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Abstract. Researches on the effect of waste recycling in the concrete industry are increasing due to its low cost as well as considering it as a significant method for protecting the environment by minimizing solid waste. This research evaluates the possibility of using concrete waste as partial replacement with coarse aggregate in Papercrete, and its effect on some concrete properties which include compressive strength, splitting tensile strength and heating resistance. Wasted paper used in this study as an additional material with three various ratios (5%, 10% and 15% by weight of cement) was mixed with concrete which have 0, 10%, 20% and 30% of concrete waste as a partial replacement of the coarse aggregate to produce twelve concrete mixtures. As compared with the plain mixture, it was found that workability decreasing with the increasing of both wasted paper and wasted concrete content. The study illustrated that the optimum percentage of adding wasted paper and wasted concrete replacement are 5% and 10% respectively, due to increasing in both compressive and tensile strength by 11.99% and 13.54% respectively compared with the plain mix.

The residual strength of concrete after heat exposure was affected significantly by the increasing of wasted paper content.

1. Introduction

As known, the governmental and educational institutions generating huge quantities of waste paper which needs about 3-12 months for degradation. So, to reduce the environmental pollutions caused by burning the wasted paper or throwing it away, it can be recycled by converting it to cardboard and paper products about 6-10 times frequently. However each recycling time results in a decreasing in the paper quality [1]. This issue motivated us to find an alternative method for recycling the wasted paper. Waste recycling is a significant method for protecting the environment and sustaining its resources. Therefore, there is a great focusing on waste recycling, especially recycling by using waste in the concrete industry. Recently, some researches focused on using wasted paper in concrete to produce what is known as papercrete as an alternative method of paper recycling. A lot of researchers explore the mechanical properties of the papercrete composite. Zaki et al. [1] stated that wasted paper could be recycled as additional material in concrete mixtures and illustrated that the mechanical properties of the produced concrete decreasing with the increasing of wasted paper ratio more than 10% by weight of cement. Gorgis et al.[2] mentioned that the fresh properties of papercrete affected obviously by increasing the wasted paper ratio and found that the concrete strength and the density reduced with increasing of wasted paper content and stated that the thermal conductivity of papercrete lower than the plain concrete. Shermale and Varma [3] found that papercrete is a lightweight substance that can be used as an infill substance in high rise buildings.

Otherwise, the old concrete buildings produce huge quantities of concrete debris. The utilization of this waste in the construction industry is considered the most practical and sustainable method for
recycling it. This type of recycling gives many advantages such as the preservation of natural resources by using these waste as fine or coarse aggregate as well as minimizing the cost of the debris transportation to the dumping or land filing sites [4]. Therefore, many researchers have been focused on the properties of concrete containing recycled concrete waste as aggregate. Al-Sulayfani et al.[5] provided a design diagram for concrete containing coarse aggregate produced from recycled concrete and illustrated that concrete strength decreased when natural coarse aggregate replaced by recycled concrete aggregate. Shahid et al.[6] stated that aggregate generated from recycled concrete waste could be treated by using epoxy resin to give a strength close to the plain concrete but with lower slump values, and that decrease could be solved by using the aggregate in saturated surface dry condition of the aggregate. Taffese [7] observed that concrete with aggregate produced from recycled concrete had performance less than the plain concrete and stated that the replacement of natural coarse aggregate by 10% of recycled concrete could increase the compressive strength by 8%.

The objective of this research is to study the influence of concrete waste content as a partial replacement of coarse aggregate for the properties of concrete containing paper waste as an additional material, which may produce a substitute solution for waste removal.

2. Properties of components and mixtures proportions

In all experiments, Ordinary Portland cement identical to the ASTM specification C(150) [8] was used to prepare the concrete mixtures. Table (1) illustrated the chemical composition and physical characteristics of the used cement in all experiments.

| Abbreviation                 | Results | ASTM C150 limitations |
|------------------------------|---------|------------------------|
| Chemical properties (%)CaO   | 63.7    | 63-11                  |
| SiO2                         | 21.53   | 21-24                  |
| Al2O3                        | 5.81    | 6-4                    |
| Fe2O3                        | 2.68    | 2-4                    |
| SO3                          | 2.28    | 2-3.5                  |
| MgO                          | 3.11    | <5%                    |
| L.O.I.                       | 0.87    | ≤3%                    |
| Bogue's equations            |         |                        |
| C3S                          | 46.45   | 45-60                  |
| C2S                          | 27.91   | 15-30                  |
| C3A                          | 11.15   | 6-12                   |
| C4AF                         | 6.87    | 6-8                    |
| Setting time (Vicat's method) Initial | 1:48(hrs.:min.) | ≥ 45 min. |
| setting Final setting        | 5:56(hrs.:min.) | ≤375 min. |
| Blaine surface area(m² / kg) | 315     | ≥ 280                  |
| Compressive strength (MPa)   |         |                        |
| 3 days                       | 16      | ≥ 12                   |
| 7 days                       | 23      | ≥ 19                   |

River sand identical to the ASTM specification C(33) [9] was used. Sieve analysis of the used sand and its physical properties were fixed as in Figure 1 and Table 2 respectively. River rounded gravel as natural aggregate conforms to the ASTM C33[9] was used. Concrete waste used in this study was obtained from the hammer cracking of tested concrete specimens to break it to smaller pieces as illustrated in Figure 2. After crushing the concrete specimens, the generated coarse aggregates were separated into different sizes by using sieves, and then these sizes were arranged to obtain a gradient similar to the used natural gravel aggregate. Sieve analysis of the used coarse aggregate and its physical properties were fixed as in Table 3 and Figure 3 respectively.
Figure 1. Sieve analysis of fine aggregate

Table 2. Physical properties of the used sand

| Aggregate Type | fineness modulus | Specific Gravity | Absorption% |
|----------------|------------------|------------------|-------------|
| sand           | 2.62             | 2.56             | 2           |

a) Tested concrete specimens waste  

b) Cracked concrete waste

Figure 2. Crushed concrete waste preparation

Table 3. Physical properties of the used coarse aggregate

| Aggregate Type    | M.A.S.(mm) | Specific Gravity | Absorption% |
|-------------------|------------|------------------|-------------|
| Grounded gravel   | 19         | 2.67             | 0.36        |
| Wasted concrete   | 19         | 2.47             | 3.47        |
The wasted paper used in this study was collected from offices, schools, and government institutions. To prevent the clumping of wasted paper together and to achieve a regular distribution during blending, wasted paper was shredded into small pieces using a paper shredding machine then immersed in water tank for three days, after that the sludge of paper was squeezed manually to remove the excess water content then it was grinded by using a mixer grinder to obtain the required sludge. After that, the wasted paper sludge was kept in plastic bags. Figure 4 shows the methodology of preparing wasted paper sludge. Table 4 shows the physical characteristics of the utilized wasted paper.

**Figure 3.** Sieve analysis of coarse aggregate

![Sieve analysis of coarse aggregate](image)

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**Figure 4.** Wasted paper preparation

![Wasted paper preparation](image)
Superplasticizer (SikaVisco Crete-5930) conforms to the ASTM C494 [10] was used in this study. Table 5 described the properties of the utilized superplasticizer.

Table 5. Superplasticizer properties

| Form          | Viscous liquid          |
|---------------|-------------------------|
| Basis         | Aqueous solution of modified polycarboxlate |
| Relative density | 1.08 g/l±0.005     |
| Appearance    | Turbid liquid            |

The water-cement ratio was kept constant as 0.45, so to obtain the same workability superplasticizer was used. Three various ratios of wasted concrete (10%, 20% and 30% as partial replacement of gravel) were added to the papercrete mixtures prepared by adding three various ratios (5%, 10% and 15% by weight of cement) of wasted paper sludge. Furthermore, the plain concrete mix was prepared for results comparison. The mix proportions were illustrated in Table 6. A slump test was performed according to ASTM C143[11]. The compressive strength test was performed according to B.S.1881: part 116[12] specifications, thus the concrete mixture was casted in six cubic (100x100x100) mm moulds. Three of them to obtain the average compressive strength and the same number for the heat resistance test. According to ASTM C496 [13] specifications, the splitting tensile strength test was performed. Six cylindrical (100x200) mm moulds were casted, three of them to find the mean of splitting tensile strength test and the same number for the heat resistance test.

Table 6. Mix proportions of concrete mixtures

| Mix ID | Cement (kg m⁻³) | Sand (kg m⁻³) | Gravel (kg m⁻³) | Wasted paper (%) | Wasted paper (kg m⁻³) | Wasted concrete (%) | Wasted concrete (kg m⁻³) | Water (kg m⁻³) |
|--------|----------------|--------------|----------------|------------------|----------------------|--------------------|-------------------------|----------------|
| M 0.0  | 335            | 760          | 1140           | 0                | 0                    | 0                  | 0                       | 150            |
| M 5.0  | 335            | 760          | 1140           | 5                | 16.8                 | 0                  | 0                       | 150            |
| M 10.0 | 335            | 760          | 1140           | 10               | 33.5                 | 0                  | 0                       | 150            |
| M 15.0 | 335            | 760          | 1140           | 15               | 50.3                 | 0                  | 0                       | 150            |
| M 0, 10| 335            | 760          | 1026           | 0                | 0                    | 10                 | 114                     | 150            |
| M 0, 20| 335            | 760          | 912            | 0                | 0                    | 20                 | 228                     | 150            |
| M 0, 30| 335            | 760          | 798            | 0                | 0                    | 30                 | 342                     | 150            |
| M 5,10 | 335            | 760          | 1026           | 5                | 16.8                 | 10                 | 114                     | 150            |
| M 10,10| 335            | 760          | 1026           | 10               | 33.5                 | 10                 | 114                     | 150            |
| M 15,10| 335            | 760          | 1026           | 15               | 50.3                 | 10                 | 114                     | 150            |
| M 5,20 | 335            | 760          | 912            | 5                | 16.8                 | 20                 | 228                     | 150            |
| M 10,20| 335            | 760          | 912            | 10               | 33.5                 | 20                 | 228                     | 150            |
| M 15,20| 335            | 760          | 912            | 15               | 50.3                 | 20                 | 228                     | 150            |
| M 5,30 | 335            | 760          | 798            | 5                | 16.8                 | 30                 | 342                     | 150            |
| M 10,30| 335            | 760          | 798            | 10               | 33.5                 | 30                 | 342                     | 150            |
| M 15,30| 335            | 760          | 798            | 15               | 50.3                 | 30                 | 342                     | 150            |

Table 4. Physical properties of the used wasted paper

| Organics Materials | 70% |
|-------------------|-----|
| In-organic materials | 30% |
| Moisture Content | 2.77% |
| Density (kg/m³) | 800 |
| Specific Gravity (SSD) | 0.98 |
3. Results and discussion

3.1. Effect of wasted concrete on the papercrete slump

Table 7 presents the slump values of concrete mixtures and the dosage of superplasticizer that used to obtain close to the concrete mixtures workability. The used superplasticizer dose was increased due to decreasing of the slump which resulted from added wasted paper that has high absorption capacity, as well as added wasted concrete which has a porous structure.

| Mix ID | wasted paper (%) | wasted concrete (%) | Admixture by weight of cement(%) | Slump (mm) |
|--------|------------------|---------------------|---------------------------------|-----------|
| M 0,0  | 0                | 0                   | 0.75                            | 14        |
| M 5,0  | 5                | 0                   | 0.8                             | 13        |
| M 10,0 | 10               | 0                   | 1.3                             | 12        |
| M 15,0 | 15               | 0                   | 2                               | 12        |
| M 0, 10| 0                | 10                  | 0.85                            | 12        |
| M 0, 20| 0                | 20                  | 1                               | 13        |
| M 0, 30| 0                | 30                  | 1.6                             | 12        |
| M 5,10 | 5                | 10                  | 1.1                             | 12        |
| M 10,10| 10               | 10                  | 1.3                             | 11        |
| M 15,10| 15               | 10                  | 2.1                             | 11        |
| M 5,20 | 5                | 20                  | 1.3                             | 13        |
| M 10,20| 10               | 20                  | 2.0                             | 12        |
| M 15,20| 15               | 20                  | 2.3                             | 11        |
| M 5,30 | 5                | 30                  | 1.5                             | 11        |
| M 10,30| 10               | 30                  | 2.3                             | 11        |
| M 15,30| 15               | 30                  | 2.6                             | 11        |

3.2. Effect of wasted concrete on the compressive strength of papercrete

Figure 5 shows wasted paper distribution in cubic sample after testing. The variations of compressive strength in concrete mixtures are presented in Figure 6. It is observable that when only wasted paper was added to the control mix, the compressive strength was increased at 5% ratio which was 31.2 MPa (1.07 times of the control compressive strength 29.2 MPa). After 5% ratio, the compressive strength was reduced, where the percentage reduction of compressive strength compared with the plain mix are 12.7% and 25.7% for 10% and 15% respectively. This behaviour of strength reduction can be explained to the cohesion reduction as well as the bonds weakness between calcium-hydrate-silicate (C-S-H) gel around the cellulosic substance. These results were verified by several researchers [1].

Otherwise, when natural coarse aggregate was the replacement by wasted concrete individually, it is obvious that the ratio of wasted concrete at 10% produced the highest value of compressive strength which was 32.6 MPa (11.6% more than the compressive strength of plain concrete). Beyond 10% ratio, the compressive strength reductions were 3.1%, and 17.5% for 20%, and 30% respectively compared to the plain concrete. This reduction can be explained to the fact that the wasted concrete has a porous structure more than the natural aggregate, moreover, the existence of old cement dusty particles on the wasted concrete surface result in aggregate weakness[4].

For the effectiveness of both wastes (wasted concrete and wasted paper), the results show that the optimum percentage of wasted paper and wasted concrete proportions are 5% and 10% respectively. For concrete mixture containing these ratios, the compressive strength reached the maximum value which was 32.7 MPa, so the increasing percentage of the compressive strength was 11.99% compared with the plain concrete. However, when the ratios increased to more than (5 and 10)% , the compressive strength was decreased obviously which was at 15% for wasted paper and 30% for wasted concrete, where the compressive strength recorded as 15.1 MPa that reduction below the plain
concrete about 48.3%, so this type of concrete mix is suitable for blocks, flower beds and furniture in public squares and stores.

![Figure 5. Papercrete cubic sample after testing](image)

![Figure 6. Effect of wasted concrete content on compressive strength of papercrete](image)

3.3. Effect of wasted concrete on the splitting tensile strength of papercrete

The variation of splitting tensile strengths in concrete mixtures are presented in Figure 7. The splitting tensile strength had the same behaviour as compressive strength. It is clear that when only wasted paper was added to the control mixture, the tensile strength was increased at 5% ratio which was 2.77 MPa (1.09 times of the control splitting tensile strength (2.55 MPa). After 5% ratio, the splitting tensile strength was reduced, where the percentage reduction of splitting tensile strength comparing with the plain mix are 8.9% and 27.6% for 10% and 15% respectively.

Otherwise, when natural coarse aggregate was the replacement by wasted concrete individually, it is obvious that the ratio of wasted concrete at 10% produced the highest value of splitting tensile strength which was 2.8 MPa (9.8% more than splitting tensile strength of plain concrete). Beyond 10% ratio, the splitting tensile strength reductions were 6.4% and 15.1% for 20%, and 30% respectively compared to the plain concrete.

For the effectiveness of both wastes (wasted paper and wasted concrete), the results show that the optimum percentage of wasted paper and wasted concrete are 5% and 10% respectively, for concrete mixture containing these ratios the splitting tensile strength reached the maximum value which was 2.9 MPa, so the increasing percentage of the splitting tensile strength was 13.54% compared with the plain mix. However, when the ratios increased to more than (5 and 10)% , the splitting tensile strength was
decreased obviously which was at 15% for wasted paper and 30% for wasted concrete. where the compressive strength recorded as 1.91 MPa that reduction below the plain concrete about 25.1%.

3.4. Effect of wasted concrete on the heat resistance of papercrete
For the fire resistance test, three samples of concrete were dried by air for one hour prior to their burn in a furnace (500°C) for one hour. Then, the samples were cooling to the room temperature in open air condition for twenty-four hours. The residual compressive and tensile strengths after heating were illustrated in Figures 7 and 8 respectively. Figures 8 and 9, show that the residual strength after heating was increased with wasted paper increasing, this behaviour may be attributed to the interior thermal insulation of wastes paper.
4. Conclusions
- The workability is decreasing with the increasing of both types of waste (wasted paper and wasted concrete), therefore, the addition of both waste require further water or chemical admixture dosages to obtain the required slump.
- The optimum percentages of added wasted paper and replaced wasted concrete are 5% and 10% respectively.
- After heating, the residual strength is increasing with wasted paper content increasing obviously.

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