Investigating the effects of limestone and rice husk ash on the mechanical and durability properties of concrete

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Abstract. Urbanisation and industrial development have led to an increasing need for a new building which in turn increase the demand for raw construction materials such as coarse aggregate. Therefore, researchers focus shifted towards implementing various materials to minimises the consumption of the earth resources. This research examines the implementation of crushed limestone as a coarse aggregate instead of traditional coarse aggregate in Iraq. Besides, rice husk ash was also used in this research project to improve the mechanical and durability properties of the developed concrete using crushed limestone. Two concrete mixtures were developed in this research. The first mixture uses the crushed limestone as aggregated without rice husk ash while the second mixture employs the crushed limestone with rice husk ash. Several tests were conducted to assess the mechanical and durability properties of the developed concrete that are slump and air contents, absorption compressive strength and flexural strength. The outcome highlighted that the concrete developed using crushed limestone has lower mechanical and durability properties compared to normal aggregate (gravel). However, the usage of the rice husk ash improved the properties of the developed concrete using crushed limestone.

Keywords: Limestone, rice husk ash, aggregate, concrete.

1. Introduction
Industrial development and urbanisation have increased the demand for new development and structures. One of the most commonly used structural materials is concrete due to its durability and strength [1, 2]. Concrete is considered an essential element from various types of structures. One of the basic elements of concrete is the aggregate which plays an essential role in the compressive strength of the concrete. The aggregate occupies the largest size of the concrete and the concrete performance is large influenced by the type of aggregate used in it [3]. Yet, this industry of concrete is considered by many researchers as a considerable source of pollution around the world. Concrete produces various types of gases that affect human health and the environment [4-6] such as greenhouse gases which causes global warming. Global warming causes a significant shortage is of freshwater and pollution [7, 8]. Additio nally, concrete production generates huge quantities of polluted water with various types of pollutants disposed of in water bodies[9-12]. These pollutants include suspended solids, organic compounds [13-17]. Accordingly, concrete factory wastewater needs advanced and effective technologies to remove the pollutants from factory effluences like
filtration [18-24], coagulation [25-29], chemical treatment [24, 30-36], and also mix methods [37-43]. In addition to environmental pollution, the large use of concrete in development has led to the extensive use of natural aggregates which led to the depletion of earth resources of natural aggregate. Based on the above effects of concrete usage, researchers have been investigating the use of other eco-friendly materials that replace the constituents of concrete to minimise the effects of concrete. Limestone is considered as one of the commonly used material to replace natural aggregates in concrete production [44-46]. The limestone mostly contains calcium carbonate, magnesium carbonate and siliceous materials in its composition [47, 48]. Using limestone as aggregates in concrete significantly minimises the environmental effects of concrete. Besides, the production of limestone is cheaper than the natural aggregates and needs less effort and energy. Besides, the production of limestone aggregate produces significantly lower quantities of pollutants such as carbon dioxide. Additionally, limestone aggregate usage in concrete produces more stable concrete and reduces the quantity of concrete waste and enhance the durability and strength of the concrete. This extends the life span of the concrete and reduces the concrete waste [49-52]. The shortage in natural aggregate has led to a significant increase in limestone usage as aggregate in concrete production around the world [53]. The coarse aggregate largely affects the concrete properties owing to the effects of gradation of the aggregate and the connection between the aggregate and other materials in the concrete [54]. The parameters of the coarse aggregate like size distribution have a significant influence on the strength of produced concrete structures. Researchers showed that the limestone meets the requirements of aggregates and could be adopted to produce concrete mixes. Therefore, the crushed limestone provides a useful alternative to the concrete aggregates that are gravel and even the sand in concrete mixtures. Researchers [55] examined the usage of the dust of the limestone in concrete. The usage of the dust of the limestone in terms of various properties like compressive strength, absorption, permeability, and others. It was found that fine aggregate can be substituted by limestone dust. In addition to aggregate replacement, researchers examined the use of other cementitious materials like silica fume, ground blast furnace slag, fly ash as cement replacement to develop eco-friendly cementitious materials to replace cement in concrete production [45, 56]. The effects of the cementitious materials depend on the dosage of the replacement materials and characteristics. For instance, Abdulredha, Muhsin, Al-Janabi, Alajmi, Gkantou, Amoako-Attah, Al-Jumeily, Mustafina and AlKhayyat [45] used silica fume as cement replacement in concrete production. They showed that the silica fume could be used as cement replacement in concrete development. Shubbar, Jafer, Abdulredha, Al-Khafaji, Nasr, Al Masoodi and Sadique [46] used ground blast furnace slag in concrete production and highlighted that the ground blast furnace slag is a useful replacement for the cement in mortars production. Generally, researchers reported that the use of cementitious materials as cement replacement generates concrete with a very good characteristic that is comparable to the concrete produced by ordinary cement [57]. This could significantly reduce the negative impact of cement and reduces the depletion of the earth resources. Based on the above the current research examines the use of crushed limestone and coarse aggregates replacement in concrete production. The use of crushed limestone as coarse aggregate replacement is based on several reasons that are wide availability of the crushed limestone, low production price of the crushed limestone, and low impact of the environmental impact of crushed limestone concrete comparing to ordinary concrete [44-46]. Besides, rice husk ash usage as cement replacement in concrete production was also investigated in concrete incorporating crushed limestone as coarse aggregate.

2. Methodology
### 2.1. Materials

To reach the goal of this research, several materials were used including ordinary Portland cement, natural coarse aggregates, crushed limestone and rice husk ash. The ordinary Portland cement meets the Iraqi standard No.5:1984 of the Iraqi Organization of Standards for Portland Cement. The cement specific gravity is 3.14. The initial setting times of the cement is 120 minutes while its final meeting time is 250 minutes. Sand is the second component used in cement production which has a specific gravity of 2.62. The particle size distribution of the sand ranged from 200μm to 4.75mm. the size gradation of the sand agrees with the limits recognised by ASTM C33M-18.

In addition, gravel and crushed limestone were used in this research as coarse aggregates. The crushed limestone was obtained from the Al-Noura factory located about 8 km south of the city of Kerbala, Iraq. The physical and chemical characteristics of the gravel and the limestone are presented in tables 1 and 2, respectively. The largest particle size for limestone particles is 25 mm. The standard ASTM C127-12 was adopted to test the characteristics of the gravel and the limestone.

Table 1: Gravel and limestone physical characteristics.

| Aggregate type | Bulk Density (g/cm$^3$) | Specific Gravity | Porosity (%) | Moisture Content (%) |
|----------------|-------------------------|------------------|--------------|----------------------|
| Gravel         | 1.60                    | 2.70             | 1.40         | 0.05                 |
| Limestone      | 1.20                    | 2.55             | 5.0          | 0.28                 |

Table 2: Gravel and limestone physical-chemical characteristics.

|            | CaO   | Al$_2$O$_3$ | MgO  | SiO$_2$HP | Fe$_2$O$_3$ |
|------------|-------|-------------|------|-----------|-------------|
| Limestone  | 53.72 | 0.168       | 1.018| 0.814     | 0.126       |
| Gravel     | 1.72  | 6.16        | 0.06 | 84.81     | 1.66        |

The characteristics of the rice husk ash are presented in table 3. The standard ASTM C618-15 was used to confirm the chemical and physical characteristic of the rice husk ash. From the table, it can be seen the specific gravities of rice husk ash is 2.18.

Table 3: Physical and chemical analysis of the rice husk ash.

| Oxide composition | Magnitude |
|-------------------|-----------|
| SiO$_2$ %         | 86.50 %   |
| Al$_2$O$_3$ %     | 0.15 %    |
| Fe$_2$O$_3$ %     | 0.31 %    |
| SO$_3$ %          | 0.14 %    |
| Na$_2$O %         | 1.40 %    |
| Strength activity Index | 130 |
| Flow table test   | 100       |
| Specific gravity  | 2.18      |

### 2.2. Testing standards

Several tests were conducted to show the performance of the concrete that contains limestone and rice husk ash. The standard followed to show the characteristic of the concrete include the slump test (ASTM C143), flexural strength test (ASTM C 78-02), compressive strength test (ASTM C39) and absorption test (BS 1881:122-1983).

### 2.3. Mixtures
Various percentages of the limestone were used to study its effects on the properties of the developed concrete. The limestone replacement ranged from 20% to 80% by weight of the coarse aggregate of the developed concrete. The concrete created from natural gravel was used as a control sample for comparison. The reference mixture was designed based on the guidelines of ACI-211.1-91. This is one to make the developed concrete comply with the requirements of workability and compressive strength. The reference mixture contains only natural sand, ordinary Portland cement and gravel. In the first group of developed concrete, the coarse aggregate of gravel is replaced with the crashed limestone with various percentages ranged from 20% to 80%. The mixtures contain crashed limestone were denoted by L followed by the percentage of the coarse limestone used. For example, when 20% of the gravel is replaced with limestone, the mixture is denoted with L20. Four mixtures were developed containing 20%, 40%, 60% and 80% limestone as coarse aggregate denoted by L20, L40, L60 and L80. Additionally, 15% of the cement was replaced with rice husk ash to show the effects of the added cementitious material on the development of the concrete containing limestone as coarse aggregate. The mixtures contain rice husk ash were denoted with the letter R to highlight the addition of the cementitious material. Based on the above, two groups of mixtures were developed as follow:

- Group one contains various percentages of the limestone only.
- Group two contains various percentages of the limestone in addition to only 20% of the rice husk ash.

The proportion of the mixtures are presented in table 4.

| Group | mixtures | Cement | Rice husk ash | Sand | Gravel | Crushed limestone | Water |
|-------|----------|--------|---------------|------|--------|-------------------|-------|
| Group 1 | L0       | 450    | 0             | 675  | 1025   | --                | 216   |
|        | L20      | 450    | 0             | 675  | 820    | 205               | 225   |
|        | L40      | 450    | 0             | 675  | 615    | 410               | 235   |
|        | L60      | 450    | 0             | 675  | 410    | 615               | 245   |
|        | L80      | 450    | 0             | 675  | 205    | 820               | 250   |
| Group 2 | L0R      | 382.5  | 67.5          | 675  | 1025   | --                | 207   |
|        | L20R     | 382.5  | 67.5          | 675  | 820    | 205               | 216   |
|        | L40R     | 382.5  | 67.5          | 675  | 615    | 410               | 221   |
|        | L60R     | 382.5  | 67.5          | 675  | 410    | 615               | 234   |
|        | L80R     | 382.5  | 67.5          | 675  | 205    | 820               | 243   |

3. Results

Several tests were conducted to show the development of the concrete using two replacement materials that are limestone and rice husk ash. Table 5 presents the results of the tests for concrete cubes that uses limestone as aggregates replacement. It is worth mention that the results reported in this table represent the average of three samples. From the table, it can be noticed that the compressive strength of the concrete decrease with an increase in the percentage the limestone replacement. It can be seen that the 7 days compressive strength decreased from 22 MPa to only 14 MPa when the fraction of the limestone increased from 0% to 80% of the coarse aggregate. similarly, the development of the compressive strength after 28 days is comparable to the development of the compressive strength after 7 days. The increases in the quantity of the limestone reduce the compressive strength significantly.

Flexural strength tests result also confirmed that the developed concrete using limestone is weaker compared to normal concrete the employs gravel in its materials. The flexural strength after 28 days
of curing decreased from 5.97 MPa to 4.32 MPa when the percentage of the limestone fraction increased from 0% to 80% substitutes. The absorption is also increased with the increase in the percentage of the limestone fraction in the concrete.

Table 5: Tests results for the new concrete mixtures without rising husk ash.

| Mixtures | Compressive strength (MPa) | Flexural strength (MPa) | Absorption (%) | Slump (mm) |
|----------|---------------------------|------------------------|----------------|------------|
|          | 7 days                    | 28 days                | 7 days         | 28 days    |                |
| Group 1  |                           |                        |                |            |
| L0       | 22.71                     | 32.21                  | 4.61           | 5.97       | 6.15          | 4.49         | 100          |
| L20      | 18.45                     | 28.40                  | 3.86           | 5.80       | 8.46          | 5.82         | 92           |
| L40      | 15.20                     | 24.01                  | 3.79           | 5.21       | 9.79          | 6.88         | 87           |
| L60      | 15.10                     | 21.85                  | 3.43           | 4.87       | 10.07         | 7.61         | 85           |
| L80      | 14.00                     | 18.97                  | 3.07           | 4.32       | 10.41         | 8.51         | 77           |

Table 6 presents the results of the tests for concrete cubes that uses limestone as aggregates replacement and rice husk ash as cement replacement. Similarly, the compressive strength increases from 32.21 MPa (28 days without rice husk ash and limestone) to 34.92 MPa (28 days with only 15% rice husk ash). However, the compressive strength of the concrete decrease with an increase in the percentage of the limestone replacement. The 7 days compressive strength decreased from 23.75 MPa to only 14.71 MPa when the fraction of the limestone increased from 0% to 80% of the coarse aggregate. The presence of the rice husk ash increases the compressive strength but the limestone still largely reduces the compressive strength. The flexural strength tests result also is not different from the compressive strength. They developed the concrete using rice husk ash with higher flexural strength. However, the flexural strength is weaker compared to normal concrete the employs gravel in its materials. The flexural strength after 28 days of curing decreased from 7.01 MPa to 5.32 MPa when the percentage of the limestone fraction increased from 0% to 80% substitutes. The absorption is also increased with the increase in the percentage of the limestone fraction in the concrete. However, 15 per cent of the rice husk ash decreased the adsorption percentage by about 8%.

Table 6: Tests results for the new concrete mixtures with rising husk ash.

| Mixtures | Compressive strength (MPa) | Flexural strength (MPa) | Absorption (%) | Slump (mm) |
|----------|---------------------------|------------------------|----------------|------------|
|          | 7 days                    | 28 days                | 7 days         | 28 days    |                |
| Group 2  |                           |                        |                |            |
| L0R      | 23.75                     | 34.92                  | 5.14           | 7.01       | 6.10          | 4.12         | 94           |
| L20R     | 19.97                     | 30.11                  | 4.86           | 6.82       | 7.34          | 5.56         | 90           |
| L40R     | 17.45                     | 25.83                  | 4.34           | 6.11       | 8.18          | 6.23         | 85           |
| L60R     | 17.13                     | 24.44                  | 3.91           | 5.75       | 8.84          | 6.75         | 79           |
| L80R     | 14.71                     | 22.76                  | 4.12           | 5.32       | 9.64          | 6.91         | 74           |

4. Conclusions
This research is conducted with the aim of investigating the effect of implementing crushed limestone as a coarse aggregate replacement and rice husk ash as cementitious materials. Several tests were conducted to understand the effects of the aforementioned materials on the mechanicals and durability characteristics. These tests include slump test, flexural strength test, compressive strength test and absorption test. The outcome showed that 15% replacement of the rice husk ash with cement increased the compressive strength, flexural strength by about 8% and 15%, respectively. The addition of about 80% of the limestone reduced the compressive strength by about 28%.

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