



## The possibility of producing an Eco-Friendly refractory concrete



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### HIGHLIGHTS

- Effective usage of alumina brick waste as aggregate in construction reduces environmental pollution.
- The inclusion of bauxite powder in RFC mixtures substantially results comparable to reference mixtures.
- A 10% bauxite powder is optimal for achieving the highest compressive strength.
- The results encourage the use of bauxite powder and alumina brick as aggregate in RFC manufacture.

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### ABSTRACT

The quantity of waste generated during construction and demolition keeps rising annually. Refractory bricks are wastes that have a detrimental effect on the environment. This paper investigates the reuse of refractory brick wastes to create environmentally friendly refractory concrete. To accomplish this goal, two percentages 10 and 25% of alumina cement will be substituted for bauxite powder, and alumina brick as the aggregate will be used instead of the natural aggregates. For each of the six types, a mix of refractory concrete (RFC), 14% water content, and a 1:3 cement/ aggregate ratio. The cast samples were stored at laboratory temperature for a full day while still in their molds. The cast samples were left for (24) hours at laboratory temperature in 100% relative humidity. After that, they were opened and placed in water for 7 days to cure. The specimens were placed in an oven to dry at 110 °C for 24 hours after seven days of curing in water. The samples were burned for two hours at temperatures between 1000–1100 °C at a rate of 3.33 °C/min. After that, they were cooled to 25 °C before being tested. Then, the cast samples were tested to determine the bulk density, shrinkage, compressive strength, modulus of rupture, and weight change. The produced RFC performed almost comparably to those obtained on conventional RFC. This implies that waste alumina bricks as aggregate, with bauxite powder, can be used to manufacture RFC.

### 1. Introduction

The world's population is growing, and civilized growth is increasing the amount of concrete consumed, placing enormous pressure on natural resources. Additionally, a large amount of concrete waste from construction and demolition is disposed of in landfills, which presents an excellent incentive to recycle and reuse construction and demolition wastes. Numerous studies have assessed the use of construction and demolition wastes as aggregates in concrete production, demonstrating that they can be substituted for natural aggregates [1]. In thermally heated equipment, the operating temperature usually does not exceed (1100–1200) °C. Therefore, the lining of such units is made of refractory concretes with alumina cement, the amount of Al<sub>2</sub>O<sub>3</sub>, which is no more than 40 percent. One of the possible ways to reduce the cost of the above refractory concrete is the replacement of the alumina cement with bauxite powder, which is approximately four times cheaper than the alumina cement. The primary industrial uses for refractory concretes are steel structure linings and steelmaking ladles. These materials are subjected to high mechanical and thermal loads throughout their service life. Over the past few decades, the industry's evolving processes have increased demand for refractory products to perform better [2]. Hosseini et al. [3] examined refractory concrete and described it as unique for use at high temperatures. It comprises binders, plasticizer liquid, refractory aggregates, and, if necessary, additional special admixtures. This type of concrete uses special binders, which are not used in regular concrete structures. The reaction between the plasticizer liquid and the binder hardens the mixtures at normal or low temperatures. Similar to other varieties of concrete, these also require water for the forming and setting processes. Since the extra water will evaporate from the concrete

during the heating process, the water content in the mixture design needs to be carefully considered. Admixtures and other chemical compounds have the potential to enhance the curing process and yield unique properties. A form of refractory concrete called free cement refractory concrete (FCRC) is created without cement by utilizing additives and various material bonds. It is less susceptible to chemical attack, molten metals, and service slags, the three main destructive forces, and has good volume stability. Dickuviene et al. [4] showed that the density of refractory concrete supplemented with micro-silica and reinforced with steel fibers at 800 °C and 100 °C increased by approximately 7% and 2% respectively. Additionally, it is mentioned that at 100°C, adding micro-silica and steel fiber reinforcement increases cold-crushed strength from 22% to 47%. This increase diminishes at a high temperature of 1000 °C and becomes 9% when steel fiber and micro-silica are added 3%. Newman and Choo [5] suggested that the occurrence of cracks in refractory concrete following the initial firing is either unusual or abnormal. These cracks may result from dehydration shrinkage or ceramic reactions between the cement and aggregates at elevated temperatures. These cracks will close when the concrete is heated to its service temperature in normal operation. Thermal expansion can be reversed during cooling and reheating after the initial firing. These cracks should not be a concern unless debris is allowed to build up in the cracks between firings. The width of the crack could then grow due to more firings. The term "waste material from the brick and tile industry" refers to waste material that is produced during the final stages of brick and tile production that is damaged. Prefabricated bricks and tiles damaged beyond tolerance limits are crushed close to the factory because they are unsuitable for sale. Sports terrain frequently uses this waste material as filler in the upper and lower layers. Global research suggests that crushed brick might be used as a concrete aggregate. This would be a great way to address the issue of ecological handling while also attempting to protect natural resources. This material may produce compressive strength comparable to concrete made with natural aggregate, depending on the type of brick products used to make the aggregate and its strength. This type of concrete has a lower thermal conductivity coefficient than concrete, which includes natural aggregate. This difference in thermal conductivity also helps explain why concrete containing crushed bricks and tiles as an aggregate has a higher fire resistance [6]. Alumina bricks are used in furnaces as liners to resist high temperatures. Alumina bricks produce structure strength, heat resistance, and mechanical and chemical stability in a furnace. Alumina is cheap, easily available, and has a high refractory property. Alumina bricks have good strength, stiffness, hardness, wear resistance, corrosion resistance, and thermal stability and are, therefore, suitable as refractory brick materials. After being subjected to high-temperature treatment, the compressive stress-strain behavior of the concretes comprising recycled refractory brick fine aggregate in the two groups of specimens, including calcium aluminate cement and regular Portland cement, was examined. The results showed that the compressive strength of recycled refractory brick aggregate concrete (RRBC) continuously decreases as temperature rises. At 600 °C, the strength loss rate of the ordinary cement series and the aluminate cement series was found to be more significant, with a loss of approximately 60% and more than 50%, respectively. At most increased temperatures, aluminate cement's normalized compressive strength is lower than regular cement's [7]. This research aims to examine how the properties of alumina cement refractory concrete are affected when alumina cement is substituted with bauxite powder. This study uses two types of aggregates: bauxite aggregate and alumina brick.

## 2. Raw materials

Generally, the properties of the raw materials and the process of synthesis or processing determine the properties of refractory concrete.

### 2.1 High alumina cement

High alumina cement (HAC) undergoes a chemical transformation known as "conversion" after drying and hardening. In certain cases, this transformation may hurt the cement's long-term durability. In the worst-case scenario, the cement acquires a greater sensitivity to corrosive attack, becomes porous, and loses a significant portion of its hydraulic strength. There have been several instances where collapses in structures using HAC concrete supports have been attributed to degradation via conversion, or at the very least, had it as a contributing component. Due to this risk, using HAC for structural reasons has always been considered a dubious technique [8]. The results of the chemical analysis for high alumina cement are displayed in Table 1, where the main constituents are silica SiO<sub>2</sub> (35.29%) and alumina Al<sub>2</sub>O<sub>3</sub> (62.34%). In addition, it has trace amounts of flux components Fe<sub>2</sub>O<sub>3</sub>, CaO, and MgO. The National Center Construction Laboratories served as the venue for this test.

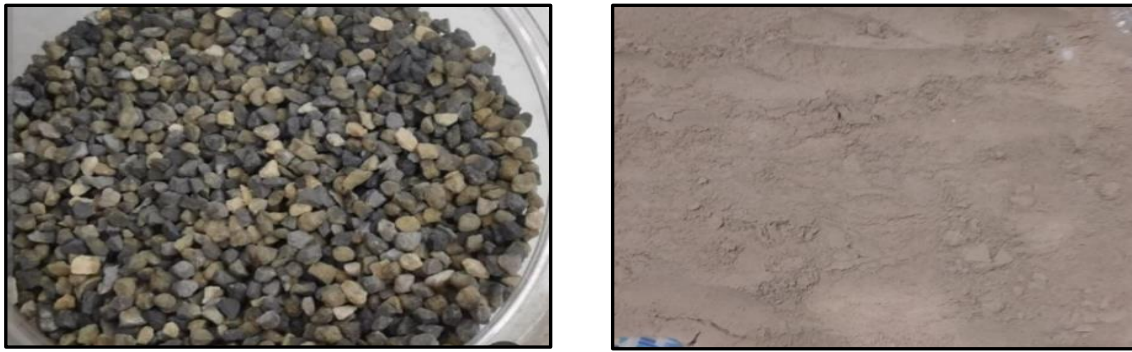
**Table 1:** Analysis of chemicals for alumina cement

Oxides	Percent
Al <sub>2</sub> O <sub>3</sub>	62.34
SiO <sub>2</sub>	35.29
SO <sub>3</sub>	0.02
CaO	0.14
TiO <sub>2</sub>	0.49
Fe <sub>2</sub> O <sub>3</sub>	0.83
L.O. I	0.15
Total	99.13

### 2.2 Bauxite aggregate

The fine aggregate shown in Figure 1A was produced by Fallujah Refractories Company and supplied by the Building Research Center for use in the production of refractories. It could exist in Iraq's western area. Tables (2 and 3) show the bauxite

aggregate's chemical and sieve analysis results. ACI Report 547-2008 specifications indicate that the sieve analysis shows that the aggregate's composition is mainly composed of alumina silicate and impurities (MgO, CaO, and F<sub>2</sub>O<sub>3</sub>), with various grades varying from (0.1 to 4.75) mm and powdered bauxite aggregates of approximately 100 μm in size as the Figure 1B.



**A: The bauxite aggregates**

**B: Bauxite aggregate as powder**

**Figure 1:** Bauxite as aggregate and powder used in this research

**Table 2:** Analyzing the sieve of bauxite aggregate

Size of sieve	%Passing
4.75 mm	100
2.36 mm	60
100 μm	9.5
Specific gravity	2.49

**Table 3:** Analysis of chemicals for bauxite aggregate

Oxides	Percent
Aluminum oxides (Al <sub>2</sub> O <sub>3</sub> )	91.8
Silicon dioxide (SiO <sub>2</sub> )	5.60
Potassium oxide (K <sub>2</sub> O)	0.27
Carbon oxide (CaO)	0.19
Titanium dioxide (TiO <sub>2</sub> )	0.96
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	0.98
L.O. I	0.14
Total	99.82

### 2.3 Alumina brick

Refractory bricks that contain at least 45% aluminum oxide are known as high-alumina bricks. Bricks with over (80%) aluminum oxides and corundum as their main constituent and bricks with between 70 and 80% aluminum oxides and mullite as their main constituent both show distinct advantages regarding load resistance, creep resistance, and hot strength. The need for high-alumina bricks is growing in most high-temperature applications, which is predicted to fuel global growth in the refractories sector. The iron and steel industries primarily use various types of refractories, but they are also used by the glass, lime, and nonferrous metals manufacturing sectors. Due to operating conditions, selecting higher quality and greater durability refractories becomes more important. Crushed alumina brick as aggregate with different grades ranging from 0.1 mm to 4.75 mm per the requirement of ACI report 547-2008 [9] is shown in Figure 2. High alumina brick was used as aggregate, and its sieve analysis and chemical analysis were displayed in Tables 4 and 5.



**Figure 2:** Crushed alumina bricks as aggregate

**Table 4:** Analyzing the sieve of alumina brick used as an aggregate

Size of sieve	Passing, %
4.75 mm	100
2.36 mm	60
100 µm	9.5
Specific gravity	2.49

**Table 5:** Analysis of the chemical makeup of bricks made of alumina

Oxides	Percent
Aluminum oxides (Al <sub>2</sub> O <sub>3</sub> )	84.07
Silicon dioxide (SiO <sub>2</sub> )	8.450
Potassium oxide (K <sub>2</sub> O)	0.389
Carbon oxide (CaO)	2.660
Titanium dioxide (TiO <sub>2</sub> )	0.099
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	3.46
L.O. I	0.15
Total	99.13

### 3. Experimental laboratory program

There is standard method to design the mixes of free cement refractory concrete so depending on ACI Report 547-2008 [9]. Where 1:3 is the percentage of cement to aggregate that was used in this research.

#### 3.1 Refractory concrete preparation

This study manually combined the ingredients for a homogeneous combination with good workability. The components were mixed in a drying stage for (3) minutes, starting with aggregate, adding high-alumina cement, and finishing with water that was 14% of the mixture's weight. Table 6 displays the proportions of ingredients and water in each composition.

According to ASTM C860 2019 [10], known as Ball-in-Hand and shown in Figure 3, the water/dry weight proportion for hand mixing should be kept to a minimum.

**Table 6:** The compositions of the mixture are expressed as a percentage of aggregate weight

Set No	Mix details Cement /aggregate (1:3)	Mix designation	Water %
1	Alumina cement 100%	Bauxite aggregate	14
2	Alumina cement 90%+10% Bauxite powder	Bauxite aggregate	14
3	Alumina cement 75%+25% Bauxite powder	Bauxite aggregate	14
4	Alumina cement 100%	Crushed alumina brick as aggregates	14
5	Alumina cement 90%+10% Bauxite powder	Crushed alumina brick as aggregates	14
6	Alumina cement 75%+25% Bauxite powder	Crushed alumina brick as aggregates	14



**Figure 3:** Ball-in-hand test

#### 3.2 Models of molding and compaction

After mixing, the mixture is poured into molds with the correct size, measuring 70.5 mm\*70.5 mm\*70.5 mm for cubic specimens and 40 mm\*40 mm\*160 mm or 285 mm\*75 mm\*75 mm for prism specimens. The interior mold interface must be

lightly oiled to prevent the mixture from adhering to the mold's surface. The mixture was compacted in two-layer molds using a tiny steel hammer to create specimens with a uniform frame and two shapes: cubic and prisms. This procedure is followed by ASTM C 862-2020 [11].

### 3.3 Drying and burning

After compacting the samples, they were left for 24-hour periods at room temperature. Next, as directed by ASTM C865-2022 [12], the molds were opened, and the samples were placed in an oven set to 110 °C for a full day to dry them out. Following drying, the specimens are fired at temperatures between (1000 and 1100) °C with a burn rate of 3.33 °C/min by ASTM C865-2022 [12]. The specimens are left at this temperature for two hours, known as the "soaking time," during which they can withstand high temperatures without sintering.

## 4. Experimental tests

The tests were conducted utilizing the American Standard for Materials and Testing, and the bulk density and compressive strength were determined per ASTM C20 and C133 [13], respectively. As per ASTM C133-2021 [14], the Modulus of Rupture was tested using center point loading, while the shrinkage was measured using BS1902: section 5.10-1986 and the weight change test [15].

## 5. Results and discussion

The change in properties of refractory concrete when alumina cement is substituted with powder bauxite aggregate at percentages of 0%, 10%, and 25% were studied. The details of the composition of the mixtures are indicated in Table 6. Bauxite aggregates or crushed alumina brick as aggregates were used in a 3:1 high volume ratio with alumina cement.

### 5.1 Bulk density

The results of bulk density for all refractory concrete mixtures are shown in Table 7 and Figure 4. Bulk density gives an early expectation of all the hardened properties of concrete, which gives an indication of whether the mix will satisfy the requirements of refractory concrete to be used to withstand prolonged high temperatures. Besides, it gives an early solution to overcome any unsatisfactory property. The bulk density for all mixes at temperatures (25, 1000, and 1100) °C ranged from 2.39 to 2.02 g/cm<sup>3</sup>. When 10% alumina cement is replaced with bauxite powder, the bulk density is lower than when 100% alumina cement is used for all aggregates. This is because the samples have minute amounts of voids and pores that retain water (mixing water and curing water) inside, which conform to refs. [16,17]. At the same time, replacing 25% of the alumina cement with bauxite powder shows a greater reduction in bulk density than replacing 10% of the alumina cement and 100% of the alumina cement for all aggregates. When firing at 1000 and 1100 °C temperatures, all refractory concrete mixes with varying percentages of replacement alumina cement and aggregate experienced an abrupt drop in bulk density, primarily due to dehydration. Results showed that the bulk density of refractory concrete made from crushed alumina bricks as aggregates was less than that of bauxite aggregate for all percentage replacements and at all temperature degrees. The reason for this decrease in bulk density was that recycled alumina bricks have a lower density in mixtures than bauxite aggregate because of their porous nature. Moreover, more water was needed to solve the friction between the alumina bricks' aggregate particles, resulting in larger voids and a lower density, which complies with refs. [18].

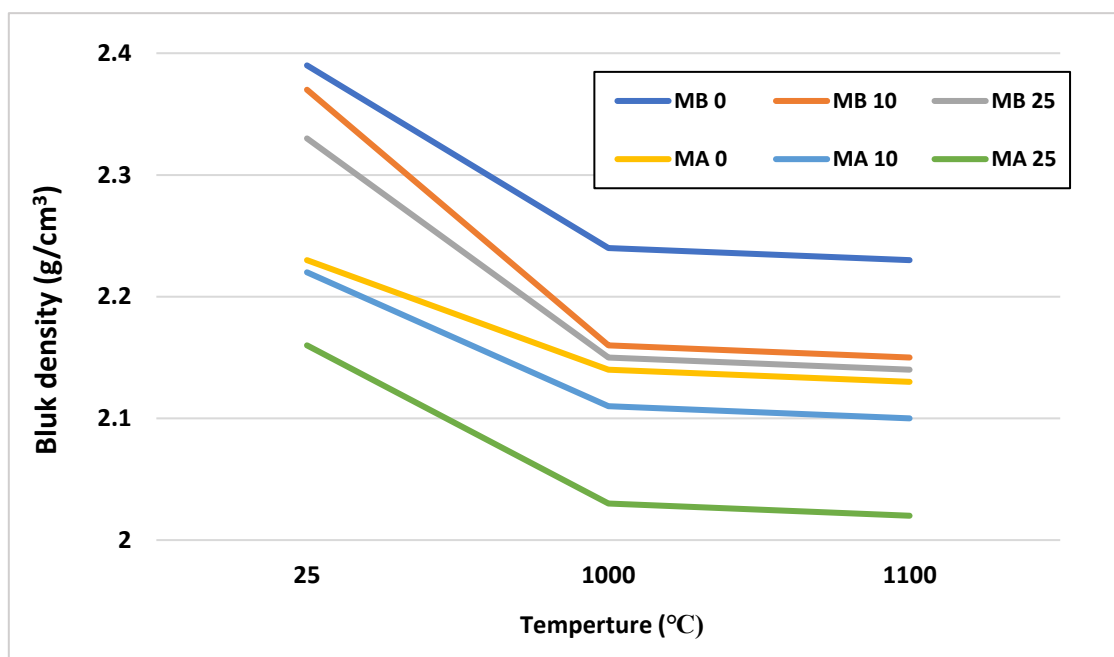


Figure 4: Refractory concrete's bulk density at various temperatures

**Table 7:** Bulk density test results for refractory concrete

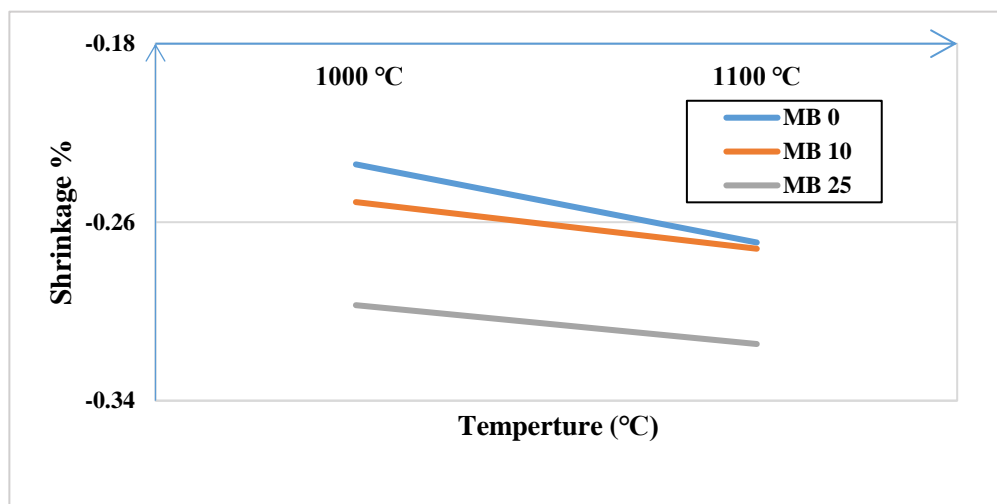
Set No	The bulk density g/cm <sup>3</sup>		
	25 °C	1000 °C	1100 °C
MB 0	2.39	2.24	2.23
MB 10	2.37	2.16	2.15
MB 25	2.33	2.15	2.14
MA 0	2.23	2.14	2.13
MA 10	2.22	2.11	2.10
MA 25	2.16	2.03	2.02

### 5.2 Shrinkage and expansion

Referring to Table 8 and Figures 5, 6, and 7, it was discovered that refractory concrete may contract during service. For all days and temperatures, the shrinkage for mixes MB 0, MB 10, and MB 25 increased with the replacement percentage, as shown in Figures 5 and 6. There was minimal shrinkage when dehydrated; however, shrinkage increases at high temperatures, contingent upon the composition and chemical structure during firing and the formation of a vitreous phase. This resulted from the specimens being exposed to air or high temperature, which caused the water in the cement paste's pores and the independence zone between the cement paste and aggregate to evaporate. This resulted in a decreased rate of hydration, which eventually faded due to a shortage of water to sustain the hydration process. Using this thereby makes the cement paste weaker and creates more space. While mixes (MA 0, MA 10, and MA 25) at 25 °C for all days, shrinkage would happen. However, the expansion would happen at 1000 and 1100 °C, as shown in Figure 7. The findings demonstrated that, for all percentage replacement and all days, shrinkage of refractory concrete produced with crushed alumina bricks as aggregates was lower than that of concrete made with bauxite aggregates, while at 1000 and 1100 °C expansion would happen opposite refractory concrete made from bauxite aggregates. The primary causes of the volume increase in refractory concrete are recrystallization processes and the oxidation of the unreacted aluminum metal.

**Table 8:** Refractory concrete shrinkage test results

Set No	Shrinkage %					
	At air temperature				At different temperature	
	1 day	3 days	7 days	14 days	1000 °C	1100 °C
MB 0	-0.0594	-0.0629	-0.1118	-0.1258	-0.2341	-0.2691
MB 10	-0.0627	-0.1115	-0.1638	-0.2579	-0.251	-0.2719
MB 25	-0.0839	-0.1579	-0.1713	-0.2622	-0.2972	-0.3146
MA 0	-0.0175	-0.0279	-0.0454	-0.1118	0.0279	0.0768
MA 10	-0.0454	-0.0594	-0.0769	-0.1153	0.0224	0.0503
MA 25	-0.0525	-0.0665	-0.084	-0.1645	0.0140	0.0335



**Figure 5:** Temperature-dependent shrinkage of refractory concrete

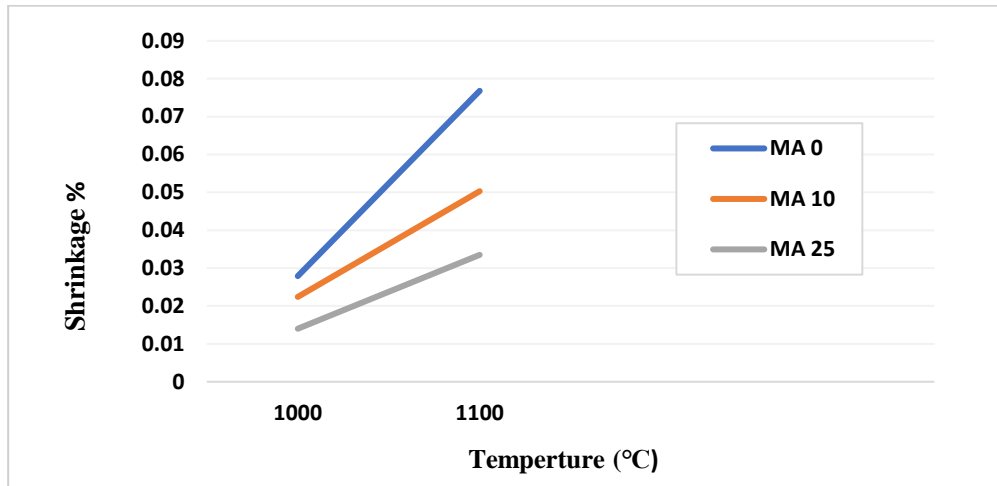


Figure 6: Temperature-dependent expansion of refractory concrete

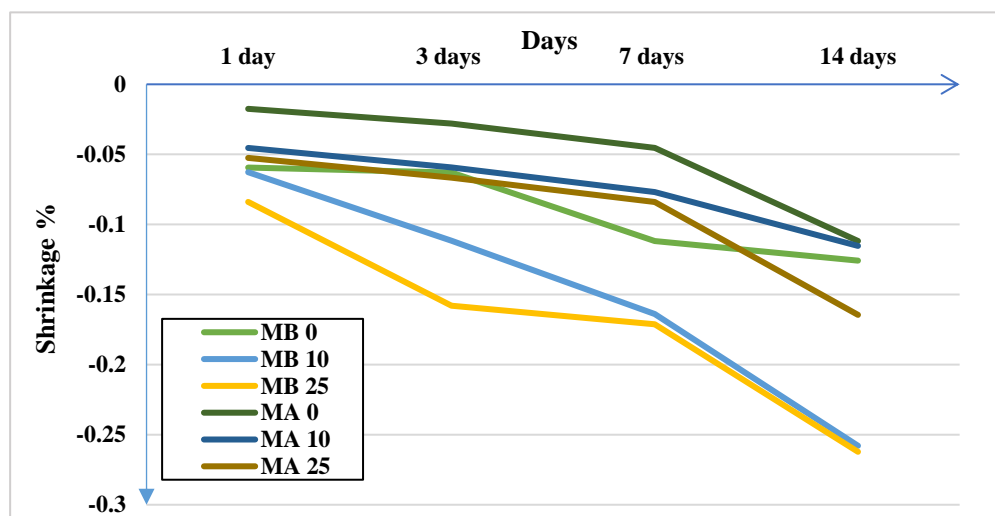


Figure 7: Shrinkage of refractory concrete on different days

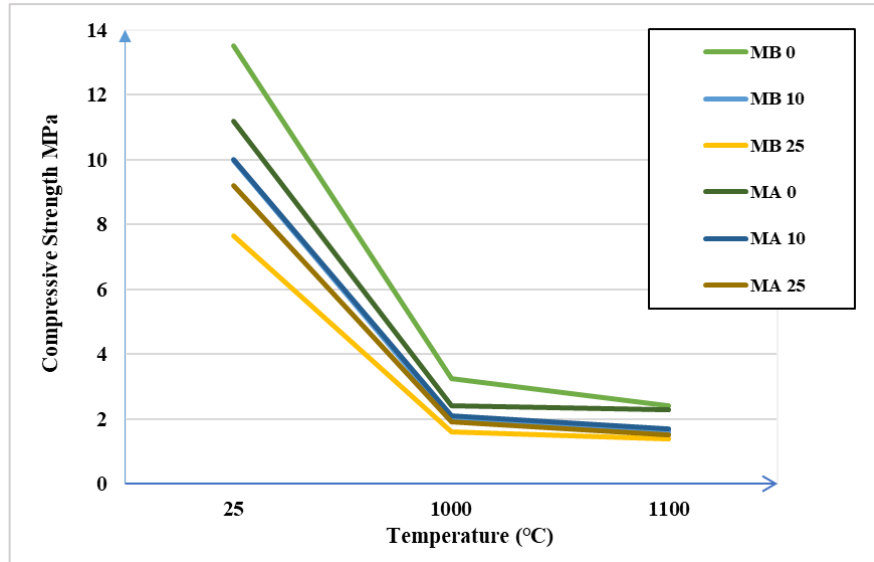
### 5.3 Compressive strength

The compressive strength results of specimens are presented in Table 9, and Figures 8 and 9 showed the method test of compressive strength for samples. For all types of aggregate and temperatures (25, 1000, and 1100) °C, the compressive strength of refractory concrete made with 10% replacement of alumina cement by bauxite powder was lower than that of refractory concrete made with 100% alumina cement. The 25% replacement bauxite powder mixture showed lower strength than the other bauxite powder percentages. Because bauxite powder did not react like alumina cement with all types of aggregate, more voids formed in the refractory concrete, decreasing compressive strength at all temperatures, which conforms to refs. [19, 20]. All the refractory concrete mixes, including control, achieved their target strength of more than 6.9 MPa according to ACI Report 547–2008 specifications. The relationship between compressive strength and the percentage of bauxite powder at various temperatures (25, 1000, and 1100) is shown in Figure 8. The compressive strength at 25 °C for MB 10, MB25, MA 10, and MA 25 decreased by 26.14%, 43.4%, 10.6% and 17.9%, while at 1000 °C decreased by 38.3%, 50.6%, 12.4% and 20%, but at 1100 °C there was a more reduction about 20.75%, 33.2%, 41.9%, 25% and 33.8% for MB 10, MB25, MA 10 and MA 25, respectively, when compared to control specimen MB 0% and MA 0%. MB25% and MA25% decreased in strength compared to other mixes and at all temperatures. For all mixes, a decrease in compressive strength was observed with an increase in temperature. The compressive strength of refractory concrete produced with crushed alumina bricks as aggregates was lower than that of concrete made with bauxite aggregates for all percentage replacements and temperature ranges.

The reduction in strength may be attributed to six reasons: (1) The crushed bricks failed to develop a proper/adequate bond with refractory concrete and alumina cement matrix; (2) Because of the high porosity of the surfaces of the crushed bricks, the mixture needs more water to get the required slump; (3) The crushed bricks made the mixture unworkable because the roughness of the surfaces of crushed brick aggregates affected the compaction distribution upon the refractory concrete layers; (4) Recycled brick aggregates have a lower rigidity than natural aggregate; (5) Due to the structural qualities of bauxite and improved compaction; (6) When crushed bricks are used as aggregate, the porosity of the refractory concrete increases, resulting in a decrease in compressive strength. When comparing the results obtained by replacing bauxite aggregate with recycled alumina bricks as aggregate or recycled magnesia bricks as aggregate, it was found that the strength of concrete was lower when using recycled magnesia bricks as aggregate, which matches references [21-23].

**Table 9:** Compressive strength test result for refractory concrete

Set No	Compressive strength MPa		
	25 °C	1000 °C	1100 °C
MB 0	13.5	3.26	2.41
MB 10	9.97	2.01	1.61
MB 25	7.64	1.61	1.4
MA 0	11.20	2.41	2.28
MA 10	10.01	2.11	1.71
MA 25	9.20	1.91	1.51



**Figure 8:** Compressive strength of refractory concrete at different temperatures



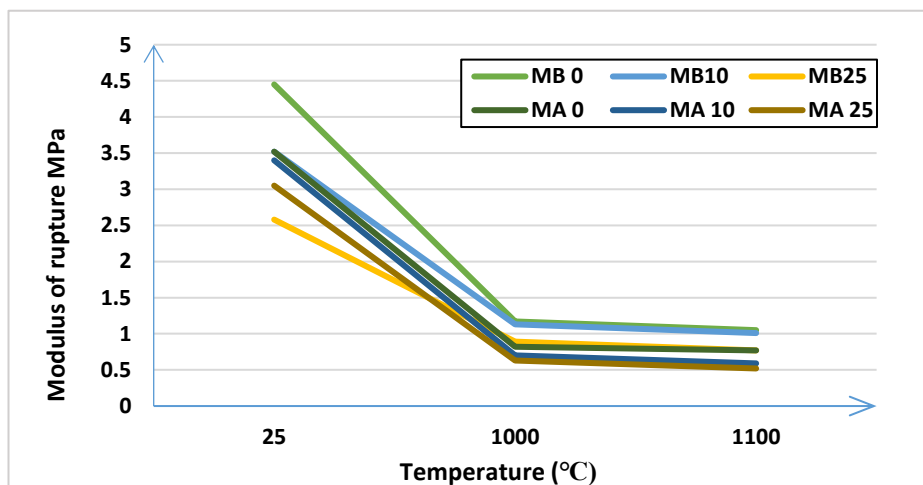
**Figure 9:** Compressive strength testing mechanism

### 5.4 Modulus of rupture

Refractories' modulus of rupture measurements can provide information about how well these materials are bonded together, and their quality is typically approximated using this attribute. Rich information regarding the fracture process can be found on fracture surfaces. The fracture surface's fractal dimension is closely associated with the mechanical characteristics of several materials, including metals, ceramics, and polymers. Since refractories are frequently subjected to high temperatures, users view the hot modulus of rupture as the most crucial test criterion for choosing these items because it truly indicates the products' performance. From the results presented in Table 10 and Figure 10, the modulus of rupture exhibited the highest strength at the MB 0% mixture. In contrast, Modulus of Rupture for MB10, MB25, MA10, and MA25 was reduced by 26.4%, 42.02%, 3.4%, and 13.35%, respectively, compared to the control mixture (MB 0%) at 25 °C. There was also a reduction in the modulus of rupture with increased temperature (1000 and 1100) °C, but in different percentages and for all mixes. This indicates that Modulus of rupture would reduce with an increase in the replacement rate of alumina cement by bauxite powder for all types of aggregate and at different temperatures. The decrease in the modulus of rupture at temperatures higher than 25 °C was ascribed to the bonding becoming weaker due to microcracks arising from the expansive phase formation, in accordance with refs. [24]. Figure 11 shows Samples' modulus of rupture test. The experimental results in Table 10 indicate that the Modulus of rupture test for refractory concrete containing crushed alumina bricks as aggregates was lower than that of concrete containing bauxite aggregates across all replacement percentages and at different temperatures due to the refractory bricks as aggregate produced by crushers have a lot of mortar on the surface, and micro-cracks on the inside of the recycled refractory bricks as aggregate may have significantly changed physical properties, such as absorption and porosity, by either the micro-cracks or the old cement mortar. It was identified that mechanical properties, such as modulus of rupture, were greatly deteriorated by the shape and number of micro-cracks.

**Table 10:** Test results of the rupture modulus for refractory concrete

Set No	Rupture Modulus (MPa)		
	25 °C	1000 °C	1100 °C
MB 0	4.45	1.17	1.05
MB 10	3.52	1.13	1.01
MB 25	2.58	0.89	0.77
MA 0	3.52	0.82	0.77
MA 10	3.4	0.7	0.59
MA 25	3.05	0.63	0.52



**Figure 10:** Rupture modulus for refractory concrete at various temperatures



**Figure 11:** Modulus of rupture testing mechanism

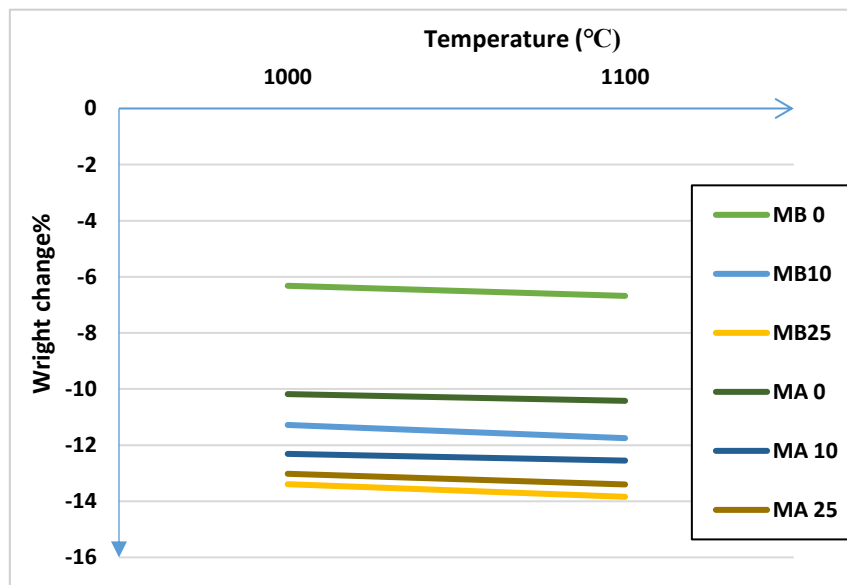
### 5.5 Weight loss after exposure to high temperatures

The investigation of weight change for each mix of refractory concrete specimens involved measuring the specimens' weights both before and after they were exposed to high temperatures. The furnace used in this study to determine the properties of the specimens exposed to high temperatures reached 1100 °C in 180 min at a rate of 3.33 °C/min. The weight losses (in percent) of the refractory concrete mixes with increasing temperatures are shown in Table 11 and Figure 12. The refractory concretes containing bauxite powder in a percentage of 25% and alumina bricks as aggregate (MA 25) showed higher weight losses when compared to the control refractory concrete (MB 0). After 1000 °C, the weight loss for refractory concrete that contains alumina cement replacement by different percentages of bauxite powder (RFCABP) increases with an increasing rate, whereas the weight loss for refractory concrete that content only alumina cement (RFCA) increases with a low rate.

These results show that the performance of (RFCA) is better than (RFCABP) when weight loss is considered. Remarkably, at any given temperature, the weight loss increased as the percentage of alumina cement replaced by bauxite powder increased for all types of aggregate due to the increased pores in (RFCABP), which led to excess free water would, where after the burning process leaves empty spaces devoid of free water were left in the refractory concrete due to evaporation of water, which led to increasing the weight loss. According to the experimental findings, at all replacement percentages (0,10 and 25)% and temperature 1000 and 1100 °C, the weight change of refractory concrete made from crushed alumina bricks as aggregates was lower than that of concrete with bauxite aggregates.

**Table 11:** Weight change test results for refractory concrete

Set No	Weight change %	
	1000 °C	1100 °C
MB 0	-6.32	-6.68
MB 10	-11.28	-11.75
MB 25	-13.39	-13.84
MA 0	-10.18	-10.42
MA 10	-12.31	-12.55
MA 25	-13.02	-13.40



**Figure 12:** Change in weight of refractory concrete at varying temperatures

### 6. Conclusion

From the present investigation on the effect of partial replacement of high-alumina cement with bauxite powder in concrete, the following conclusions were drawn:

- 1) The compressive strength of refractory concrete mixes made from 100% alumina cement outperforms mixes made from replacement alumina cement with bauxite powder in percentage (10 and 25)%.
- 2) A 25% replacement of high alumina cement with bauxite powder results in a greater reduction than in any other mix.
- 3) At 1000 and 1100 °C, the compressive strength, rupture modulus, bulk density, and weight change would all decrease.
- 4) The compressive strength, rupture modulus, bulk density, and weight of refractory concrete made from crushed alumina bricks as aggregates were less than those made from bauxite aggregates for all percentage replacements and at all temperatures. The compressive strength, rupture modulus, bulk density, and weight of refractory concrete made from crushed alumina bricks as aggregates were less than those made from bauxite aggregates for all percentage replacements and at all temperatures.

- 5) At 1000 and 1100 °C, the expansion would happen in refractory concrete made from crushed alumina bricks, as aggregates were opposite to those made from bauxite aggregates.
- 6) The findings support the use of bauxite powder in refractory concrete.

### Author contributions

Conceptualization, W. Abd , M. Salman and S.Sadeq, data curation,W. Abd; formal analysis, W. Abd and M. Salman; investigation,Abd and M. Salman; methodology, W. Abd; project administration, M. Salman and S.Sadeq, resources, W. Abd; software, W. Abd and M. Salman; supervision, M. Salman and S.Sadeq; validation, W. Abd , M. Salman and S.Sadeq; visualization, W. Abd , M. Salman and S.Sadeq; writing—original draft preparation, W. Abd ; writing—review and editing, W. Abd and M. Salman.; writing. All authors have read and agreed to the published version of the manuscript.

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### Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

### Conflicts of interest

The authors declare that there is no conflict of interest.

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