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WASTE-WISE CONSTRUCTION: AN EXPLORATION OF CRUSHED CLINKER BRICK AS A SUSTAINABLE COARSE AGGREGATE IN CONCRETE MIXES

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Abstract
The particle size distribution of aggregates plays a crucial role in determining the properties of concrete. Traditionally, sieves have been used to measure aggregate gradation, wherein the percentage of material passing through each sieve is calculated. A well-optimized gradation ensures maximum concrete density, resulting in enhanced compressive strength—the fundamental mechanical property for evaluating concrete quality. Although other concrete parameters like tensile and flexural strength rely on compressive strength, the proportion of aggregates used in concrete (70-80%) underlines their significant influence. Notably, the particle size distribution of aggregates has been found to substantially impact concrete compressive strength, with larger coarse aggregates contributing to increased strength. Due to environmental concerns and the need for sustainable practices, the exploration of alternative materials for coarse aggregates in concrete production has gained traction. Conventional sources like river gravel are ecologically taxing, leading to river subsidence and environmental degradation. In this regard, research has shown the viability of clinker brick waste as a substitute for natural coarse aggregate, yielding concrete with comparable compressive strength to that of conventional crushed stone aggregate. However, there remains a lack of investigation into adjusting the coarse aggregate gradation of clinker brick waste. This study aims to determine the effects of adjusting the aggregate grading of crushed clinker brick waste, utilized as a replacement for coarse aggregate, on various concrete properties. The research assesses slump, density, and compressive strength for concrete mixes targeting strengths of 20 MPa, 25 MPa, 30 MPa, and 35 MPa. Furthermore, the study seeks to explore gradation adjustments that could potentially lead to achieving compressive strengths of up to 40 MPa. The adjustments adhere to the aggregate grading limitations outlined in SNI 7656-2012, classifying them as upper, middle, and lower limits. The investigation encompasses an array of alternative coarse aggregate materials, including paper scraps, plastic scraps, post-consumer glass, expanded polystyrene, crushed rubber, coconut shells, and building debris. This exploration is crucial as it addresses the pressing demand for concrete while promoting sustainable resource management. The benefits of employing alternative materials are manifold, encompassing the reduction of natural coarse aggregate demand, lowered environmental impact in production, potential weight reduction in concrete, and fostering recycling and waste management options.

Keywords: Particle size distribution, aggregates, sieves, gradation, compressive strength, concrete

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1. Introduction

The particle size distribution of aggregates is typically measured using sieves, which are screens with openings of different sizes. Aggregates are placed on the sieves, and the sieves are shaken to allow the smaller particles to pass through and collect in a container below. The gradation is then determined by calculating the percentage of material that passes through each sieve [1]. The appropriate gradation of aggregates can fill the micro pores in the concrete, resulting in maximum concrete density. As a result, the concrete's compressive strength is enhanced. The compressive strength is one of the most important mechanical properties of concrete and is the basis for evaluating the quality of concrete [2][3]. In general, other concrete parameters like tensile strength and flexural strength are estimated using the compressive strength. The proportion of aggregates used in concrete ranges from 70-80%, so the influence of aggregates will be very considerable [4]. The concrete compressive strength is significantly affected by the particle size distribution of the aggregates. It has been reported that concrete compressive strength increases with increasing coarse aggregate particle size [5].

In the production of normal concrete, the aggregate commonly used for construction consists of coarse aggregate and fine aggregate in the form of sand and river gravel or crushed stones. In addition to being economical, river aggregates have a suitability and regular gradation as a result of the degradation or selection by the river itself. However, in contrast to these advantages, the continuous and long-term extraction of river gravels can lead to river subsidence, which has an impact on the destruction of the watershed. In this instance, according to a study by Alkhaly et al. (2015), clinker brick waste can be utilized as a substitute source of natural coarse aggregate for making concrete [6]. In that study, clinker brick aggregate was 100% substituted, and the resulting concrete had a compressive strength equal to that of normal concrete made with crushed stone aggregate. The investigation did not modify the coarse aggregate gradation of the clinker brick.

In addition to clinker bricks, a variety of additional materials, including paper scraps, plastic scraps, post-consumer glass, expanded polystyrene, crushed rubber, coconut shells, and building debris, can be used as substitutes for natural coarse aggregate [7][8][9].

Considering the rising demand for concrete today, which requires an environmentally friendly handling of natural resources, it is critical to substitute alternative materials for coarse aggregates in the production of concrete [10]. There are various advantages of employing alternate coarse aggregate materials in concrete production [11] [12][13][14]:

1. The use of alternative materials can help reduce the demand for natural coarse aggregate, which is a limited resource.
2. The use of alternative materials can help reduce the environmental impact of concrete production, as the production of natural coarse aggregate requires a significant amount of energy and resources.
3. The use of alternative materials can help to lower the weight of concrete, which can be advantageous in some applications.
4. The use of alternative materials use can help provide new options for recycling and waste management, as many alternative materials are derived from waste products.

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Based on the explanation above, the purpose of this study was to determine the effect of adjusting the aggregate grading of crushed clinker brick waste used as a replacement for coarse aggregate in concrete mixes on the slump, density, and compressive strength of concrete produced at target strengths of 20 MPa, 25 MPa, 30 MPa, and 35 MPa. Gradation adjustments are expected to allow for the achievement of compressive strengths of up to 40 MPa. The coarse aggregate grading has been adjusted in accordance with aggregate grading limitations based on SNI 7656-2012, which are classified as upper, middle, and lower limits.

2. Literature Review

2.1. Aggregate characteristics effect on concrete

The properties of aggregates have a significant effect on the properties of concrete. In fresh concrete mix, the workability is more influenced by the shape and texture of the aggregate than in hardened concrete. Smooth and rounded aggregates will make the concrete easier to cast. The size, shape, moisture content, specific gravity, and density of coarse aggregates affect the strength and durability of concrete. Aggregate with round, smooth particles require less paste for a given slump than mixtures with flat, elongated, angular and coarse particles [16]. The use of alternative materials for coarse aggregates, gives a compressive strength of artificial aggregate concrete that is 15-20% lower than that of conventional natural aggregate concrete, but meets the quality requirements of concrete grade.

2.2. Clinker brick waste

The process of producing clay bricks is generally carried out traditionally, hence there is a wide range in the quality of the bricks.. The essential components of clay bricks, which are clay, sand, and water, The production process begins with the extraction of clay, which is then mixed with water and moulded using wooden moulds. The moulded dough is then dried in the sun for several days. After drying, the bricks are taken to the brick kiln, which is burned manually with firewood without temperature control [18]. The overburning results in a byproduct that called clinker brick (**Fig.** 1), which during combustion distorts its structure and colour to reddish-black, making it unusable for building purposes. As a result of the high temperature, clinker bricks will not deteriorate further, even if they are soaked in water for an extended period. Clinker bricks offer rigid, hard, and sharp physical characteristics. The geological setting from which the material is sourced affects the characteristics of clinker bricks [6].

Fig 1. Waste clumpy clinker bricks that are reddish-black in color.

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According to the research of Alkhaly et al. (2015) [6], the concrete mix that used 100% clinker aggregate as a replacement was able to achieve its target compressive strength of 20 MPa and qualifies for the category of structural concrete. The densities of concrete were reduced by 8.8% compared to crushed stone, resulting in an improved strength-to-density ratio. However, clinker aggregate concrete is unable to be categorized as lightweight concrete, as its density is above 2000 kg/m^3.

2.3. The standard gradation curve of coarse aggregate

The acceptable gradation range for coarse aggregates is described in a variety of standards and specifications, and the gradation curve can be used as a quality control to confirm that the aggregate meets specified requirements. A coarse gradation curve is a graphical representation of the grading distribution of aggregates. It shows the proportion of different particle sizes present in a sample of coarse aggregate. The gradation curve is obtained by plotting the percentage of aggregate passing each sieve size against the sieve size. Aggregate gradation is determined by conducting a sieve analysis [15]. Aggregate gradation affects the number of voids in the mix and determines mix workability and stability. The grading of coarse aggregate also affects the amount of cement and water requirements,, pumpability, and durability of concrete [19]. the following are the five types of size distribution curves [16]:

1. Dense-graded: This type of curve has a wide range of particle sizes, having a large number of small fragments which connect gaps created by the larger particles. The mixture that results is thick and offers good stability and strength..
2. Gap-graded: This curve has a range of particle sizes, but with an obvious variation in the distribution of the smaller and larger particles.

A finer component or binder can be placed to the gap to fill it, producing a dense and stable mixture.

3. Uniformly graded: This curve has a narrow range of particle sizes, with a roughly uniform size distribution among all particles. Due to the homogeneity of the particles, This mix is workable and produces a good surface texture, but may lack stability.
4. Open-graded: This curve has a wide range of particle sizes, but with a high proportion of larger particles and a lower proportion of smaller particles. This results in a porous mix that allows water to drain quickly. This makes it suitable for use in areas with heavy rainfall.
5. Poorly graded: This curve has a range of particle sizes, but with an inappropriate distribution, which results in voids being created between the particles. This mix is unstable and may require additional binders or fines to provide stability and strength.

SNI 7656-2012 is a standard for concrete mix design in Indonesia; it specifies the gradation requirements for coarse aggregates and the table below shows the gradation specifications for a nominal maximum size of 19 mm.

Table 1. Graduation requirements for coarse aggregate based on SNI 7656-2012

Percentage of aggregate
Seive sizes
passing
(mm)

(% cummulative)

25	100
19	90-100
9,5	20-55
4,75	0-10
2,38	0-5

Based on **Table 1**, the gradation limits can be represented on a graph, as shown in **Fig. 2**.

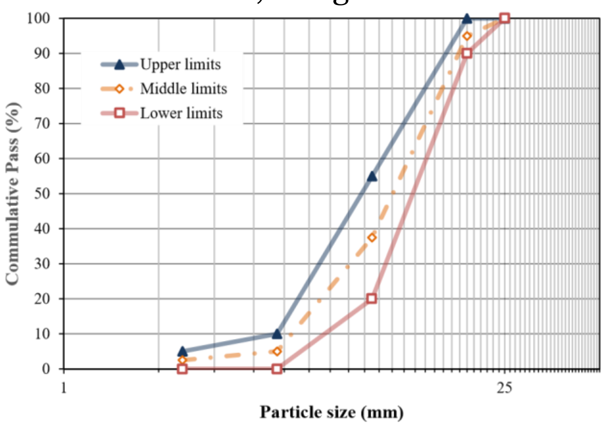

Fig 2. The SNI 7656-2012 standard aggregate gradation limits for the nominal maximum size of 19 mm

3. Methods

3.1. Material

The type I cement produced by PT Semen Andalas Indonesia was used to carry out this study. The sand from Krueng Mane, North Aceh Regency, is used as fine aggregate. Clinker bricks waste from Ulee Pulo village, North Aceh district, was processed into coarse aggregate with a sieve size of 25 mm passing and 2.36 mm retained. The upper, middle, and lower limits of the aggregate gradation curve on **Fig. 2** are used to determine the size of the crushed clinker bricks. Water from the Malikussaleh University Civil Engineering Department's laboratory building is used to produce the concrete mix.

Table 2. Result of sieve analysis of clinker aggregate and river sand

Seive sizes (mm)	Percentage of aggregate passing (% cummulative): Clinker aggregates			River sand
	Upper limits	Middle limits	Lower limits	
25	100	100	100	100
19	98.67	94.99	92.55	100
9.5	54.5	38.51	30.45	100
4.75	9.83	5.01	2.62	100
2.36	4.97	2.51	0.0	85.28
1.18	0	0	0	68.63
0.60	0	0	0	52.42

0.30	0	0	0	22.90
0.15	0	0	0	2.33

3.2. Preparation of clinker aggregate

The preparation of the clinker aggregate starts with the process of collecting a number of waste clinker bricks and then crushing them by hand to obtain a clinker aggregate with a size ranging from 2.36 mm to 19 mm (**Fig. 3**). Sieve analysis tests were used to obtain clinker aggregates for the upper, middle and lower limit gradations [20]. The clinker aggregates were grouped according to the size of each sieve, as shown in **Table 2**. The aggregates are then remixed with different sizes of clinker, from the smallest to the largest, to produce clinker aggregates that meet the specified particle size limits. Furthermore, the physical properties of all materials used are presented in **Table 3**.

Table 3. Physical properties of materials

Description		Clinker aggregates			River sand
		Upper limits	Middle limits	Lower limits	
Nominal maximum size (mm)		19.00	19.00	19.00	4.75
Specific gravity	Saturated surface dry (SSD)	1.99	2.00	2.00	2.62
	Oven dry (OD)	1.96	1.97	1.98	2.56
Absorption (%)		1.82	1.41	1.17	2.38
Moisture content (%)		0.06	0.08	0.08	1.73

Fig 3. Crused clinker aggregate with a size of 2.36 mm to 19 mm

3.3. Composition of concrete mix

The mix proportion design refers to SNI 7656-2012 [15], with the material proportion calculated using an absolute volume method. The targets for compressive strengths are 20 MPa, 25 MPa, 30 MPa, 35 MPa, and a slump of 75–100 mm. A total of 60 cylinders with a 150 mm diameter and 300 mm height were assembled as test specimens. The following table shows the material proportions for each type of concrete:

Table 4. Mix Design composition based on SNI 7656-2012

Target Strength (MPa)	Concrete type	Weight of materials per 1 m^3 (kg)			
		Cement	Sand	Clinker	Water
20	20U	332	804	756	212
	20M	332	800	763	208
	20L	332	798	765	206
25	25U	391	754	756	211
	25M	391	737	763	193
	25L	391	747	765	206
30	30U	442	710	756	211
	30M	442	706	763	208
	30L	442	703	765	206
35	35U	489	648	742	206
	35M	489	644	748	204
	35L	489	642	750	202

U = Upper limits; M = Middle limits; L = Low limits

3.4 Preparation and curing of specimens

The materials weighed as specified in **Table 4** are then mixed using a small laboratory drum mixer to produce a fresh and homogeneous concrete mixture. After the slump test, the concrete mix was placed in three layers in a steel cylinder mold of 150 x 300 mm, and each layer was compacted 25 times using a tamping rod. A total of five cylinder test specimens were cast for each concrete type. The surface of the specimen was covered with cement paste to smooth it out about 4 hours later. Each specimen was taken out of the mold after 24 hours, and treatment continued by immersing it in water at room temperature for up to 28 days.

3.5 Testing programs

The relative consistency of the concrete mix was assessed using the slump test method according to SNI 1972:2008 in order to determine workability [22]. The mold placed on a flat, moist, nonabsorbent surface and held in place during filling. The concrete filled in three layers with 25 strokes of the tamping rod in each layer. The top layer heaped and additional concrete added if there is subsidence during rodding. After rodding the top layer, the surface struck off and the mold removed carefully in a vertical direction. The slump measured immediately by determining the vertical difference between the top of the mold and the displaced original center of the top surface of the specimen (**Fig 4**a).

(a) (b)

Fig 4. Testing programs on fresh and hardened concrete: (a) slump test to determine the workability of fresh concrete; (b) compressive strength test setup

The wet density of concrete refers to the density of the freshly mixed concrete mix before it has set and hardened. It is also commonly known as the unit weight of concrete. Concrete wet density (D) is determined immediately after slump testing using the following formula:

$$D = M/V \ (\text{kg/m}^3) \quad (1)$$

Where M and V are the mass and volume of the cylindrical sample, respectively.

The compressive strength of the specimens was measured at 28 days of age using a compressive strength test in accordance with SNI 19742011 [23]. A hydraulic compression testing machine with a maximum loading capacity of 1500 kN (Fig. 4b) was used to apply a compressive axial load to molded cylinders at a rate that maintained the range specified until failure. The compressive strength (fc') of the specimen was determined by dividing the maximum force achieved during the test by the cross-sectional area of the specimen as follows:

$$f_c' = P/A \ (\text{MPa}) \quad (2)$$

Where P is maximum load and A is cross-sectional area of the cylindrical sample.

4. Result and Discussion

4.1. Slump and density of concrete

The height of the slump is an expression of the viscosity, or fluidity, of the fresh concrete mix. There are several factors that can influence the slump of concrete mixtures, including:

1. Water content and the water-to-cement ratio affect the slump of concrete. Excessive water causes an excessive slump, while insufficient water makes the mixture stiff. A higher water-to-cement ratio increases the slump, but too much water weakens the concrete, and too little makes it unworkable [24].
2. Aggregate size, shape, texture, and grading impact the slump and workability of concrete. Smooth, rounded aggregates require less paste and increase the slump, while coarse aggregates reduce it. Better grading results in fewer voids, making it essential to use wellgraded aggregates to achieve the desired slump and workability [25].

3. Cement content affects the slump; more cement increases it, less decreases it. Maintaining the correct water-cement ratio is vital for the desired slump and strength [4].
4. Temperature is crucial and affects the slump of concrete. Higher temperatures cause faster slump loss, while lower temperatures slow down setting time and reduce slump. The increase in concrete temperature decreases slump, requiring additional water. The hydration reaction speeds up during hot weather, making it challenging to handle, place, and finish the concrete. Considering temperature during mixing, transportation, and placement is essential for desired workability [4].
5. Mixing time is critical to maintaining the slump of concrete mixtures. Overmixing can cause slump loss, while undermixing can cause inconsistency. Longer mixing times can lead to evaporation and coarse aggregate wear, resulting in slump loss. The appropriate mixing time is necessary to ensure consistency without evaporation or material development [24].
6. Chemical admixtures modify concrete properties; e.g., plasticizers increase slump while retarders decrease it. Admixtures improve workability, durability, and strength. Incorporating fine materials reduces cement content and cost, while smoothing and rounding aggregates make the concrete more workable. Therefore, considering the use of admixtures, cement content, and aggregate shape and texture is crucial to achieving the desired properties [26].

The slump of the concrete mixture can be impacted by its density. In general, higher-density mixes (i.e., those containing more aggregate and less water) will result in a lower slump. This is because the aggregate particles take up more space in the mix. This leaves less space for the cement paste to flow and maintain slump. Conversely, lower-density mixes (i.e., mixes with less aggregate and more water) will typically have a higher slump as there is more space for paste flow and slump maintenance. However, it's important to note that the relationship between density and slump is not linear, and there are many other factors that can affect slump, including the type of aggregate used, the water/cement ratio, and mix design [24].

From **Table 4**, It can be observed that as the target strength targets increases from 20 MPa to 35 MPa, the amount of cement required increases while the amount of sand and water required decreases. Depending on the desired concrete quality, the amount of clinker required ranges from 742 to 765 kg per cubic metre. The slump height and density as a result of these mix design parameters is shown in **Table 5**.

Table 4. Results of slumps and concrete densities

Target Strength (MPa)	Concrete type	Slump (mm)	Density (kg/m^3)
20	20U	85	2103.01
	20M	90	2102.09
	20L	90	2099.38
25	25U	90	2111.74
	25M	95	2083.28

	25L	95	2108.79
30	30U	85	2118.26
	30M	90	2118.57
	30L	95	2106.50
35	35U	85	2083.80
	35M	90	2083.60
	35L	90	2080.70

The slump height varies between 85 mm and 95 mm, indicating differences in the workability of the concrete mixes. The obtained slump height for each type of clinker concrete has complied with the designed slump specifications, which range from 75 to 100 mm. The reduction in slump height was not considerably impacted by the gradation of the coarse aggregate from clinker bricks. Furthermore, the density varies between 2080.70 kg/m3 and 2118.57 kg/m3, demonstrating that the concrete mixtures' mass per unit volume also varies. The density of the concrete is influenced by the amount of clinker aggregate in the mix. The density of the concrete decreases as the amount of clinker used increases. This is consistent with the claim that using alternate materials contributes to lighter concrete, which may be helpful in some applications [11][12][13][14].

4.2. Achievement of concrete compressive strength at grades 20 MPa and 25 MPa

Normal concrete is a type of concrete that is commonly used in construction. It has a compressive strength of 15 MPa to 40 MPa and density ranges from 2200 kg/m3 to 2500 kg/m3 [15]. The lowest possible compressive strength that can be used for structural concrete is 17 MPa [27]. The selection of concrete grade (target strength) is done according to the construction criteria, such as the required load carrying capacity, and environmental conditions. The selection of concrete grade also depends on material availability, cost, and construction schedule. Therefore, it is very important to select the right grade of concrete for each application to ensure the safety, durability, and efficiency of the structure. For instance, Grade 20 MPa concrete is used for domestic purposes such as slabs, beams, columns and foundations, if the structure weight is not heavy. Grade 25 MPa concrete is used for reinforced concrete structures, bridges, heavy-duty industrial floors, and in middle-rise buildings.

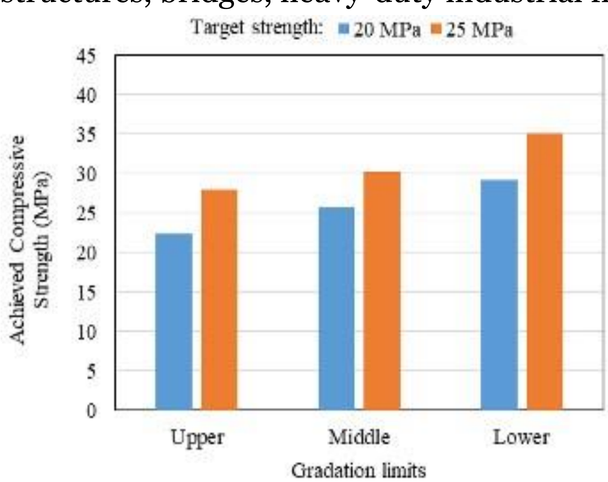

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Fig. 5 Achievement of concrete compressive strength at grades 20 MPa and 25 MPa.

Fig. 5 shows the achievement of concrete compressive strength at grades 20 MPa and 25 MPa. For all varieties of concrete, the achieved strength was more than the target strength. The strength values that were achieved ranged from 22.41 MPa to 35.08 MPa. The achieved strength then rises when the aggregate gradation changes from the upper limit to the lower limit for each target strength. Evenmore, the concrete strength achieved at the lower limit gradation improved by 45.45% and 40.32%. for the target concrete strengths of 20 MPa and 25 MPa, respectively. This demonstrates that, even within the same concrete grade, the aggregate gradation used to produce concrete has an impact on the concrete's strength.

4.2. Achievement of concrete compressive strength at grades 30 MPa and 35 MPa

Grade 30 MPa concrete and above are used for higher grades of concrete, such as bridges, high-rise buildings, and other structures that require high strength. The achievement of concrete compressive strength at grades 30 MPa and 35 MPa is presented in **Fig. 6.**

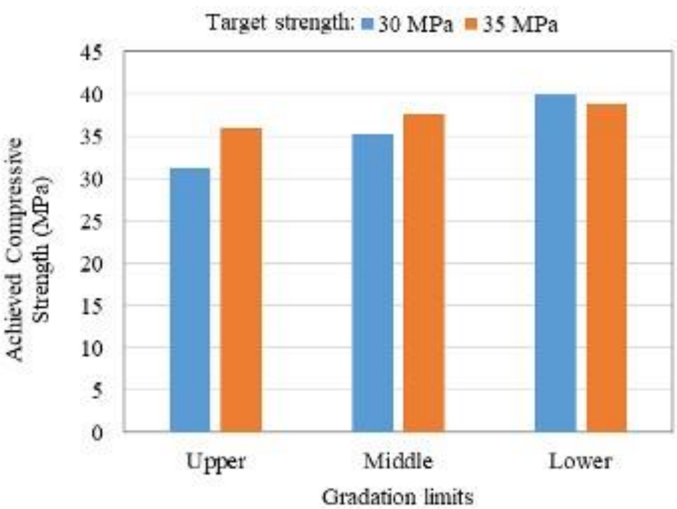

Fig. 5 Achievement of concrete compressive strength at grades 30 MPa and 35 MPa.

The target strength for concrete grades of 30 MPa and 35 MPa was obtained over the required strength. The compressive strength achieved ranged from 33.21 MPa to 39.95 MPa. As in concrete grades 20 MPa and 25 MPa, the obtained strength then rises when the aggregate gradation changes from the upper limit to the lower limit for each target strength. Meanwhile, the concrete strength achieved at the lower limit gradation improved by 33.17% and 10.91% for the target concrete strengths of 30 MPa and 35 MPa, respectively. These percentage results are lower than the 20 MPa and 25 MPa grades. Although at a concrete grade of 30 MPa, the compressive strength was 39.95 MPa, or obtained a grade of 40 MPa.

5. Conclusions

This study discusses the use of crushed clinker brick waste as coarse aggregate for making normal concrete. The main findings that can be drawn from the investigation are as follows:

1. The measured slump height for each type of coarse aggregate gradation limits satisfies the slump height specifications. The gradation of the coarse aggregate from clinker bricks had no significant impact on the reduction in slump height;

2. Variations in the quantity of clinker aggregate used in the concrete mix have an impact on the density of concrete. Clinker aggregate concrete has a density of under 2200 kg/m^3, which is lower than that of regular concrete made with natural aggregate;
3. Concrete's compressive strength is increased significantly by adjusting the gradation of coarse aggregate using unused clinker bricks. The largest increase in the compressive strength of clinker concrete occurs at the lower limit of coarse aggregate gradation, with a compressive strength of up to 40 MPa.

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