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Tesis

Mechanical analysis of concrete using over-burnt bricks as coarse aggregate

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Mechanical Analysis of Concrete Using Over-burnt Bricks as Coarse Aggregate

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Abstract The purpose of the project is to experimentally evaluate the properties of concrete in a hardened state when the coarse aggregate is replaced in dosages by over-burnt crushed bricks obtained from the artisanal brick kilns in the city of Huancayo. This material was chosen due to the abundance of artisanal brick kilns in the area, which generates waste in its preparation polluting the environment, so this material was used in order to give it an added value and improve the properties of concrete. To fulfill the objective of the research, the mechanical properties of the concrete were determined in the laboratory, compressive strength tests, tensile strength tests and flexural strength tests at 28 days were carried out in dosages of 5%, 10% and 15% of over-burnt crushed brick using a mix design of 210 kg/cm ^{2}with the ACI method. It was determined that the percentage of 10% was the one that provided the highest compressive strength with a value of 323.54 kg/cm^2; likewise a tensile strength of 24.89 kg/cm^2 was achieved with the same percentage; with respect to flexural strength, a maximum of 65.39 kg/cm^2 was achieved with a 5% replacement. It was recommended to use 10% of over-burnt crushed bricks since this was the optimum percentage to improve the mechanical properties of the hardened concrete based on the standard sample.

Keywords Over-burnt Bricks, Strength, Mechanical Properties, Aggregates and Concrete

1. Introduction and Background

In recent years, the demand for brick has been growing in line with the development of the construction sector and the need for new engineering works, which has led to the existence of companies in different parts of the world that produce it. In the case of the Junín region, there is an average of 191 artisan producers according to the Ministry of Production [1], specifically in the province of Huancayo where most of the artisan brick kilns are located because in this place there is a large amount of raw material for the manufacture of bricks. Artisan bricks are composed mainly of grit, clay, and water; grit is a type of aggregate similar to sand, but it has finer particles; the manufacturing process of these artisan bricks is described in Figure 1. The brick kilns of Huancayo generate a large amount of solid waste that is thrown in embankments or in inadequate places because of bad practices and failures in the artisanal production processes; this waste is approximately 20% of the total bricks produced; it is known that the percentage of masonry units discarded due to over firing is between 5% to 15% of the total [2], since they manufacture bricks with predominantly manual procedures. These over-burnt bricks from the production process of artisanal brick kilns are discarded due to over firing, which causes a slight deformation in its geometry in some of its areas and its color is not uniform. It is for this reason that in the search for solutions to the problem of inadequate management of solid waste generated in this industry has led to the proposal to evaluate the use of crushed over-burnt bricks as a replacement for coarse aggregate in the mechanical performance of concrete. The present research seeks to contribute to environmental engineering by providing an added value to the over-burnt bricks, when used as coarse aggregate, and to know if this solid waste contributes beneficially to improving the mechanical properties of hardened concrete.

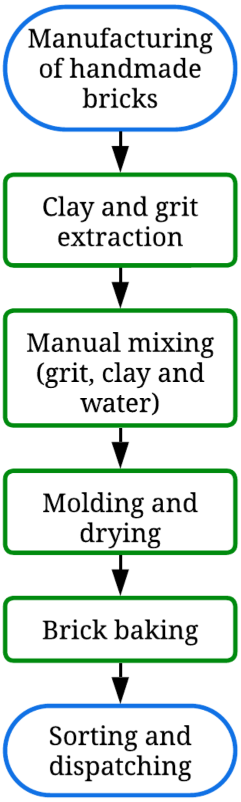

Figure 1. Handmade brick manufacturing flowchart

Among the studies related to the use of brick waste for the improvement of concrete was found in India by Praveen [3], who proposed 10% brick waste in an M30 mix design, which obtained 33.50 Mpa in the compressive strength test, 1.80 Mpa in the tensile test and 3.6 Mpa in the flexural test, all of which were at 28 days of curing.

Another research in Peru by Kallak [4] concludes that the compressive strength of concrete decreases up to 85% as the percentage of brick replacement in the mix increases, while Rojas [5] concludes that the compressive strength does not change if the brick replacement is not higher than 20%, especially if it is in a saturated state. Unlike the previous studies, this research will use the over-burnt bricks from the waste of artisanal brick kilns as a replacement of the coarse aggregate in concrete, evaluating in this study replacements of 5%, 10% and 15% to determine the optimum percentage in its application, in addition to the fact that these wastes tend to have greater hardness compared to traditional bricks.

The incorporation of crushed over-burnt bricks as a replacement for coarse aggregate is expected to be a good option and help improve the mechanical properties of hardened concrete, which will benefit both economically and environmentally.

2. Materials and Methods

Mechanical analysis of concrete, using over-burnt bricks as coarse aggregate, presents a quantitative approach, an applied research design and correlational objectives. Firstly, the study area was defined, the province of Huancayo as shown in Figure 2 which is the capital of the Jun ń region in Peru was chosen. Due to the fact that according to [1], there are 128 artisanal brick kilns, generating large amounts of solid waste in its production and implementation, being a high pollutant for the city [6]. We worked with the artisanal brick kiln called Povis located in the district of Tambo, as shown in Figure 3, where the samples were taken for the research.

Figure 2. Geographical location of brick plants

Figure 3. Povis artisanal brick kiln

2.1. Materials

2.1.1. Coarse Aggregate

The coarse aggregate comes from the disintegration of volcanic rock, extracted naturally from boulders, or crushed by machinery, classified by ASTM C33 [7] in diameter greater than 4.75mm, ideal for the preparation of concrete. For this study, coarse aggregate was obtained from the quarry located in the district of Huamancaca Chico, department of Junín in Peru, this aggregate is a machine-crushed type with a smooth texture, then it was taken to the laboratory to identify its properties which are shown in Table 1. For the study carried out, percentages of 5%wt, 10%wt and 15%wt of the coarse aggregate were replaced by crushed over-burnt bricks to improve the mechanical properties of the concrete.

Table 1. Coarse aggregate characteristics

TRES DE DICIEMBRE QUARRY	
MAXIMUM SIZE (mm)	25.40
UNIT WEIGHT (kg/m^3)	1685
SPECIFIC GRAVITY	2.69
MOISTURE CONTENT (%)	0.26
CLOGGING CAPACITY (%)	0.85
SUCS CLASSIFICATION	Poorly graded gravel (GP)

2.1.2. Fine Aggregate

The fine aggregate is of alluvial origin or the result of the disintegration of volcanic rocks, classified by ASTM C33[7] with particle sizes no larger than 4.75 mm to a minimum size of 75 microns. For the preparation of the concrete specimens, fine aggregate extracted from the Huamancaca Chico quarry, which is located 45 minutes from the city of Huancayo, was used, then the fine aggregate was taken to the laboratory to identify their characteristics which are shown in Table 2 to develop a mix design; there was no evidence of silt and clay in the fine aggregate, which means it is an ideal material in the region.

Table 2. Fine aggregate characteristics

TRES DE DICIEMBRE QUARRY	
FINENESS MODULUS	3.05
UNIT WEIGHT (kg/m^3)	1547
SPECIFIC GRAVITY	2.61
MOISTURE CONTENT (%)	0.54
ABSORPTION CAPACITY (%)	1.14
SUCS CLASSIFICATION	Poorly graded sand (SP)

2.1.3. Over-burnt Bricks

The handmade brick is composed of clayey and sandy materials, compressed, and subjected to firing [8], allowing to improve its properties, considered a basic component for construction [9]. Due to the manufacturing method, the bricks are usually over-burnt and discarded. For the elaboration of the research work, the bricks that were over-burnt and discarded by the artisan brick kiln Povis were used, and then crushed in a crusher, selecting the material of sizes between 2.38mm to 25.4mm, taking advantage of the angular particles with rough surfaces, transferring it to the laboratory to identify the necessary characteristics to develop a mix design; the characteristics obtained are shown in Table 3. For the study carried out, 5%, 10% and 15% of crushed brick were considered to replace the coarse aggregate.

Table 3. Characteristics of crushed brick

POVIS BRICK KILN	
MAXIMUM SIZE (mm)	19.05
UNIT WEIGHT (kg/m^3)	846
SPECIFIC GRAVITY	1.62
MOISTURE CONTENT (%)	0.03
ABSORPTION CAPACITY (%)	10.7

2.1.4. Water

Water is a fundamental component in the preparation of concrete, determining the consistency or fluidity [10], and when in contact with cement, it generates a series of reactions that influence the physical and mechanical properties of the concrete. Before the water is combined with the aggregates and cement, it must be free of sulfates, chlorides, or organic matter. Due to the absorption of the crushed bricks, it is important to consider the amount of water that should be added to have a good workability, strength, and durability of the material [11].

2.1.5. Cement

Type I Andean Portland cement was used, which meets the requirements of ASTM C-1157 [12], resistant to contact with sulfate soils and salty substances, ideal for all types of structures, floors, and foundations. It was used in the elaboration of standard concrete and in concrete with the replacement of coarse aggregate with crushed over-burnt bricks. Table 4 shows the cement properties given by the manufacturer.

Table 4. Cement properties

CEMENTO PORTLAND TIPO I	
NAME	Andean Type I
MATERIAL	Cement
PRESENTATION	Bag (42.5kg)
CHARACTERISTICS	Obtained from the joint grinding of type I clinker, pozzolan and gypsum.
STANDARD	NTP-334.009 / ASTM-150

2.2. Dosage Method

For this research, a mix design was made for a compressive strength of 210 kg/cm ^{2} being this the standard value of the study, for this first part the conventional coarse aggregate was used, and then it was replaced in percentages of 5%wt, 10%wt and 15%wt of burnt crushed bricks. The concrete mix design was carried out using the method described in the ACI standard [13], since it allowed working in a precise and fast way with the guarantee of obtaining reliable results [14], for this design the physical properties of the conventional aggregates were considered but not the burnt brick, a ratio w/c=0.55 was taken as a base since a decrease in workability was foreseen due to the burnt brick, a design slump of 5 inch was used and an air content of 1.50%. Finally, Table 5 shows the weights of the materials for 1m ^{3} of concrete for a mix design of 210 kg/cm ^{2}.

Table 5. Mixing design for the standard sample

MATERIALS	QUANTITY (kg/m ^{3})	VOLUME (m ^{3}/m ^{3})
Cement	363	0.117
Fine aggregate	631.31	0.246
Coarse aggregate	1172.02	0.424
Water	198	0.198
Air	1.5%	0.015
Unit weight	2363	2363

For the mix design using the overburnt bricks; concrete strength (f'c), maximum size of the coarse aggregate, concrete slump, water content, air content, water/cement ratio, cement proportion were defined as the previous pattern mix design; and for this case we only partially replaced in percentages of 5%wt, 10%wt and 15%wt crushed over-burnt bricks in the coarse aggregate as shown in Table 6.

Table 6. Mix design with incorporation of over-burnt brick

MATERIALS	**5%wt (kg/m ^{3})**	**10%wt (kg/m ^{3})**	**15%wt (kg/m ^{3})**
Cement	363	363	363
Fine aggregate	631.31	631.31	631.31
Coarse aggregate	1113.42	1054.82	996.22
Water	198	198	198
Crushed brick	58.60	117.20	175.80

2.2.1. Compressive Strength

The compressive strength of concrete is the most common test because the most important properties of concrete are directly related to compressive strength [15]. The test was carried out according to the parameters of ASTM C39 [16]. To obtain the samples, specimens of 15.25 cm in diameter and 30.5 cm high with a metal base were used, the prepared concrete was placed, and simultaneously a compaction was performed with a smooth rod in three layers, of which 25 blows were applied and then left to dry for 24 hours. To perform the compression test, machinery capable of foreseeing a constant load speed until the sample fractures was used. The compression tests were carried out at 28 days, during which the specimens were in the saturation pool at a temperature of approximately 22 ℃. To determine the compressive strength of the specimens of 0%wt, 5%wt, 10%wt and 15%wt of crushed over-burnt bricks, the following formula was applied (1).

$$f'c = \frac{P}{S} \tag{1}$$

$f'c$ = Compressive strength (kg/cm ^{2})
P = Maximum load (kg)
S = Loading surface area (cm ^{2})

2.2.2. Tensile Strength

The tensile strength test was performed according to ASTM C496 [17], using for this test the same dimensions as the compression test specimens, as well as their preparation and curing of the samples. The test allowed indirect visualization of the adhesion of the over-burnt brick, aggregates, and cement. The test consisted of applying a compressive force along the concrete mold located horizontally, causing tensile stresses in the plane containing the applied load and compressive stress in the applied load area until failure by cracking [17], allowing to identify the value of the tensile strength. The following formula (2) was used to obtain the result of the concrete tensile strength of the specimens of 0%wt, 5%wt, 10%wt and 15%wt.

$$St = \frac{2\times p}{\pi\times t\times d} \quad (2)$$

St = Tensile Strength (kg/cm²)
p = Maximum load (kg)
d = Specimen diameter (cm)
t = Specimen height (cm)

2.2.3. Flexural Strength

The flexural strength test was performed in accordance with ASTM C293 [18], using a simple concrete beam with a cross section of 15cmx15cm and a length of 50cm. For the preparation of the specimens, the recommendations of ASTM C31 [19] were considered, making blows every 14 cm of horizontal section and 54 blows for each concrete layer to release air bubbles. The test was performed after 28 days of curing, placed in the constant compression machine, centered on the support blocks, and then applying the load in the third points between the supports until the sample is broken, finally the average width and height were determined. The flexural strength test allowed to know the resistance to moment failure of a beam represented as the Modulus of Rupture (MR). To obtain the results of the flexural strength of the 0%wt, 5%wt, 10%wt and 15%wt specimens, the following formula was used (3).

$$Mr = \frac{3\times P\times L}{2\times b\times h^2} \quad (3)$$

Mr = Modulus of rupture (kg/cm²)
P = Maximum load (kg)
L = Clearance between supports (cm)
b = Specimen width (cm)
h = specimen height (cm)

3. Test Results and Discussion

The physical properties of the fresh concrete and the results of the mechanical tests, such as compressive strength, tensile strength and flexural strength are shown below. The results obtained were analyzed to determine the feasibility of the work.

3.1. Physical Properties of Concrete

Table 7 shows the physical properties of fresh concrete such as unit weight, slump, and air content for the analyzed samples of 0%wt, 5%wt, 10%wt and 15%wt.

The results obtained for the unit weight of the concrete for both the standard mix and the mixes with over-burnt bricks were within the normal allowable limits of 2200 kg/m³ to 2400 kg/m³ according to the standard [20]. On the other hand, the results obtained for concrete slump differed between the standard mix and the mixes with over-burnt bricks; the standard mix being very workable and the mixes with over-burnt bricks as poorly workable according to the standard [21], noting that 15%wt is the one with the most unfavorable result. Finally, it was observed that the air content increased as the percentages of brick increased, this occurs due to the pores contained in the brick particles.

Table 7. Properties of fresh concrete

PERCENT (%)	UNIT WEIGHT (kg/m³)	SLUMP (inch)	AIR CONTENT
0	2364	4.84	1.50%
5	2358	1.84	1.70%
10	2352	1.34	2.00%
15	2259	0.60	2.60%

3.2. Compressive Strength Test

Table 8 shows the results obtained from the compression resistance test of 0%wt, 5%wt, 10%wt and 15%wt of over-burnt brick at 28 days of curing, it is worth mentioning that 3 specimens were tested for each dosage according to ASTM Standard C39 [16].

Table 8. Compressive Strength after 28 days of curing

Specimen	0%	5%	10%	15%
S-01 (kg/cm²)	234.10	273.41	326.89	296.95
S-02 (kg/cm²)	235.33	271.86	329.55	300.81
S-03 (kg/cm²)	234.85	275.20	323.41	294.06
Average	234.76	273.49	326.62	297.27
SD	0.62	1.67	3.08	3.39
A - SD	234.14	271.82	323.54	293.89

The compressive strength of 234.14 kg/cm² of the standard sample tested at 28 days was expected according to the mix design of 210 kg/cm², and this strength obtained from the standard sample can serve as a reference to compare the behavior of the samples with replacements because they were worked under the same preparation conditions in the laboratory. According to Figure 4, all percentages of brick replacements have a higher compressive strength than the standard sample, which is an indication that the properties of the over-burnt bricks improve the quality of the concrete, but there is a higher strength with the 10% replacement dosage.

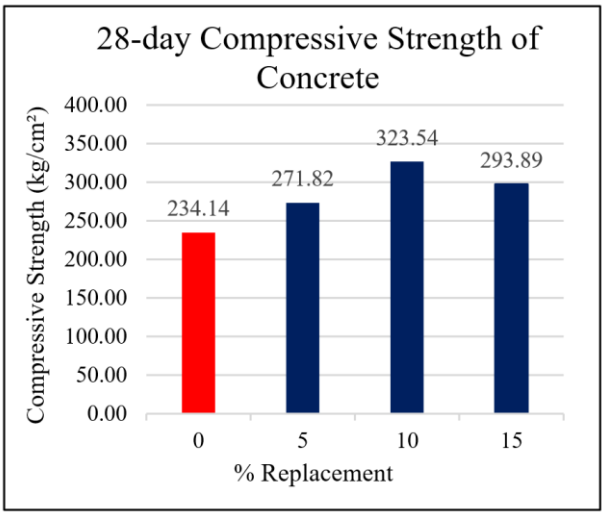

Figure 4. Average compressive strength after 28 days of curing

The improvement of the mechanical resistance of the concrete when using over-burnt brick is also due to the higher absorption that exists when combining the bricks to the mix, as mentioned before, the bricks worked without being saturated, so the pores of the brick absorbed the water of the mix, thus decreasing the water-cement ratio and therefore increasing the compressive strength, at the same time generating a better connection between the cement paste and the brick. However, when the water absorption in the mix is excessive, there is no longer enough water available for the reaction of the cement, which causes the mechanical strength to decrease, which explains the tendency to decrease the strength for replacements greater than 10%. This decrease may also be due to the low workability of the concrete, which causes poor compaction due to the difficulty of placement because of the low slump of the mix.

3.3. Tensile Strength Test

Table 9 shows the results obtained from the tensile strength test of 0%wt, 5%wt, 10%wt and 15%wt of over-burnt bricks at 28 days of curing, it is worth mentioning that 3 specimens were tested for each dosage according to ASTM C496 [17].

Table 9. Tensile Strength after 28 days of curing

Specimen	0%	5%	10%	15%
S-01 (kg/cm^2)	23.15	23.87	25.35	21.35
S-02 (kg/cm^2)	24.41	26.41	25.58	22.67
S-03 (kg/cm^2)	23.65	25.09	24.85	20.53
Average	23.74	25.12	25.26	21.52
SD	0.63	1.27	0.37	1.08
A - SD	23.10	23.85	24.89	20.44

The tensile strength with replacements of over-burnt bricks varies very little with respect to the strength of the standard sample, being 15% the dosage that gives a value of 20.44 kg/cm^2, which was lower than the standard sample, at the same time the lowest. On the other hand, the best performance in tensile strength was 10% of the over-burnt brick, like the behavior of the compressive strength.

As shown in Figure 5, the results have the tendency to rise slightly up to 10% and then it starts to decrease as it did in the compressive strength results. As in the previous analysis by increasing more than 10% of over-burnt brick, it produces a high absorption that causes a lack of paste so that it does not guarantee the adhesion between the mix and the aggregates, this explains the low tensile strength with the 15% dosage. Given the bar graph shown in Figure 5, it can be determined that the tensile strength is not affected exponentially by the incorporation of over-burnt bricks up to a dosage of 15%.

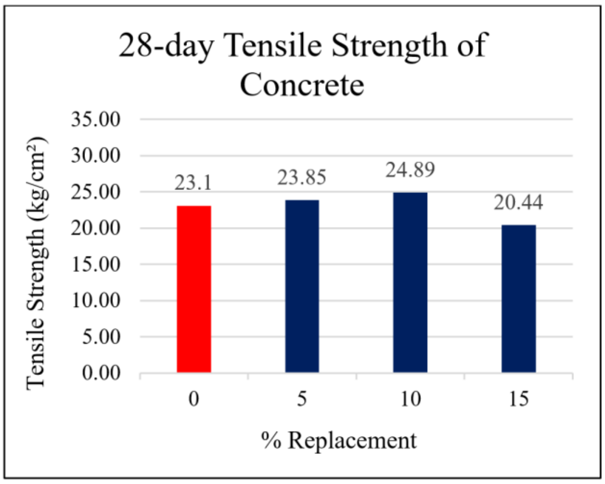

Figure 5. Average tensile strength after 28 days of curing

Table 10 shows the relationship between tensile strength and compressive strength at 28 days of curing, the tensile strength of the standard sample and 5% brick are within the range of 8 to 15% with respect to the compressive strength according to [22], except for 10% and 15% brick, this is due to the very high value of the compressive strength which causes a lower value of the f't / f'c ratio.

Table 10. Relationship between tensile strength and compressive strength

Percentage (%)	Tensile Strength (kg/cm^2)	Compressive Strength (kg/cm^2)	f'_t / f'_c
0	23.10	234.14	9.86%
5	23.85	271.82	8.77%
10	24.89	323.54	7.69%
15	20.44	293.89	6.95%

3.4. Flexural Strength Test

Table 11 shows the results obtained from the flexural strength tests of 0%, 5%, 10% and 15% of over-burnt bricks at 28 days of curing, it is worth mentioning that 3 specimens were tested for each dosage according to ASTM C496 [17].

Table 11. Flexural Strength after 28 days of curing

Specimen	0%	5%	10%	15%
S-01 (kg/cm^2)	60.56	68.31	64.75	58.01
S-02 (kg/cm^2)	62.63	65.29	63.48	60.33
S-03 (kg/cm^2)	63.95	67.15	61.87	57.69
Average	62.38	66.92	63.37	58.68
SD	1.71	1.52	1.44	1.44
A - SD	60.67	65.39	61.92	57.24

The highest flexural strength achieved was with the 5% dosage of over-burnt brick, obtaining a value of 65.39 kg/cm^2, which is higher than the standard strength. On the other hand, with 15% brick, it is still the worst dosage since it decreased the flexural strength by 6% compared to the standard sample.

According to Figure 6, it is again observed that the flexural strength (modulus of rupture) decreases as the percentage of over-burnt brick replacement increases. A slight increase in strength can be seen with respect to the standard of 5% replacement. This indicates that the presence of a small amount of brick favors the flexural strength, but as it increases, it decreases, this is consistent with the previous results obtained in the other mechanical properties. In addition, it can be said that possibly the greater hardness of the over-burnt brick also implies a lower deformation capacity, making the concrete less capable of breaking in flexural-traction as it contains a greater amount of brick.

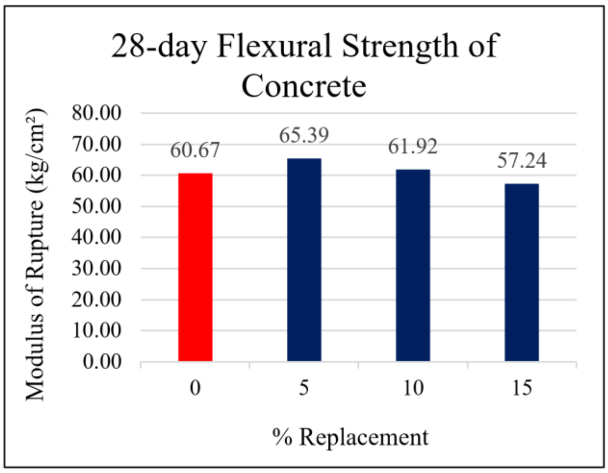

Figure 6. Average flexural strength after 28 days of curing

The modulus of rupture varies between 10% to 15% of the compressive strength [22], and his relationship depends on the type, dimensions and volume of coarse aggregate used. Table 12 shows that the modulus of rupture is higher than expected, so it is considered that the materials used have favored the behavior of the concrete. The angular shape of the crushed over-burnt brick and its surface roughness benefit the union with the cement paste if the brick is present in small quantities [23], the flexural/compression ratio for the same concrete remains high (greater than 10%), which indicates a good flexural behavior.

Table 12. Relation between modulus of rupture and compressive strength

Percentage (%)	Modulus of Rupture (kg/cm^2)	Compressive Strength (kg/cm^2)	MR / f'_c
0	60.67	234.14	25.91%
5	65.39	271.82	24.06%
10	61.92	323.54	19.14%
15	57.24	293.89	19.48%

4. Conclusions

The over-burnt brick as a replacement of the coarse aggregate in the mechanical properties of hardened concrete is an excellent option since it was possible to increase the compressive, tensile, and flexural strengths for a mix design of 210kg/cm^2. The compressive strength increases up to the dosage of 10% over-burnt brick replacement, improving by 38.18% with respect to the standard sample, then as the dosage of brick increases, the compressive strength tends to decrease. On the other hand, the tensile strength does not change significantly with dosages of 5%, 10% and 15%; only 10% improves by 7.75% with respect to the standard sample. Finally, it was concluded that the flexural strength tends to decrease with higher brick content from 5% onwards; only 7.78% improvement was achieved with respect to the standard sample with 5% replacement.

The optimum dosage of replacement is the one that achieves the best behavior of the concrete in hardened state, for this research according to the characteristics of the over-burnt crushed brick, its workability, its results of compressive strength, tensile strength and flexural strength, 10% had a better behavior, with this percentage the properties of the concrete are considered acceptable with respect to the standard strength.

The hardness and absorption of the over-burnt brick as a replacement for the coarse aggregate are important characteristics for the concrete to behave in a different way affecting properties such as workability, compressive strength, tensile strength, and flexural strength. It is recommended to evaluate new conditions to improve the workability of the concrete mix with crushed over-burnt brick replacements, the incorporation of a plasticizing admixture that allows the mix to reach the adequate workability can be a good alternative for replacement values higher than 15%.

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