

# Replacement of Fine Aggregate with Refractory Brick Residue in Concrete Exposed to Elevated Temperatures

Bereche, Jhan<sup>1</sup> ; García, Juan<sup>1,\*</sup> 

<sup>1</sup>Universidad Señor de Sipán, Faculty of Engineering, Architecture and Urbanism, Chiclayo, Peru

**Abstract:** Refractory brick waste, added to the fires originated in structures, makes it possible to bring together two problems to contribute to sustainable construction and introduce new aggregate alternatives in concrete. The objective of the study was to produce concrete with less fine aggregate and to evaluate a more sustainable concrete, using refractory brick residues (RBR) to replace fine aggregate in five percentages 10 %, 20 %, 30 %, 40 % and 50 % to be exposed to direct fire. The design was based on a water-cement w/c ratio of 0.71 and the production of 144 RBR-based concrete specimens. The fresh samples were subjected to slump and fresh unit weight tests, the cylindrical specimens prepared after 28 days of curing were subjected to compressive strength at room temperature and various temperatures (200 to 1 000 °C) for different times of 15, 30 and 60 minutes. In addition, a Three Factor statistical analysis of variance was performed with respect to the compressive strength at 28 days. The results showed that the RBR influences the concrete mix are less workable and reduce the fresh unit weight at higher substitution percentages. On the other hand, the ideal dosage was with the percentage of 40RBR as opposed to the other dosages subjected to heat, being insignificant at 15-minute exposure, but relevant at 30 and 60 minutes. It is concluded that RBR significantly influences the improvement of its mechanical properties under high heat and the amount of residues is limited to a specific dosage, providing a sustainable constructive approach to direct controlled fire exposures.

**Keyword:** Fire; concrete; refractory brick waste; temperature; times

## Reemplazo del Agregado Fino por Residuo de Ladrillo Refractario en Concreto Expuesto a Elevadas Temperaturas

**Resumen:** Los desechos de ladrillos refractarios, sumado a los incendios que se originan en las estructuras, hacen posible juntar dos problemáticas para contribuir a una construcción sustentable para introducir nuevas alternativas de áridos en el concreto. El objetivo del estudio fue producir concreto con menos agregado fino y evaluar un concreto más sostenible, utilizando residuos de ladrillos refractarios (RLR) para reemplazar el agregado fino en cinco porcentajes 10 %, 20 %, 30 %, 40 % y 50 % para ser expuestos a fuego directo. El diseño se basó en una relación agua-cemento a/c de 0.71 y en la elaboración de 144 probetas de hormigón a base de RLR. Las muestras frescas se sometieron a ensayos de asentamiento y peso unitario fresco, las probetas cilíndricas preparadas tras 28 días de curado se sometieron a resistencia a compresión a temperatura ambiente y diversas temperaturas (200 hasta 1 000 °C) durante diferentes tiempos de 15, 30 y 60 minutos. Además, se realizó un análisis estadístico de varianza de Tres Factores con respecto a la resistencia a compresión a los 28 días. Los resultados mostraron que el RLR influye en que la mezcla de hormigón sea menos trabajable y reduzca el peso unitario fresco a mayores porcentajes de sustitución. Por otro lado, la dosificación ideal fue con el porcentaje de 40RLR a diferencia de las otras dosis sometidas a calor, siendo insignificante la exposición de 15 minutos, pero si relevantes a 30 y 60 minutos. Se concluye que el RLR influye significativamente en la mejora de sus propiedades mecánicas sometidas al calor elevado y la cantidad de residuos se limita a una dosis específica, lo cual proporciona un enfoque constructivo sostenible frente a exposiciones de fuego directo controlado.

**Palabras clave:** Fuego; hormigón; residuos de ladrillos refractarios; temperatura; tiempos

### 1. INTRODUCTION

Globally, the materials used in construction are exposed to incidents such as high temperature fires (Aboutaleb et al., 2017; Humaish et al., 2020).

Fire poses a serious threat to the life of structures (Memon et al., 2019). Cases such as the Plasco Tower in Tehran was the victim of a catastrophic fire, perceiving lateral displacements and bending moments in pillars for 3 and a half hours, leading to its imminent collapse (Akbar et al., 2020; Da Silva et al.,

\*gchumacerojuanm@uss.edu.pe  
Recibido: 20/09/2023  
Aceptado: 27/02/2024  
Publicado en línea: 31/05/2024  
10.33333/rp.vol53n2.08

CC 4.0

2020). For they show the serious problem, it brings after a severe exposure to direct fire (Bo et al., 2020). Thus, above 300 °C, concrete loses almost 30 % of its original value; furthermore, in the temperature range of 400 to 800 °C, most of the initial strength is lost, and between 600 to 800 °C, the compressive strength was almost nil, as mentioned in Calmeiro and Correia (2014) and Han et al. (2020).

In the environmental aspect, the rapid increase in the amount of industrial waste is one of the main reasons that has led countries to adopt stricter environmental and sustainable policies (Sangi-Gonçalves et al., 2022). However, it is necessary to estimate the effect of the use of bricks as concrete aggregate to implement it as a component of concrete (Moreno et al., 2019). Thus, the total or partial substitution of this component is a key challenge to address the negative environmental effects and costs associated with the aggregate extraction process, without significantly affecting the properties of concrete and mortar manufactured with them (Feijoo et al., 2021). In Peru, refractory waste from the replacement of bricks from local metal smelters leads to the accumulation of these materials around cities and dumps.

In the compilation of literary information on topics related to refractory concretes, it is mentioned that they have an adequate performance at temperatures up to 1 000 °C, as expressed by Bareiro et al. (2020). However, this leads to mechanical deterioration at the structural level, due to spalling of the concrete when exposed to fire as mentioned Carrizo et al. (2020) and Ma et al. (2018). Even so, many Latin American countries persist in improving their structures in the face of these phenomena caused by various factors (Flores et al., 2018). Thus, it is important to consider studies on these issues, since concrete shows considerable reductions in strength and elasticity when subjected to earthquakes, fire or chemical interaction, as expressed by Galvez et al. (2020). Due to the fact that in Latin America, specifically in Peru, there is not much information on this type of concrete with refractory materials as a substitute for fine aggregate.

Likewise, there have been several researches that show the reuse of this material in the preparation of concrete, such as the research of Liu et al. (2018), where they tested the mechanical behavior of concrete after exposure to elevated temperatures up to 800 °C, obtaining optimum results. On the other hand, other studies used ultra-high performance fibers before and after heat treatment in a temperature range from 400 °C, 700 °C and 1 000 °C, achieving optimum residual strength in compression and flexure, being developed by Sobia et al. (2015) and Cruz et al. (2015).

According to studies by Baradaran and Nematzadeh (2017), it was concluded that workability is affected with doses of 25, 50, 75 and 100 % of refractory material, with slump ranging from 70 mm to 55 mm. On the other hand, the specific surface area of materials such as refractory brick powder is relevant when it is lower than that of cement to attribute a better workability in concrete as expressed by Sevim et al. (2023). Consequently, a level of flowability is achieved using superplasticizer (Shirani et al., 2021). On the other hand, the density reduction was affected using pumice from 12.3 % to

41.5 %, for the treatments from 25 % to 100 % pumice, respectively due to the porous structure of pumice, which translates into light weighting (Uysal et al., 2004). According to Zeghad et al. (2017), the results show that concretes made with refractory bricks based on silica-zirconium have a slightly higher density than other concretes, due to the specific mass of the brick. However, the use of recycled refractory brick aggregate shows a decrease with the increase of the maximum substitution ratio of 18 %, as expressed by Khattab and Hachemi (2021).

Within the mechanical properties such as compressive strength, concrete calcined under fire at 800 °C for 20 minutes showed a compressive strength loss rate of 66.3 % (Shui-Jun et al., 2013). The investigation of Molay et al. (2019), found that at 28 days the concrete with limestone, quartzite and granite subjected to 25 °C and 650 °C for 2 hours, it was observed that the concrete with granite had higher resistance at all temperatures compared to the concrete with quartzite and limestone (Tufail et al., 2017). In addition, the studies of Zeghad et al. (2017) observed that the concretes with alumina based on ground refractory bricks show a higher value of strength at 93 MPa, but not exceeding the standard sample of 120 MPa. Ahn et al. (2016), noted that the strength of concrete decreases as the exposure temperature increases, retaining 19.5 % and 51.7 % of the original strength after exposure to 800 °C. By substituting 50% of fine aggregate by refractory material, the residual strength of concrete exposed to 800 °C improves, but showed higher reduction values above 200 °C, as mentioned by Baradaran and Nematzadeh (2017). Also, Varona et al. (2018) clarify that lower residual strengths were obtained after exposure to higher mechanical test ages, making dehydration deterioration at elevated temperature more detrimental. Therefore, it is recommended to replace coarse and fine aggregate with 20 % refractory brick aggregate, for the use in the production of concrete at room temperature (Hachemi et al., 2023).

In this context, the objective of this research was to evaluate the influence of replacing fine aggregate with refractory bricks waste (RBR) on the compressive strength of structural concrete exposed to four different temperature ranges, every 3 time intervals, respectively. This type of concrete constitutes an environmental alternative to waste refractory bricks. On the other hand, although there are recent reviews on the use of refractory waste in construction, there is a knowledge gap because they do not highlight the effect at shorter exposure times; moreover, on the three-factor statistical analysis of variance with respect to compressive strength. Therefore, this study provides a synthesis of the results and, the possibility of establishing the use of this material in areas where the availability of natural aggregates is limited or impractical and, discuss the possibility of using this material against this uncontrolled occurrence of fire in a structure.

## 2. MATERIALS AND METHODOLOGY

### 2.1 Ordinary Portland Cement Type I

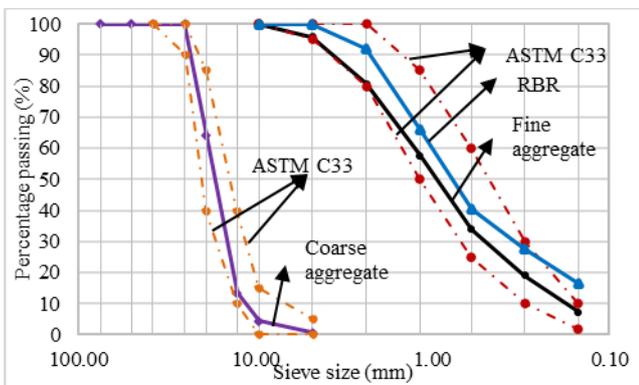
Type I ordinary Portland cement was used according to ASTM C150 (2012), as seen in Table 1, the chemical and physical analyses of the cement used are given, respectively.

**Table 1.** Chemical, physical and mechanical composition of Portland cement

Description	Specification	Manufacturer's results
MgO (%)	6.00 maximum	2.20
SO <sub>3</sub> (%)	3.00 maximum	2.70
Loss on ignition (%)	3.50 maximum	3.10
Specific weight	No specified	3.12
Setting time initial (minutes)	< 45 minimum	110
Setting time final (minutes)	> 375 maximum	238

**2.2 Aggregates and refractory brick residue**

Fine and coarse aggregate from the quarry bank of the Lambayeque region, Peru, were used. Additionally, refractory brick residue obtained from a local company was used as fine aggregate. Some of the physical properties are shown in Table 2, and the gradations of the aggregates under ASTM C136 (2001), are shown in Figure 1.



**Figure 1.** Coarse, fine and RBR aggregate granulometry

**Table 2.** Some properties of natural aggregates

Properties	Fine aggregate	Coarse aggregate	Refractory brick residue
Fineness modulus	3.05	---	2.57
Maximum size (mm)	---	19	---
Specific weight	2.51	2.69	2.34
Water absorption (%)	1.38	0.93	2.80
Moisture content (%)	0.98	1.21	0.33

**2.3 Refractory brick residue**

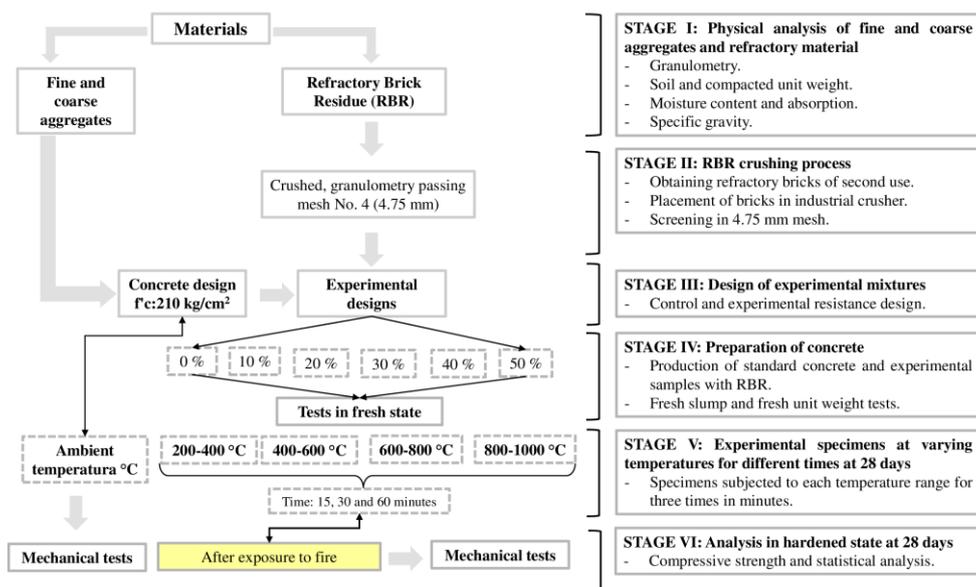
The refractory brick residue (RBR) was obtained from the recycling process of discarded refractory bricks from a metal smelting factory (used as lining). Figure 2 shows the different sizes of the aggregates used and of the refractory material itself.



**Figure 2.** a) Coarse aggregate, b) fine aggregate, c) refractory brick residue < 5 mm

**2.4 Methodology**

A control mix was made for a target strength of 210 kg/cm<sup>2</sup> with no replacement of refractory brick waste fine aggregate labeled RBR0 and five mixes with replacement levels of 10 %, 20 %, 30 %, 40 %, and 50 % RBR labeled RBR10, RBR20, RBR30, RBR40, and RBR50, respectively according to American Concrete Institute 211.1 (1993) procedures. A constant water/cement (w/c) ratio of 0.71 was used and no superplasticizer was used in any of the mixes; the proportions are shown in Table 3. The research methodology is presented in a process flow diagram in Figure 3.



**Figure 3.** Research process flow

The natural aggregates and refractory brick residue particles were mixed in a dry state for approximately one minute, then cement was added and mixed for an additional one minute. Half of the mixing water was added to the mixer and mixed for an additional one minute. Subsequently, the specimens were demolded after one day of processing, then poured and cured

in water at room temperature by complete immersion until the day of testing under supervised conditions in accordance with the regulations (ASTM C192M, 2015). Likewise, three test bodies were considered to obtain a statistical average, corresponding to each test to be evaluated, to be subjected to curing for 28 consecutive days, respectively.

**Table 3.** Amount of materials per 1 m<sup>3</sup> of concrete

Labels	Cement	Water	Fine aggregate	Coarse aggregate	RBR	w/c	<sup>a</sup> Compressive strength (kg/cm <sup>2</sup> )
RBR0	395	282	838	863	Control	0.71	227
RBR10	395	282	754	863	84	0.71	203
RBR20	395	282	670	863	168	0.71	238
RBR30	395	282	587	863	251	0.71	239
RBR40	395	282	503	863	335	0.71	248
RBR50	395	282	419	863	419	0.71	246

<sup>a</sup> The compressive strength of the mixtures was obtained from unheated or room temperature specimens, at 28 days.

**2.5 Procedure for heating experimental samples**

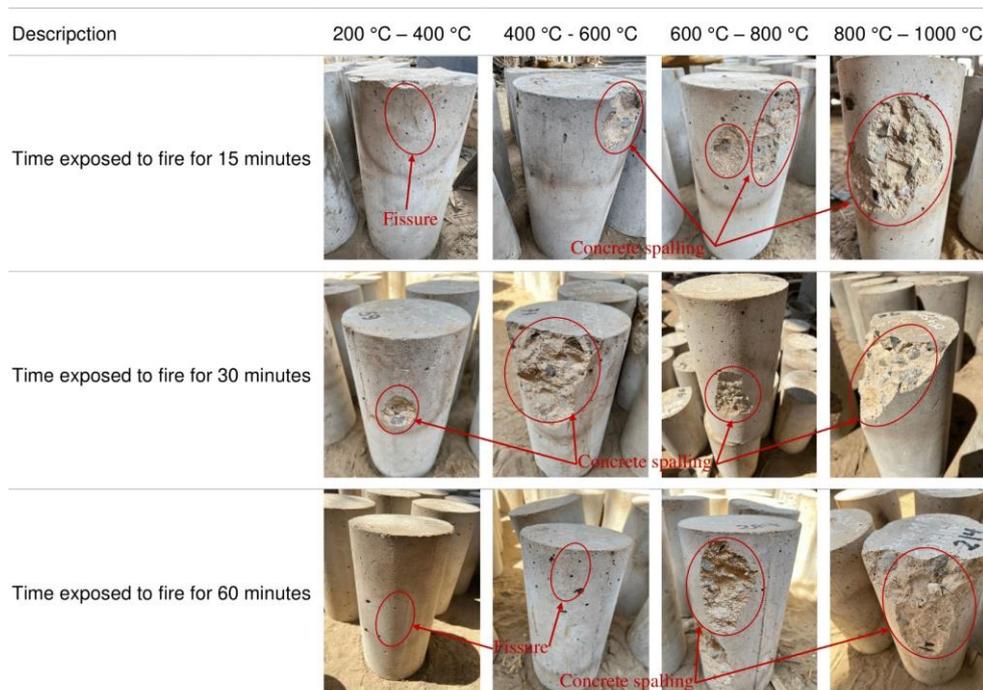
The specimens were placed coded in the ordered temperature ranges and according to the exposure time of study. The incineration process of the specimens was carried out under constant supervision. The artisanal kiln operated with high pressure burners, the heating capacity of the kiln was limited, the heating rate was 80 °C/min at the beginning.

The artisanal furnace was capable of reaching temperatures up to 1 250 °C, with dimensions of 5 000 mm (length) x 1 300 mm (width) x 500 mm (height), consisting of a body with refractory brick walls and a rigid steel lid with a layer of refractory sand, to avoid heat losses. The evaluation of the evolution over time of the temperature inside the furnace was measured with a thermocouple (maximum measurement of 1 200 °C).

It should be noted that more accelerated cooling (by cold water spray or water immersion) results in even lower residual properties. A quench was performed after 24 hours. After the incineration process of the modified concrete specimens, the textures, cracking and spalling of the mass of each specimen were observed, as shown in Figure 4.

**2.6 Experimental procedures**

The properties considered are the slump under international considerations (ASTM C143/C143M, 2012) using Abrams cone; unit weight (ASTM C138/C138M, 2014), using Washington pot equipment and Tests such as compressive strength according to parameters (ASTM C39M, 2014).



**Figure 4.** Texture of specimens against high temperature exposure

### 3. RESULTS AND DISCUSSIONS

#### 3.1 Slump test

The workability was affected by the inclusion of RBR in the concrete mixes, since it is a material with low absorption and a surface texture different from that of sand, which caused it to cover a larger surface, thus reducing its workability. The slump result for the standard mix (RBR0) was 88.9 mm, while the slump values for RBR10, RBR20, RBR30, RBR40 and RBR50 were 88.9, 81.3, 76.2, 63.5 and 50.8 mm, respectively, the reduction range being between 0 and -42.85 %. In fact, as the RBR content increases, the slump of the mixture with refractory material decreases. In addition, the superplasticizer additive was not used in any experimental mixture, the results are shown in Table 4.

These results are similar to Baradaran and Nematzadeh (2017), workability was affected reporting similar significant reductions with slump ranging from 85, 70, 65, 60 and 55 mm as a function of replacing 0, 25, 50, 75 and 100 % refractory material in the concrete mix, respectively. Refractory brick dust is relevant when it is less than that of cement to attribute better workability in concrete (Sevim et al. (2023). Consequently, a level of flowability will be achieved by using superplasticizer (Shirani et al., 2021).

#### 3.2 Fresh unit weight test

Table 4 shows the results of the fresh unit weight sample where its internal behavior varies significantly with the inclusion of RBR. When compared with the control specimen and the experimental specimen with 10 % RBR, the density went from 2 372 to 2 345 kg/m<sup>3</sup>, a percentage change of -1.14 %, while with the maximum dose of 50 % RBR, it suffered a percentage change of -2.45 % with respect to the standard specimen. It should be clarified that the specific gravity of the refractory material was 2.34, being lower than the specific gravity of the fine aggregate, which was 2.51, directly influencing the density of the concrete.

As mentioned in Uyal et al. (2004), when adding other types of aggregates such as pumice in replacement doses every 25 % to 100 %, its density decreases to 1 329 kg/m<sup>3</sup> from 2 270 kg/m<sup>3</sup>, the value of the reference sample. Now using refractory brick, above 50 % substitution, the reduction in concrete density is less than 10 % (Khattab and Hachemi, 2021). The characteristics of refractory brick such as alumina-based, magsium-based or silica-zirconium-based give slightly higher density compared to conventional concrete (Zeghad et al., 2017).

**Table 4.** Effect of RBR on slump and unit fresh weight

Labels	Slump (mm)	Variation ± (%)	Unit fresh weight (kg/m <sup>3</sup> )	Variation ± (%)
RBR0	88.90	0	2 372	0
RBR10	88.90	0	2 345	-1.14
RBR20	81.30	-8.54	2 340	-1.35
RBR30	76.20	-14.28	2 329	-1.81
RBR40	63.50	-28.57	2 325	-1.98
RBR50	50.80	-42.85	2 314	-2.45

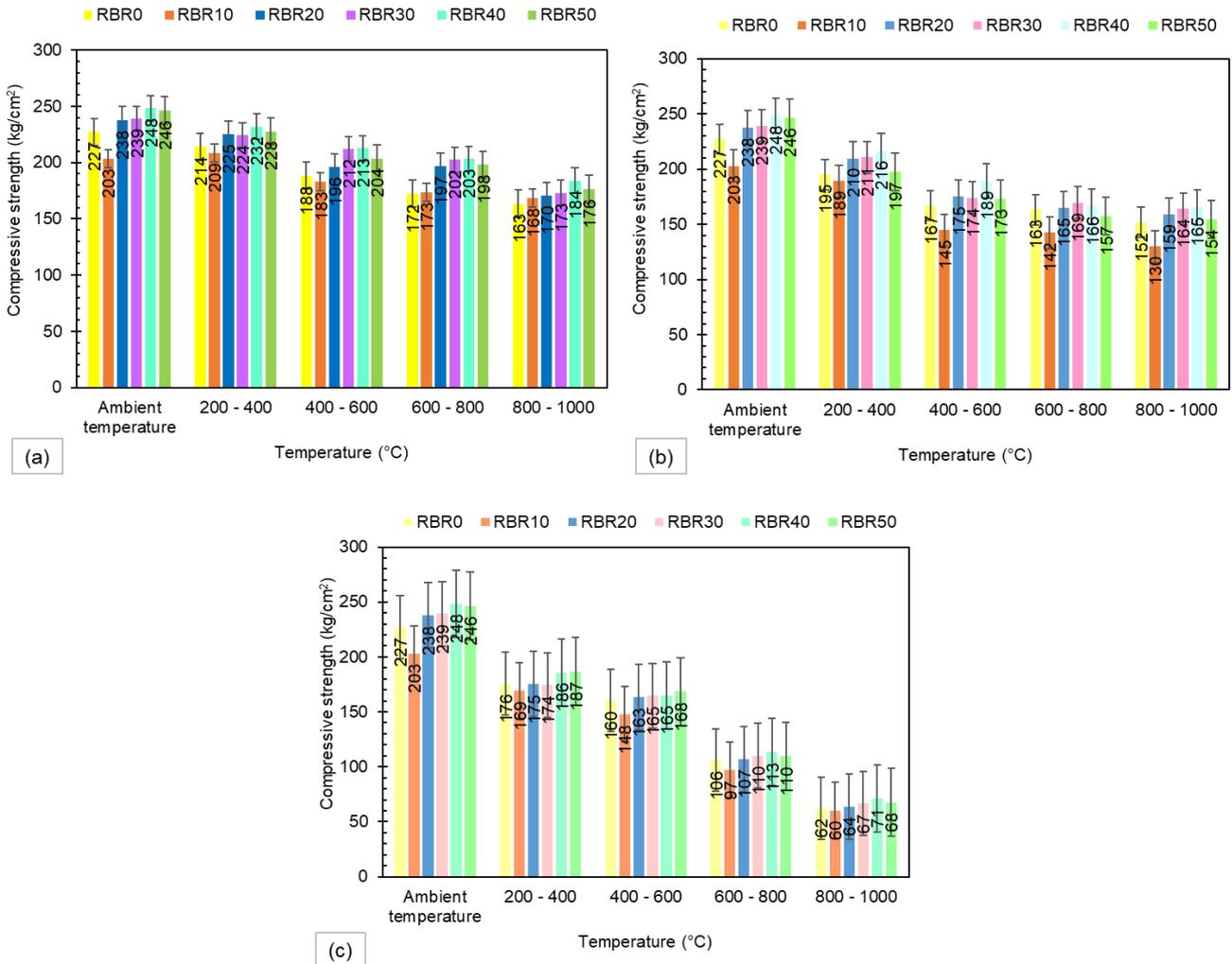
#### 3.3 Compressive strength

The compressive strength results were determined using the requirements of ASTM C39M, with specimens subjected to room temperature (Approx. 29 °C) and specimens with the effect of elevated temperatures after 28 days of curing as shown in Figure 5.

In Figure 5(a), the effect of RBR on the compressive strength subjected between 400 °C to 600 °C was observed, where less affectation was obtained in the specimens, they had a slight spalling after 5 minutes of being placed in the oven, this test group did not present abrupt explosions of the concrete mass and the cracking is faint in the external faces of each specimen. With the experimental samples of 10 % to 30 % of RBR, they represented resistance variations between 2.83 % and 12.57 %; however, with the samples of 40 % to 50 % of RBR, they suffer detachment of their mass in the middle zone of each specimen, but suffer resistance variations between 12.92 % and 8.14 % with respect to the sample RBR0. It is observed that during 15 minutes there is not much degradation of the concrete when exposed to fire, even between 800 - 1 000 °C the minimum resistance reaches 163 kg/cm<sup>2</sup> (RBR0) and the maximum of 184 kg/cm<sup>2</sup> (RBR40).

As shown in Figure 5(b), the results of the specimens exposed to 30 min times at different temperatures varied. The specimens with refractory material substitution are stronger than their control specimen, indeed the highest strength for specimen RBR40 was 189 kg/cm<sup>2</sup> (13.37 %), at the temperature range 400 - 600 °C. However, with ranges between 600 - 800 °C and 800 - 1 000 °C the strength increases are between 4 % and 9 %, respectively, for specimen RBR40. Similarly, it had results to investigations on fire calcined concrete at 800 °C in 20 min, where its compressive strength loss rate was 66.3 % (Sui-Jun et al., 2013). In Figure 5(c), it was observed that the experimental specimens at higher temperature for 60 minutes, the strengths had a maximum of 71 kg/cm<sup>2</sup> which represents 14.44 % with respect to the RBR0 sample. However, they already show a low resistance value compared to lower exposure times.

Regarding previous research on the use of aggregates as a substitute for other, Arioiz (2007) mentions that this reduction was very pronounced beyond 800 °C, the effects of the w/c ratio and the type of aggregate on the relative strength of concrete decreases as the exposure temperature increases, the effect of high temperatures on concrete strength was more pronounced for concrete mixes produced by river gravel aggregate. Meanwhile, the study shows that brick refractory in replacement of fine aggregate, indicates that it performs better than conventional aggregates. In other studies, Baradaran and Nematzadeh (2017) objects that the results showed that brick refractory aggregate and aluminate cement improve the residual compressive strength to double beyond the temperature of 800 °C.



**Figure 5.** Effect of RBR on the compressive strength of concrete exposed to high temperatures a) at 15 minutes of breakage, b) at 30 minutes of breakage, c) at 60 minutes of breakage

Results of studies indicate that concrete with aggregates fully or partially replaced with recycled concrete aggregate (RCA) exhibits good performance under elevated temperatures and can be considered comparable to conventional concrete, furthermore disintegration was observed when concrete with RCA was heated up to 750 °C. The results of residual mechanical properties tests show some variation between concretes made with different percentages of RCA substitution as focused by the studies of Sarhat and Sherwood (2013). However, research according to Abbu et al. (2022) constant the exposure of concrete to higher temperatures has two main effects on compressive strength: when lightweight concrete mixtures were heated to 250 °C and 350 °C, their strength increased; however, when heated to 450 °C, most of the mixtures lost some of their original strength.

### 3.4 Three-Factor Analysis of Variance statistical model

As shown in Figure 6, we know that the p-value of significance associated with the interaction of the three factors under study, recorded a value less than 0.05, ( $p = 6.18 \times 10^{-13} < 0.05$ ), affirming that there is a significant effect of the interaction of the three factors on the variable compressive strength, as well as the best combination of levels in the factors Time (minutes), Temperature and Mixture that maximizes the compressive strength based on the visualization of the box plot and the post hoc Tukey's multiple comparison post hoc test. Meanwhile, samples: RBR0, RBR10, RBR20, RBR30, RBR40, RBR50 for the statistical analysis respectively. The analysis corresponds to mix RBR40, at room temperature °C, at 15, 30 and 60 minutes, reaching an average resistance of 248.33 kg/cm<sup>2</sup> in each combination. The Three-Factor Analysis of Variance test was applied for compliance with normality of the residuals (Shapiro Wilk,  $p = 0.3943 > 0.05$ ), finding a significant effect in the interaction ( $p = 6.18 \times 10^{-13} < 0.05$ ).

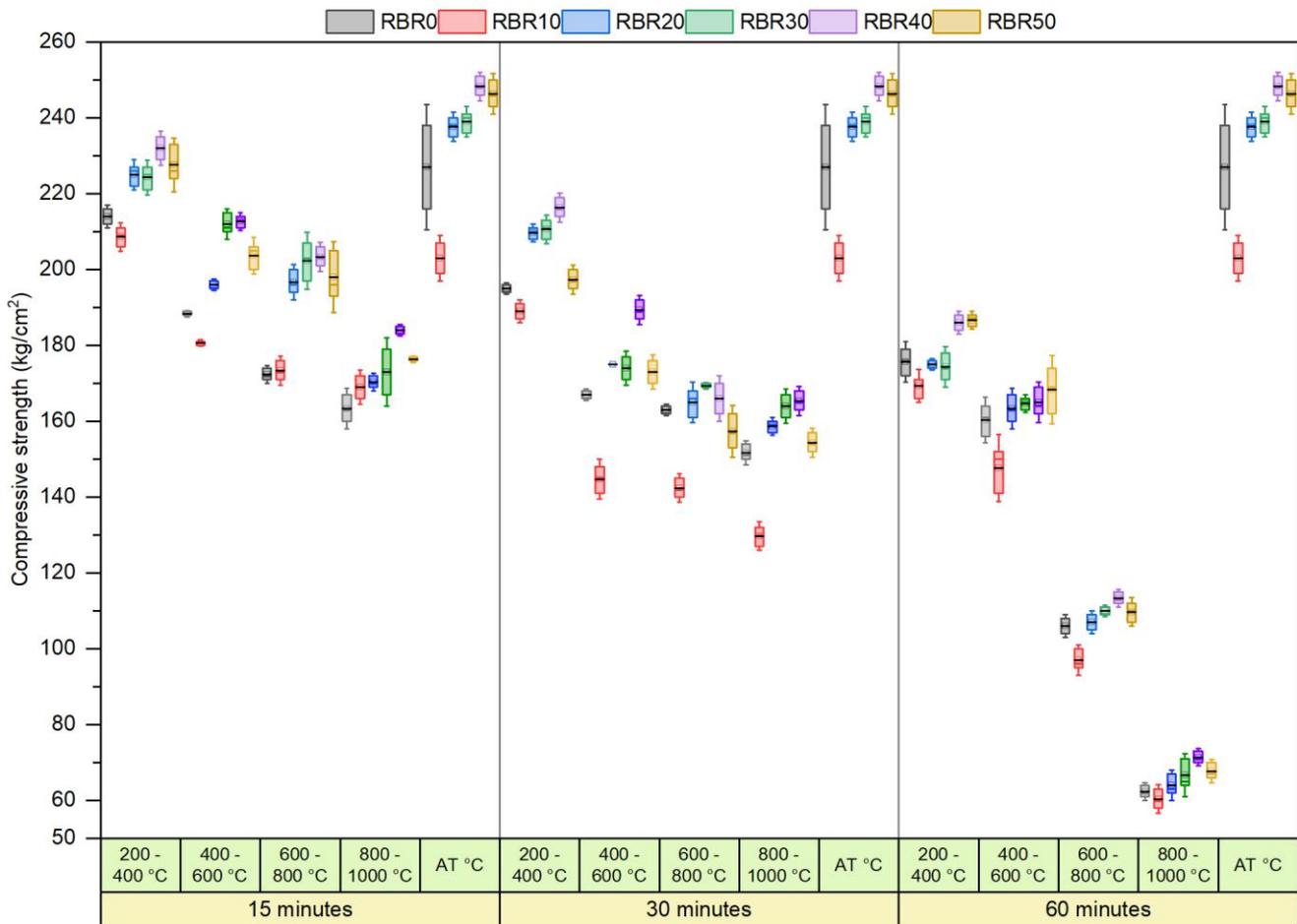


Figure 6. Box plots of compressive strength at 28 days, by treatment, temperature and time

#### 4. CONCLUSIONS

This research presents the results of an experimental study conducted to evaluate the influence of refractory brick waste as a replacement of fine aggregate for the production of structural concrete against exposure to high temperatures, showing relevant findings on the compressive strength of concrete against temperature ranges and exposure times. It also promotes the generation of research due to the lack of knowledge of this type of sustainable studies applied in Peru. Based on the results obtained in this study, the following conclusions can be drawn:

Workability and fresh unit weight were affected up to 50 % replacement of the refractory material. It is recommended that a superplasticizing admixture be used in future studies to improve workability so that it does not become a limiting factor in the application of the study.

It is concluded that from 20, 30 and 40 % RBR in concrete exposed at 800 – 1 000 °C had significant increases on compressive strength at 28 days. However, using doses of 10 and 50 % RBR, its compressive strength decreased below that of the control sample under room temperature as well as exposure to different temperatures.

As findings, it was observed that the low RBR content (up to 40 %) constitutes a technically viable alternative in the construction industry. In addition, the use of RBR has a sustainable impact to the extent that refractory brick waste is reused and overexploitation of fine aggregates from Peruvian quarries is avoided.

#### REFERENCES

- Abbu, M., Al-Attar, A. A., Alrahman, S. A., and Al-Gburi, M. (2022). The mechanical properties of lightweight (volcanic pumice) concrete containing fibers with exposure to high temperatures. *Journal of the Mechanical Behavior of Materials*, 32(1), 20220249. <https://doi.org/10.1515/jmbm-2022-0249>
- Aboutaleb, D., Safi, B., Crahour, K., and Belald, A. (2017). Use of refractory bricks as sand replacement in self-compacting mortar. *Cogent Engineering*, 4(1), 1-8. <https://doi.org/10.1080/23311916.2017.1360235>
- Ahn, Y., Jang, J., and Lee, H. (2016). Mechanical properties of lightweight concrete made with coal ashes after exposure to elevated temperatures. *Cement and Concrete Composites*, 72, 27-38. <https://doi.org/10.1016/j.cemconcomp.2016.05.028>
- Akbar, A., Garivani, S., Shahmar, A., and Heshmati, M. (2020). Structural investigation of the collapse of the 16-story Plasco building due to fire. *Structural Design*

- of Tall and Special Buildings, 30(1), 1-20. <https://doi.org/10.1002/tal.1815>
- American Concrete Institute 211.1. (1993). Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. In A. C. 211.1, *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*. United States: American Concrete Institute.
- Arioz, O. (2007). Effects of elevated temperatures on properties of concrete. *Fire Safety Journal*, 42(8), 516-522. <https://doi.org/10.1016/j.firesaf.2007.01.003>
- ASTM C136. (2001). *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*. West Conshohocken: ASTM Internacional.
- ASTM C138/C138M. (2014). *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*. West Conshohocken, PA: ASTM International.
- ASTM C143/C143M. (2012). *Standard Test Method for Slump of Hydraulic-Cement Concrete*. West Conshohocken, PA: ASTM International.
- ASTM C150. (2012). Cement, Standard Specification for Portland. In A. C150, *Standard Specification for Portland Cement*. West Conshohocken: ASTM International.
- ASTM C192M. (2015). *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*. West Conshohocken: ASTM International.
- ASTM C39M. (2014). *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. West Conshohocken, PA: ASTM International.
- Baradaran, A., and Nematzadeh, M. (2017). The effect of elevated temperatures on the mechanical properties of concrete with fine recycled refractory brick aggregate and aluminate cement. *Construction and Building Materials*, 147, 865-875. <https://doi.org/10.1016/j.conbuildmat.2017.04.138>
- Bareiro, W., Silva, F., and Dominguez, E. (2020). Thermo-mechanical behavior of stainless steel fiber reinforced refractory. *Construction and Building Materials*, 240, 1-16. <https://doi.org/10.1016/j.conbuildmat.2019.117881>
- Bo, W., Jie, G., Lu, Z., and Luzhe, W. (2020). Experimental study on fire resistance of full-scale earthquake damaged reinforced concrete columns. *Journal of Building Structures*, 41(11), 1-15. <https://doi.org/10.14006/j.jzjgxb.2019.0473>
- Calmeiro, D. S., and Correia, R. J. (2014). Residual mechanical properties of calcareous and granite aggregate concretes after fire. *Magazine of Concrete Research*, 66(16), 1400005. <https://doi.org/10.1680/mac.14.00005>
- Carrizo, L., Villagrán, Y., Pittori, A., and Zega, C. (2020). Incidencia de polvo calizo, puzolana natural y escoria en hormigones expuestos a altas temperaturas. *Ingenio Tecnológico*, 2, 1-12. Retrieved from <https://ingenio.frlp.utn.edu.ar/index.php/ingenio/articulo/view/22>
- Cruz, R., Zapata, L., Quintero, L., and Herrera, J. (2015). Physical and mechanical characterization of concrete exposed to elevated temperatures by using ultrasonic pulse velocity. *Revista Facultad de Ingeniería Universidad de Antioquia*, (75), 118-129. <https://doi.org/10.17533/udea.redin.n75a12>
- Da Silva, F., Silva, M., and Munaiar, J. (2020). Simulação termomecânica de prismas com blocos de concreto em situação de incêndio. *Revista Materia*, 25(1), e-12561. <https://doi.org/10.1590/s1517-707620200001.0886>
- Feijoo, B. A., Tobón, J. I., and Restrepo-Baena, O. J. (2021). Substitution of aggregates by waste foundry sand: effects on physical properties of mortars. *Materiales De Construcción*, 71(343), e251. <https://doi.org/10.3989/mc.2021.10320>
- Flores, V., Jiménez, V., and Pérez, A. (2018). Influencia de la incorporación de vidrio triturado en las propiedades y el comportamiento a alta temperatura de morteros de cemento. *Boletín de la Sociedad Española de Cerámica y Vidrio*, 57(6), 257-265. <https://doi.org/10.1016/j.bsecv.2018.03.001>
- Galvez, J., Barzola, C., Gomez, R., and Torre, A. (2020). Estudio de las diatomitas de Ica como materia prima en la fabricación de áridos artificiales de arcilla para su uso como agregados ligeros en mezclas de hormigón diseñados en base a las exigencias de la NTP y ASTM. *Investigación & Desarrollo*, 20(1), 113-134. <https://doi.org/10.23881/idupbo.020.1-9i>
- Hachemi, S., Khattab, M., and Benzetta, H. (2023). Enhancing the performance of concrete after exposure to high temperature by coarse and fine waste fire brick: An experimental study. *Construction and Building Materials*, 368, 130356. <https://doi.org/10.1016/j.conbuildmat.2023.130356>
- Han, L., Zhou, K., Tan, Q., and Song, T. (2020). Performance of steel reinforced concrete columns after exposure to fire. *Engineering Structures*, 211, 1-12. <https://doi.org/10.1016/j.engstruct.2020.110421>
- Humaish, A., Essa, A., and Edan, A. (2020). Fire resistance of selected construction. *AIP Conference Proceedings*, 2213(1), 1-10. <https://doi.org/10.1063/5.0000053>
- Khattab, M., and Hachemi, S. (2021). Performance of recycled aggregate concrete made with waste refractory brick. *International Journal of Engineering Research in Africa*, 57, 99 - 113. <https://doi.org/10.4028/www.scientific.net/JERA.57.9>
- Liu, Y., Jin, B., Huo, J., and Li, Z. (2018). Effect of microstructure evolution on mechanical behaviour of concrete after high temperatures. *Magazine of Concrete Research*, 70(15), 770-784. <https://doi.org/10.1680/jmacr.17.00197>
- Ma, Q., Lin, Z., Guo, R., Yan, F., He, K., Zhao, Z., . . . Bai, Y. (2018). Performance of modified lightweight aggregate concrete after exposure to high temperatures. *Magazine of Concrete Research*, 70(24), 1243-1255. <https://doi.org/10.1680/jmacr.18.00033>
- Memon, S., Shah, S., Khushnood, R., and Baloch, W. (2019). Durability of sustainable concrete subjected to elevated temperature – A review. *Construction and Building Materials*, 199, 435-455. <https://doi.org/10.1016/j.conbuildmat.2018.12.040>

- Molay, T., Lery, M., Fidele, T., Franck, H., and Bienvenu, N. (2019). Mechanical and physical performances of concretes made from crushed sands of different geological nature subjected to high temperatures. *Engineering Science and Technology, an International Journal*, 22, 1116-1124. <https://doi.org/10.1016/j.jestch.2019.02.007>
- Moreno, L., Ospina, M., and Rodríguez, K. (2019). Resistencia de concreto con agregado de bloque de arcilla triturado como reemplazo de agregado grueso. *Ingeniare*, 27(4), 635-642. <https://doi.org/10.4067/S0718-33052019000400635>
- Sangi-Gonçalves, H., Penteado-Dias, D., and Castillo-Lara, R. (2022). Replacement of hydrated lime by lime mud-residue from the cellulose industry in multiple-use mortars production. *Materiales De Construcción*, 72(347), e292. <https://doi.org/10.3989/mc.2022.17721>
- Sarhat, S. R., and Sherwood, E. G. (2013). Residual mechanical response of recycled aggregate concrete after exposure to elevated temperatures. *Journal of Materials in Civil Engineering*, 25(11), 1721 - 1730. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0000719](https://doi.org/10.1061/(ASCE)MT.1943-5533.0000719)
- Sevim, O., Alakara, E. H., and Guzelkucuk, S. (2023). Fresh and Hardened Properties of Cementitious Composites Incorporating Firebrick Powder from Construction and Demolition Waste. *Buildings*, 13(1), 45. <https://doi.org/10.3390/buildings13010045>
- Shirani, K., Reisi, M., and Savadkoobi, M. S. (2021). Eco-friendly High-Strength Refractory Concrete Containing Calcium Alumina Cement by Reusing Granite Waste as Aggregate. *International Journal of Concrete Structures and Materials*, 15(48). <https://doi.org/10.1186/s40069-021-00483-8>
- Shui-Jun, Y., Peng-Fei, Z., Xiao-Fang, Y., Hong, Z., and Xiao-Li, C. (2013). Refractory performance study on foamed concrete and concrete. *3rd International Conference on Civil Engineering, Architecture and Building Materials, CEABM 2013*. Jiaozuo: Applied Mechanics and Materials. <https://doi.org/10.4028/www.scientific.net/AMM.357-360.1034>
- Sobia, A., Azmi, I., Hamidah, M., and Rafeeqi, S. (2015). Elevated temperature resistance of ultra-high-performance fibre-reinforced cementitious composites. *Magazine of Concrete Research*, 67(17), 923-937. <https://doi.org/10.1680/mac.14.00134>
- Tufail, M., Shahzada, K., Gencturk, B., and Wei, J. (2017). Effect of Elevated Temperature on Mechanical Properties of Limestone, Quartzite and Granite Concrete. *International Journal of Concrete Structures and Materials*, 11(1), 17-28. <https://doi.org/10.1007/s40069-016-0175-2>
- Uysal, H., Demirboğa, R., Şahin, R., and Gül, R. (2004). The effects of different cement dosages, slumps, and pumice aggregate ratios on the thermal conductivity and density of concrete. *Cement and Concrete Research*, 34(5), 845-848. <https://doi.org/10.1016/j.cemconres.2003.09.018>
- Varona, F., Baeza, F., and Iborra, S. (2018). Estudio de las propiedades mecánicas residuales de hormigones expuestos a altas temperaturas. *Hormigón y Acero*, 69(286), 235-241. <https://doi.org/10.1016/j.hya.2017.04.004>
- Zeghad, M., Mitterpach, J., Safi, B., Amrane, and Saidi, M. (2017). Reuse of Refractory Brick Wastes (RBW) as a Supplementary Cementitious Material in a Concrete. *Periodica Polytechnica Civil Engineering*, 61(1), 75-80. <https://doi.org/10.3311/ppci.8194>

## BIOGRAPHIES



**Jhan Brinner, Bereche Bello**, Civil Engineer by the Universidad Señor de Sipan, with experience in state works and municipalities of the Lambayeque region. Assistant supervision of infrastructure works such as schools, construction of roads and sidewalks, quality of concrete on site.



**Juan Martín, García Chumacero**, Civil Engineer from the Universidad Señor de Sipan, studying a Master's Degree in Geology at the Universidad Nacional Mayor de San Marcos, Lima, Peru. Engineer dedicated to the area of research as a consultant and researcher in different branches of civil engineering such as concrete technology, roads and soil and slope stability, seismic analysis of structures among other areas, experience in writing research reports, scientific and review articles, contribution as a reviewer of a scientific article of the Journal Faculty of Engineering-University of Antioquia and Archives of Civil and Mechanical Engineering. Experience in supervision of educational infrastructure works and real estate projects at national level.

