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# Effect of Corn Stover Ash Reinforced with Cabuya Fiber on the Mechanical Properties of Concrete

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## Abstract

Currently, organic wastes are an environmental problem generating pollution, bad odors and accumulation of residues in northern Peru, among these products are corn stover and cabuya, predominant materials in the area. Therefore, this research focuses on determining the effect of optimum temperature and optimum percentage of corn stover ash (CSA) reinforced with different proportions of cabuya fiber (CF) on the mechanical properties of concrete. Two conventional designs of standard concrete called A and B (21 and 28 MPa) were made, to these designs were added percentages of CSA in 7%, 10%, 12% and 15% by substitution of the weight of cement to determine the optimum percentage, which was reinforced with percentages of cabuya fiber in 0.5%, 1%, 1.5% and 2% in volume of the concrete. The results showed that the optimum mix was A/B+7CSA, evidencing an improvement in compressive strength of 2.7% as opposed to the optimum CSA +CF hybrid mix, where it was observed that its mechanical properties of compressive strength, tensile strength, flexural strength and static modulus of elasticity decreased to 15.8%, 11.30%, 5.14% and 10.5%, respectively. It is concluded that corn stover ash reinforced with cabuya fiber does not positively influence the mechanical properties of concrete; however, it is an environmentally sustainable alternative to be used in non-structural concrete.

**Keywords:** corn stover ash; cabuya fiber; compressive strength; tensile.

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## Introduction

The most demanded composite material in the construction industry is concrete; however, it requires a compound such as cement, which is produced in the world in approximately 1.5 million tons, and it is estimated that consumption may increase up to 225% by the year 2050 (Muthukrishnan et al., 2020; Saleh et al., 2020; Lakshmi et al., 2020). In addition, cement production accounts for about 7% of the carbon dioxide generated, causing high environmental pollution; for this reason, the use of industrial waste with higher pozzolanic capacity is emerging as an alternative to improve the properties of concrete (Pinheiro et al., 2020; Rendón et al., 2019).

On the other hand, it follows that corn is a crop that is widely planted around the world, so there is a great opportunity for the use of corn stover ash (CSA) as a substitute for concrete. Other materials such as biochar for use in concrete require a combustion temperature of 500°C to 600°C for 1 hour, which is lower than the temperature required to produce cement clinker at 1400 °C (Shakouri et al., 2020a; Wang et al., 2020). Mostly corn stover ash is burned at a temperature of 500 °C showing a higher pozzolanic activity, also a reduction of Fratini, $C_aO$ of 93.2% and a Chapelle activity of 856.3 mg/g (Shazim et al., 2020).

In accordance with, (Lei et al., 2020) demonstrated that CSA is an effective way to solve environmental problems, being also a feasible input to be used as a sustainable and recyclable material in reinforcement to produce fiber cement and other concretes. Indeed, (Memon et al., 2020; Muhammad et al., 2018), showed that the calcination temperature of corn stover does not affect its pozzolanic activity; however, the incorporation of ash under optimum conditions improves the mechanical properties and durability of the cement.

In this sense, according to (Odeyemi et al., 2020), showed that the addition of 5% CSA improved the compressive strength up to 6.64% compared to the standard concrete. Meanwhile, ( Aksog˘an et al., 2015) mentioned that the compressive strength at 7 and 28 days, adding 10% and 15% corn ash reduced this property up to 2.4%

(Mahmoud et al., 2020), analyzed that a 5% substitution of untreated corncob ash improved the compressive and tensile strength by 8.45% and 7.5%, respectively, compared to the standard concrete. Likewise, (Shakouri et al., 2021b) state that the substitution by weight of cement in 5% and 20% CSA pretreated with chloride solution, shows that 5% CSA improves its tensile and flexural strength up to 5.51%, and with 20% CSA significantly decreases its mechanical properties of concrete.

Considering, another attractive input for concrete manufacturing is cabuya fiber (CF), due to its mechanical characteristics of good resistance capacity, low density, low specific weight and environmentally sustainable (Purwanto E. et al., 2019a). As stated by, (Sooksaen et al., 2018), mention that short fibers can be used as internal reinforcement of concrete, mainly influencing its workability in the fiber-cement matrix, and on the other hand giving it good compressive and tensile strength. It should be noted that the fibers obtained are the product of regrown plants and renewable raw materials, with peculiar and positive characteristics (Anania & D'agata, 2019).

According to literature with cabuya fiber, (Mylsamy & Rajendran, 2021), stated that CF in doses of 0.25%, 0.5% and 0.75% with size variations of 30, 70 and 100 mm in length, it was observed that with 0.25% of CF and with the dimension of 30 mm in length, it manages to increase its compressive and tensile strength by up to 15% and 10%. Other studies, such as (Sakuri et al., 2020), showed that addition of 0.3% CF improves its flexural strength by 31%. (Mohamed et al., 2020), observed an increase in both the bending stress and bending modulus of the hybrid specimens. Similar behavior, is mentioned by (Mohamed et al., 2020) where they added doses of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% CF by volume, stating that adding 0.3% prudently improves flexural and tensile strength by up to 6.5% and 3.0%, respectively. (Oktarina et al., 2020) showed that 0.4% CF by volume of concrete increases its compressive and tensile strength by 24.31% and 77.12%, respectively.

According to, (Pratyush & Rahul, 2018), Cabuya fibers were added at concentrations of 0.5% and 1%, showing that the fiber at 0.5% achieves tensile and flexural strengths of up to 65% and 35%, respectively, indicating that the greater the length of 40 mm, the lower the fiber strength as it states (Juarez et al., 2009). Therefore, (Purwanto E. et al., 2019b), added doses of 1.0%, 2.0%, 3.0% and 4.0% CF with respect to the volume of concrete and with lengths of 10, 15, 20 and 25 mm respectively, showing that from 1% to 3% its tensile strength decreased by 25%. Regarding the static modulus of elasticity test, there is no study between these two materials as a hybrid mixture of optimum CSA + CF in concrete, however, it is necessary to perform an exhaustive analysis on the static modulus of elasticity with the hybrid mixture of optimum CSA reinforced with CF.

There is a diversity of scientific research related to CSA and, on the other hand, to CF applied to structural concrete. However, there are no related studies on the hybrid mixture of these two materials, motivating the authors to investigate about it. In this context, a novel research work is presented that studied the effect of corn stover ash reinforced with cabuya fiber using local materials from the northern zone of Peru on the mechanical properties of concrete; the parameters established were the optimum temperature of the ash based on the application of a statistical method of the DUNNET test, the determination of the optimum content of CSA. In this way, we seek to insert these organic materials to the construction industry for the use of structural or non-structural concrete, mitigating in turn the reduction of waste generated by the local population with a sustainable approach to the accumulation of waste.

## Materials and Methodology

### Aggregates

Granular materials from the Lambayeque region located in Peru were used, the coarse and fine aggregates were characterized for the design of mixtures, the physical characterization of the aggregates is shown in **Table 1**. Particles passing through a 4.75 mm sieve and hanging on a 0.075 mm sieve are known as fine aggregate. Particles hanging on the 4.75 mm sieve are known as coarse aggregate (Parashar & Gupta, 2021).

Table 1

Physical characteristics of natural aggregates

| Properties | Unit | Fine aggregate | Coarse aggregate | Standards |
|---|---|---|---|---|
| Fineness modulus | - | 2.79 | 7.06 | ASTM C33 |
| Nominal maximum size | Inches | - | 1/2 | ASTM C33 |
| Loose unit weight | $kg/m^3$ | 1.51 | 1.26 | ASTM C29 |
| Compacted unit weight | $kg/m^3$ | 1.62 | 1.48 | ASTM C29 |
| Specific gravity | $g/cm^3$ | 2.68 | 2.73 | ASTM C127-128 |
| Apparent specific weight | $g/cm^3$ | 2.81 | 2.79 | ASTM C127-128 |
| Moisture content | % | 1.04 | 0.2 | ASTM C566 |
| Absorption | % | 1.74 | 0.86 | ASTM C127-128 |

### Portland Cement Type I

The cement used is Portland cement type I (42.5kg) from southern Peru. The predominant characteristics of this cementitious material are detailed in the technical specifications under ASTM C150-12 in **Table 2**.

Table 2

Chemical, physical and mechanical characteristics of Portland Type I cement

| Named elements | Unit | Quantity | Specifications |
|---|---|---|---|
| $M_gO$ | % | 2.2 | 6.0 maximum |
| $SO_3$ | % | 2.7 | 3.0 maximum |
| Loss on ignition | % | 3.1 | 3.5 maximum |
| Insoluble residue | % | 0.7 | 1.5 maximum |
| Specific gravity | $g/cm^3$ | 3.15 | Not specified |
| Design 1 | MPa | - | 21 minimum |
| Design 2 | MPa | - | 28 minimum |

### Characteristics of corn stover ash

Corn stover is a predominant residue in the area of San Ignacio, Cajamarca. The research is based on the use of corn stover ash left at different temperatures (400, 450, 500, 550 °C) subjected in an artisan oven for 1 hour of continuous burning, the parameters evaluated are carried out under considerations of the ASTM C618 standard, this material in its original form and converted into ash are shown in Fig. 1. The corn stover ash was obtained by controlled temperature in an artisan oven ( Aksog˘an et al., 2015).

The corn stover incineration process was carried out at different temperatures that were analyzed during 1 hour of burning with a variation between ±10°C, allowing it to cool for 24 hours. Approximately 1 ton of corn stover produces between 100 and 120 kilograms of ash. The ash was crushed in the Angeles machine to obtain a gradation similar to cement; this material was passed through the N°100 mesh (0.150 mm) and retained in the N°200 mesh (0.075 mm), respectively, for its subsequent use in the concrete. The dosages taken into account in this study are based on (Shakouri et al., 2021b; Aksog˘an et al., 2015; Odeyemi et al., 2020), due to studies mentioning that 5% CSA is the optimum at an optimum burning temperature of approximately 500 °C; therefore, a desirable range between 5 to 15% is proposed for the analysis of the present study.

This material was subjected to various physical tests, which are shown in Table 3.

Table 3

Physical properties of corn stover ashes

| Physical Properties | Unit | Quantity | Standards |
|---|---|---|---|
| Density | g/cm$^3$ | 2.19 | (ASTM C188) |
| Pozzolanic | % | 74.87 | (ASTM C009) |
| Fineness | % | 34.29 | (ASTM C430) |
| Humidity | % | 1.1 | (ASTM C311) |

## Characteristics of cabuya fiber

Cabuya (*Furcraea cabuya*), belonging to the botanical family Asparagaceae, is a fiber plant used for the reinforcement of composite materials in concrete. The material was extracted from the highlands of the town of San Ignacio, Cajamarca, where it lives and grows. The fiber process was considered a standard size of 50 mm long and an average diameter of 0.14 mm, a specific weight of 1.49 g/cm$^3$ under ASTM D792 considerations. This material was pre-treated with water and lime to increase the surface roughness and allow better adhesion with the concrete components. This pretreatment for drying was left for one week in conditions of 27 °C at room temperature. The dosages of cabuya fiber and length size were considered according to studies such as (Mylsamy & Rajendran, 2021; Sakuri et al., 2020; Purwanto E. et al., 2019a), in the present study, a range of 0.5 to 2% with a size in length of 50 mm was proposed, with the pretreatment considered. The different materials underwent different processes from burning corn stover, corn stover ash, extraction of cabuya leaves and cabuya fiber as shown in Fig. 1.

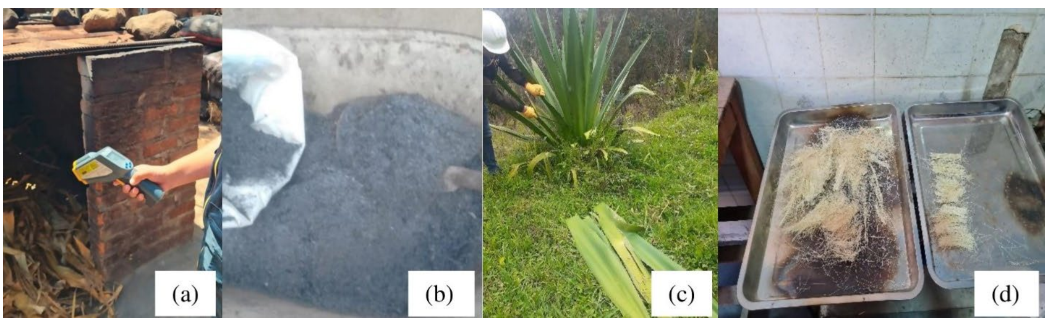



Fig. 1

(a) corn stubble,
(b) corn stubble ash,
(c) cabuya leaves,
(d) cabuya fiber

## Choice of optimum CSA temperature

To obtain the optimum CSA temperature, the DUNNET mean comparison test was considered, a control group or so-called standard concrete without treatment was compared with all the other samples, so it should only be used when it has a control group. It was decided to consider ash proportions of the temperatures analyzed at 400, 450, 500 and 550 °C, labeled as follows: T400°C, T450°C, T500°C, T550°C. After one day, each sample was taken and labeled in hermetic bags for its mechanical evaluation after 28 days of rupture and curing under immersion in potable water according to ASTM C192 criteria. The design mix was made for 21 MPa (untreated standard concrete) and this sample was combined with a random dose taken by the researcher of 7% CSA replacing the weight of the cement, for evaluation by subjecting them to different heat conditions.

## Design of experimental mixtures

The mix design was carried out according to the ACI.211-93 method for a standard sample, then the same methodology was applied for samples with treatment. For the development of this research, tests were developed to determine the physical properties of the aggregates, the optimum burning temperature of corn stover ash CSA, then the designs of conventional mixes f'c: 21 MPa and 28 MPa denominated with the letter A and B, no superplasticizer was used, designs A and B had a water-cement ratio of 0.53 and 0.48, respectively. Substituting corn stover ash 7%, 10%, 12% and 15% in weight of cement incorporating cabuya fiber 0.5%, 1%, 1.5% and 2% depending on the volume of concrete were elaborated. Finally, the optimum percentages of corn stover ash and cabuya fiber were determined. A total of 720 specimens were made between standard concrete units and the improvement with CSA and reinforced with the optimum of CSA + CF, all the samples were evaluated by laboratory tests. The specimens were labeled, demolded the following day and subjected to a curing process under water immersion according to ASTM C192, and subsequently evaluated by mechanical tests performed at 7, 14 and 28 days, respectively. The proportioning is shown in Table 4 for the respective combinations and standard concretes of the present study. In addition, a process flow was prepared to detail the study, divided into stages, as shown in Fig. 2.

Table 4

Quantity of material per cubic meter for each sample with and without treatment

| Experimental designs | Type I cement (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Water (Lts) | CSA (kg/m$^3$) | CF (kg/m$^3$) |
|---|---|---|---|---|---|---|
| A | 151.8 | 291.98 | 275.68 | 81.24 | Control | Control |
| A+7CSA | 132.52 | 291.8 | 275.51 | 81.91 | 9.98 | 0 |
| A+10CSA | 128.82 | 287.89 | 271.82 | 82.20 | 14.31 | 0 |
| A+12CSA | 125.95 | 285.81 | 269.86 | 82.17 | 17.18 | 0 |
| A+15CSA | 122.74 | 281.02 | 265.33 | 82.79 | 21.66 | 0 |
| A+7CSA+0.5CF | 133.86 | 280.75 | 265.29 | 80.94 | 10.08 | 3.39 |
| A+7CSA+1CF | 134.02 | 281.30 | 265.44 | 81.01 | 10.11 | 6.34 |
| A+7CSA+1.5CF | 134.44 | 279.96 | 264.54 | 81.26 | 10.12 | 10.17 |
| A+7CSA+2CF | 135.03 | 279.17 | 263.79 | 81.59 | 10.16 | 13.53 |
| B | 169.55 | 275.02 | 259.87 | 81.87 | Control | Control |
| B+7CSA | 154.96 | 269.79 | 254.93 | 80.45 | 11.66 | 0 |
| B+10CSA | 149.96 | 266.16 | 251.51 | 80.40 | 16.66 | 0 |
| B+12CSA | 147.27 | 162.88 | 248.40 | 80.70 | 20.08 | 0 |
| B+15CSA | 143.50 | 257.48 | 243.30 | 81.30 | 25.32 | 0 |
| B+7CSA+0.5CF | 155.64 | 268.94 | 254.13 | 80.78 | 11.72 | 3.39 |
| B+7CSA+1CF | 155.88 | 268.32 | 254.11 | 80.62 | 11.74 | 6.79 |
| B+7CSA+1.5CF | 156.32 | 268.10 | 253.34 | 81.10 | 11.77 | 10.17 |
| B+7CSA+2CF | 157.00 | 267.26 | 252.54 | 81.43 | 11.82 | 13.53 |

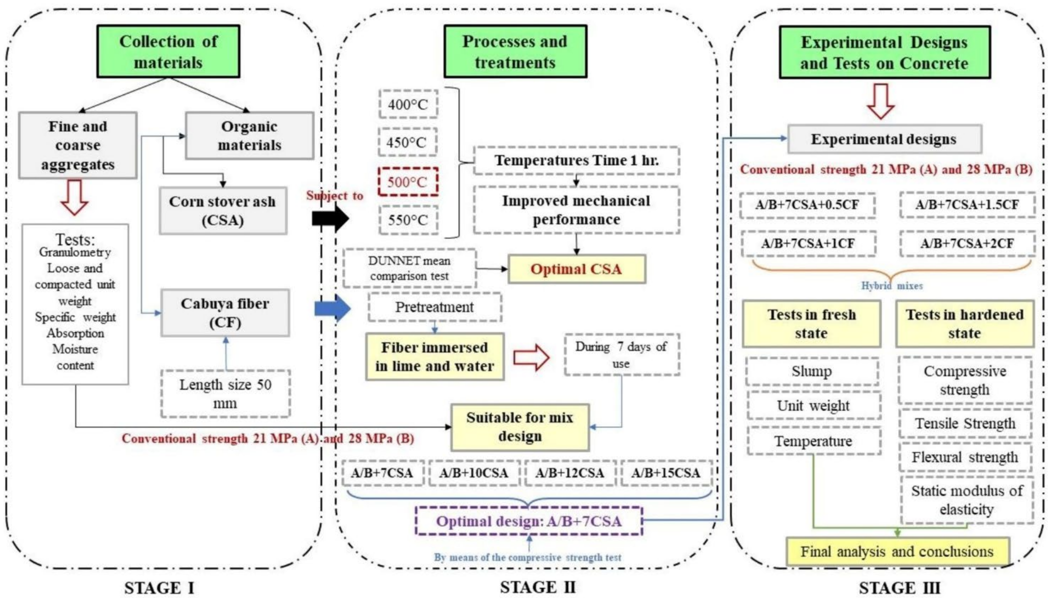



Fig. 2

Process flow methodology

# Results and Discussion

## Compressive strength test to obtain optimum temperature

As shown in Table 5, according to the DUNNET mean comparison test, different numerical values are shown for the compressive strength in MPa at 28 days of rupture of concrete specimens containing CSA with different mineralogical composition under influential parameters such as varying temperature. The mechanical strength values at 28 days of rupture are observed, being predominant the specimen subjected to a temperature of 500 °C, with an increase of 3.13% with respect to the other specimens subjected to different temperatures, and even an increase with respect to the standard concrete specimen without treatment.

Table 5

DUNNET mean comparison test (0.05) to determine the optimal CSA temperature vs compressive strength

| Treatments | | N | Subset | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 |
| Untreated standard concrete | 7 d | 3 | | 16.23 | | | |
| | 14 d | 3 | | | 18.31 | | |
| | 28 d | 3 | | | | 21.55 | |
| T400°C | 7 d | 3 | 14.51 | | | | |
| | 14 d | 3 | | | 18.43 | | |
| | 28 d | 3 | | | | 20.62 | |
| T450°C | 7 d | 3 | 14.91 | | | | |
| | 14 d | 3 | | | 18.40 | | |
| | 28 d | 3 | | | | 21.34 | |
| T500°C | 7 d | 3 | 15.49 | | | | |
| | 14 d | 3 | | | 18.77 | | |
| | 28 d | 3 | | | | | 22.16 |
| T550°C | 7 d | 3 | 15.45 | | | | |
| | 14 d | 3 | | | 18.65 | | |
| | 28 d | 3 | | | | | 21.83 |

Note: N, refers to the concrete specimen with international standard dimensions; d, refers to the day of rupture.

The temperatures considered in the study were based on scientific literature where different optimum temperatures are presented. It should be noted that this study proposes an analysis of four temperatures to choose the one with the best mechanical behavior, as shown in Table 5. The results of the compressive strength with the optimum burned CSA ash are given in the treatments 500 °C and 550 °C obtained values of 22.16 MPa and 21.83 MPa respectively, data that corroborate with literature according to (Shazim et al., 2020), who determined that the optimum combustion temperature for corn stalk ash was 500 °C, obtaining 96.8 % of pozzolanic activity; likewise according to (Mahmoud et al.,

2020) y (Wang et al., 2020) determined that the combustion temperature for corn stover is between 500 °C and 600 °C.

For the analysis of the results, the analysis of variance was used, which yielded the significance values P-value (0.00), indicating that the treatments under study had an influence on the compression test for resistance 21 MPa. Likewise, the values obtained in the reliability tests, coefficient of variability (CV) was 1.29 and the coefficient of determination ($R^2$) was 99.43, which are within the ranges for laboratory studies, so the data are considered reliable.

## Fresh state in experimental samples

As shown in Table 6, the tests considered as slump, unit weight and temperature for both treated and untreated samples, under the conditions of the international standards ASTM C143M, ASTM C138M and ASTM C1064M, respectively. It is observed that the slump results, unlike the conventional samples A and B, increase, evidencing that the workability decreases, even with the hybrid combination of CSAoptimal + CF, this workability is more affected due to the fact that when adding these materials they absorb water in a certain way in the design, on the other hand, the chemical behavior generated by the inclusion of this ash, mainly affects its workability. This is in agreement with the work of (Wongsa et al., 2020) on the characteristics of fly ash-based geopolymer pastes reinforced with natural fiber (0, 0.3, 0.5, 0.7 and 1.0 wt.% cotton fiber), which showed that geopolymer pastes reinforced with high cotton fiber contents exhibited low workability. Workability decreased as the proportion of bagasse ash in the mixture increased (Parashar & Gupta, 2021).

The unit weight test for both designs shows with the CSA a reduction in value because the material being substituted for the cement shows a lower specific gravity than the cement. However, this changes when CF is added being a higher value than the conventional A and B samples, showing to be a denser material with this component. Finally, the temperature test does not show to be significant in the taking of this value showing no variance of 1 °C, compared to the conventional samples, not affecting the conditions of the concrete in fresh state. The denser concrete is stronger and has less voids and porosity, when compared to the standard concrete, the coconut fiber with a dosage of 2.0 percent had the highest density (Ahmad et al., 2022).

Table 6

Slump, unit weight and temperature tests for each sample with and without treatment

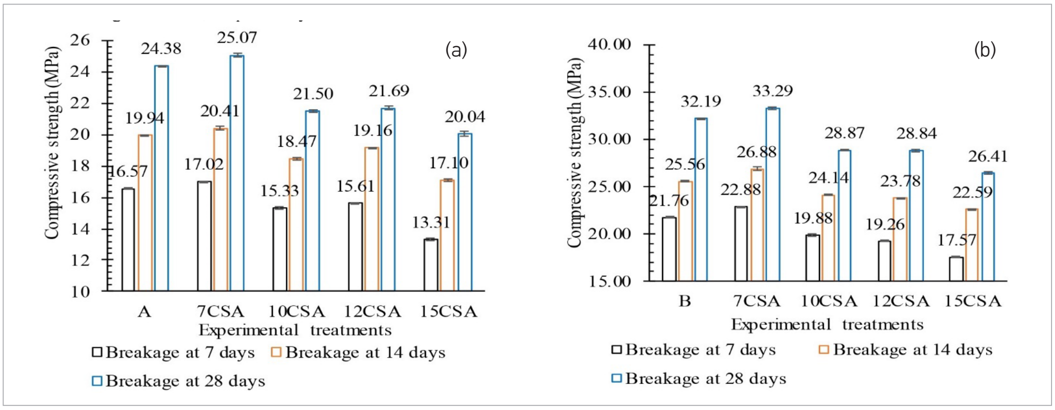
| Experimental designs | Slump (Inches) | Unit weight (kg/m$^3$) | Concrete temperature (°C) |
|---|---|---|---|
| A | 4 | 2468 | 25.2 |
| A+7CSA | 4.1 | 2372 | 25.6 |
| A+10CSA | 4.2 | 2291 | 25.9 |
| A+12CSA | 4.4 | 2214 | 26.1 |
| A+15CSA | 4.45 | 2123 | 25.8 |
| A+7CSA+0.5CF | 4.5 | 2516 | 25.8 |
| A+7CSA+1CF | 4.4 | 2520 | 25.6 |
| A+7CSA+1.5CF | 4.2 | 2564 | 25.3 |
| A+7CSA+2CF | 4.6 | 2612 | 25.5 |
| B | 4 | 2516 | 27.2 |
| B+7CSA | 4.2 | 2396 | 26.2 |
| B+10CSA | 4.3 | 2454 | 26.6 |
| B+12CSA | 4.3 | 2447 | 26.4 |
| B+15CSA | 4.6 | 2363 | 25.9 |
| B+7CSA+0.5CF | 4.2 | 2543 | 26.5 |
| B+7CSA+1CF | 4.5 | 2544 | 26.4 |
| B+7CSA+1.5CF | 4.4 | 2591 | 26.4 |
| B+7CSA+2CF | 4.4 | 2708 | 26.6 |

## Compressive strength applied to optimum design with CSA

As shown in Fig. 3, the behavior of the CSA directly influences this property by improving its resistance, except for using only the lowest dosage proposed, which represents the mixture called A and B corresponding to the 7CSA treatment. This is due to the high pozzolanic value contained in this processed material already converted into ash at its optimum combustion temperature, being significant in the compressive strength of the concrete, proving to be an effective cement substitute for both design A and B, respectively.

Fig. 3

Compressive strength, (a) experimental design A, (b) experimental design B




As shown in Fig. 3, the results of the compressive strength of optimum CSA are shown in MPa, with respect to design A, when substituting 7% cement for CSA, obtaining a result of 25.07 MPa, showing an increase of 2.7% with respect to sample A. On the other hand, in design B, the 7% CSA sample obtained a result of 33.29 MPa, increasing by 4.4%; values that reflect similarity with the literature according to (Odeyemi et al., 2020), who determined that the compressive strength by incorporating 5% ash improved by 6.64% with respect to the standard concrete (17.61 MPa). Likewise, as pointed out by ( Aksog˘an et al., 2015) claim that 10% CRM decreases by 2.4% with respect to the standard concrete sample, thus reducing the compressive strength.

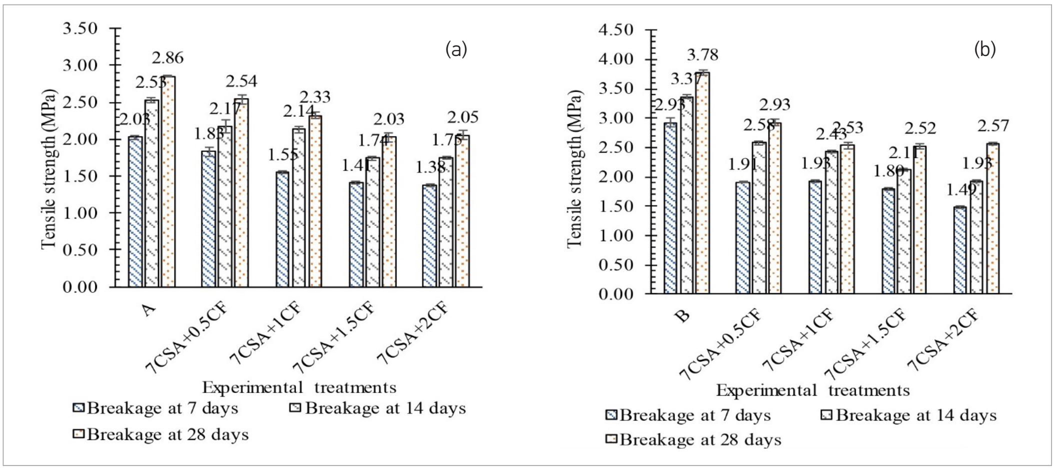
For the analysis of the results, the analysis of variance was used, which yielded the significance values P value (0.00), indicating that the treatments under study influenced the compression test for both design strength A and B, respectively. Likewise, the values obtained in the reliability and coefficient of variability (CV) tests were 0.39 and 0.42, respectively, and the coefficient of determination ($R^2$) of 99.98 and 99.96 are within the ranges for laboratory studies, so the data are reliable.

### Compressive strength applied with optimum design of CSA + various doses of CF

As shown in Fig. 4, the concrete compressive strength results obtained in MPa, it is observed that the behavior is not influential when combining CSA with CF in the hybrid mix, since the CF does not manage to provide the strength that was believed to have, but it does contribute to the reduction of cracks or abrupt breakage in this test performed by ASTM C39 standard.

Fig. 4

Compressive strength with (optimum CSA) + CF, (a) experimental design A, (b) experimental design B




This may be due to the fact that unlike using CSA that provides significant strength with the optimum combination A/B + 7CSA, the inclusion of the hybrid mixture with cabuya fiber reduces its mechanical property, showing that it does not reach a minimum design strength of 21 and 28 MPa.

On the other hand, these results are within the category of non-structural concretes with design strengths of 17.5 MPa and 14 MPa, respectively.

Taking into account (Mylsamy & Rajendran, 2021), the researchers state that the incorporation of 0.25% of fiber with a dimension of 30 mm in length increases its compressive strength up to 15% with respect to the standard concrete; however, in the research, according to the opinion of (Shakouri et al., 2021b) reveals that the inclusion of 20% CSA reduces the strength of the concrete and its optimum ratio was considered to be 5% by weight of cement. The scientific literature differs with certain authors such as (Oktarina et al., 2020) where they claim that 0.4% fiber by volume inclusion increases the compressive strength by 33.40 MPa influencing it by 20.34%; similarly, according to (Juárez et al., 2009), alludes that the optimum fiber length size is 30 mm, as it improves the mechanical properties of concrete, and the high fiber-to-length ratio reduces the strength and increases the deformation of concrete.

For the analysis of the results, the analysis of variance was used, which yielded the significance values P value (0.00), indicating that the treatments under study influenced the compression test for both conventional design A and B, respectively. Likewise, the values obtained in the reliability tests and coefficient of variability (CV) were 0.57 and 0.63 respectively, the coefficient of determination ($R^2$) were 99.94 and 99.92, being within the ranges for laboratory studies, so the data are reliable.

## Tensile strength with optimum design with CSA + various doses of CF

The results presented in MPa, shown in **Fig. 5**, refer to the tensile test under the parameters of ASTM C462. The control designs named A and B, showed that none of the experimental treatments exceeds the tensile strength of standard concrete subjected to 28 days of curing; the samples A/B + CSA + CF show values below the minimum experimental design strength, all these results are statistically similar; likewise, we can observe that the treatments with the lowest values were when CF is included in its different dosages with respect to the volume of concrete.

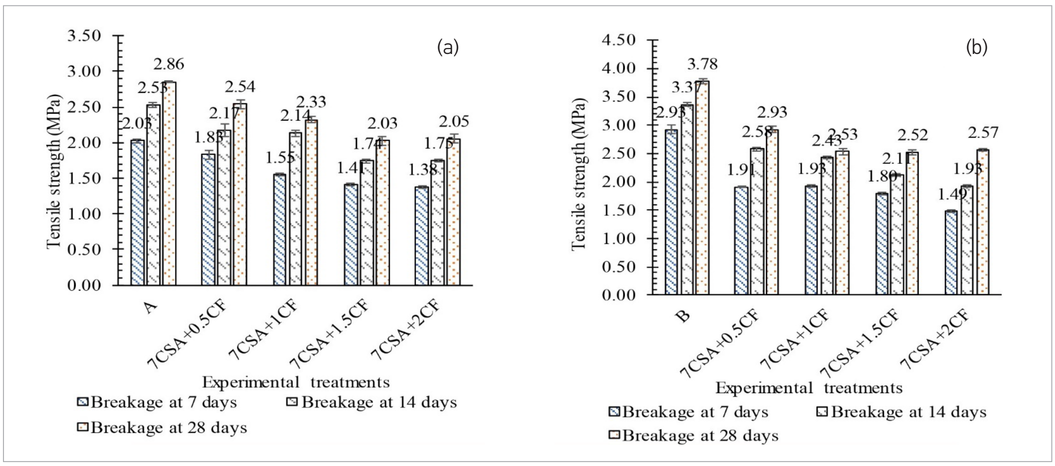



Fig. 5

Tensile strength with (optimum CSA) + CF, (a) experimental design A, (b) experimental design B

This conclusion differs with the argument with the research according to (Pratyush & Rahul, 2018), they argue that adding 0.5% fiber achieved tensile strength up to 65%, other studies (Oktarina et al, 2020) demonstrated with the addition of 0.4% fiber achieved tensile strength up to 77.12% and as pointed out by (Mohamed et al., 2020), indicates that 0.3% improved tensile strength up to 30%.

For the analysis of the results, the analysis of variance was used, which yielded the significance values P value (0.05), indicating that the treatments under study influenced the tensile test for both designs A and B. Likewise, the values obtained in the reliability tests and coefficient of variability (CV) were 2.14 and 1.25, respectively, and the coefficient of determination ($R^2$) were 99.28 and 99.89, which are within the ranges for laboratory studies, so the data are reliable.

### Flexural strength with optimum design with CSA + various doses of CF

As shown in Fig. 6, the results obtained in MPa on flexural strength under ASTM C78 parameters, it was observed that the various hybrid combinations do not show a better performance in this test, which leads to the conclusion that the CF does not show to be influential in increasing the strength, on the contrary, it reduces it by almost 40% approximately. This may be due to the fact that the CF does not have good mechanical properties; in addition, it is added according to the volume of the concrete. It also integrates the possibility that the pretreatment carried out somehow degrades certain properties, after being included in the concrete. On the other hand, the relationship between flexural strength and tensile strength shows that the integration of CSAoptimum + CF, causes the internal structure of the element, the orientation of the fibers or crystals in the material and other aspects to cause low strengths as the CF increases.

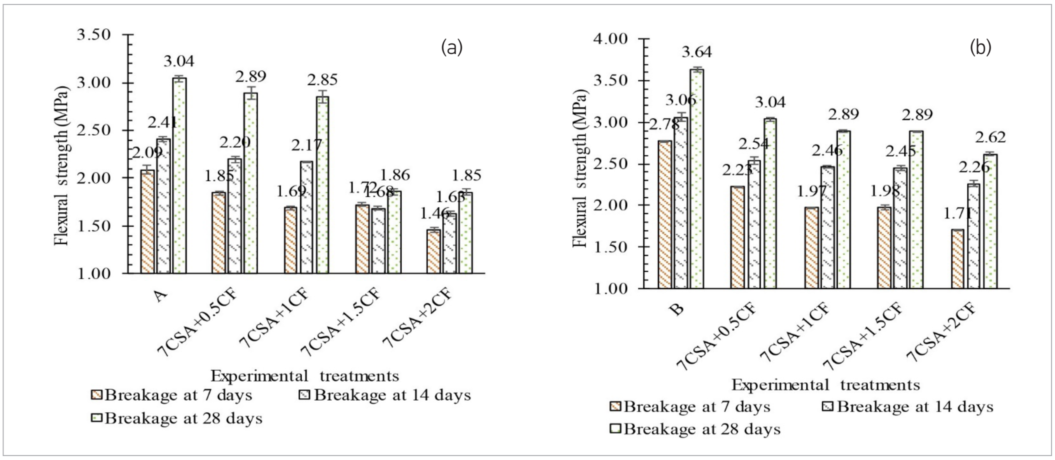



Fig. 6
Flexural strength with (optimum CSA) + CF, (a) experimental design A, (b) experimental design B

In this regard, several authors show discrepancies between their results and those of the current research, for example, according to (Sakuri et al., 2020) mentioned that the optimum proportion is 0.3% of CF for a greater strength gain, as well as the study by (Mohamed et al., 2020). However, states (Mohamed et al., 2020). However, states (Di Bella et al., 2014) that, added 2% CF, the results showed decrease in flexural strength by 10.8%; furthermore, according to (Pratyush & Rahul, 2018), they showed that flexural strength develops better effects with the optimum percentage of 0.5% reaching a strength of up to 35%.

For the analysis of the results, the analysis of variance was used, which yielded the significance values P-value (0.00), indicating that the treatments under study influenced the flexural test for both design strength A and design B. Likewise, the values obtained in the reliability tests, coefficient of variability (CV) were 1.54 and 1.09 respectively, the coefficient of determination ($R^2$) had values of 99.71 and 99.78, being within the ranges for laboratory studies, so the data are reliable.

### Static modulus of elasticity with optimum design with CSA + various doses of CF

As shown in Fig. 7, the experimental test of the static modulus of elasticity presented values in GPa, being performed considering the international normative parameters according to ASTM C469. It was evidenced that the deformations did not have a good performance, not being optimal in all its hybrid combinations of CSAoptimal + CF; however, these deformations can be analyzed to be admitted for non-structural concretes.

The results of the static modulus of elasticity of the conventional design A and B at 28 days show higher values than the experimental treatments such as A/B + 7CSA + 2CF, where the lowest values were observed with respect to the A and B standard concrete; this is due to the fact that in the hybrid mix treatments, the behavior generated by the ash with the fiber is not the most adequate, even with the mechanical properties of the aggregates that provide substantial resistance, so it was expected to have the same outcome with the hybrid mix CSAoptimal + CF, but it was not enough to improve this important property. As expressed by (Anania & D'agata, 2019) which, by incorporating 0.1% of cabuya fibers, increases the static elastic modulus by up to 60%. As for the addition of 4% sisal fibers per mass of cement, satisfactory results were observed for the modulus of elasticity of the composite with sisal fibers treated and immersed in kerosene oil (Bahja et al., 2021).

For the analysis of the results, the analysis of variance was used, which yielded the significance values P value (0.00), indicating that the treatments under study had an influence on the modulus of elasticity test performed for both conventional design strength A and B, respectively. Likewise, the values obtained in the reliability tests, coefficient of variability (CV) were 1.93 and 1.93 respectively, the coefficient of determination ($R^2$) were 99.49 and 99.80, being within the ranges for laboratory studies, so the data are reliable.

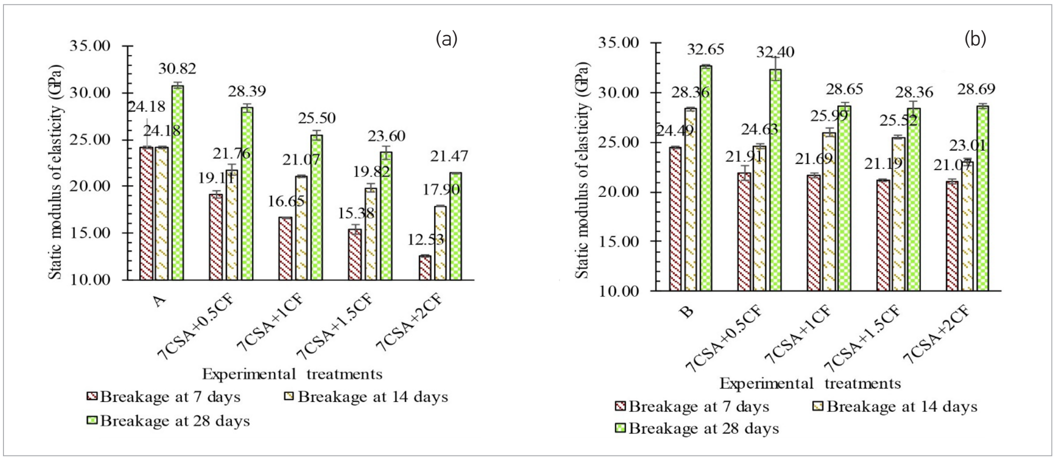



Fig. 7

Modulus of static elasticity with (optimal CSA) + CF, (a) experimental design A, (b) experimental design B

## Statistical Analysis

The results were checked with the DUNNET Test to determine the highest and lowest averages, also an Analysis of Variance (ANVA) which determined that the P Value (0.000) is < 0.005, causing the null hypothesis ($H_0$) to be rejected, concluding that the treatment methods studied, that is, the percentage of CSA and the hybrid mixture of CSA with CF included their responses to compression, flexure, tension and static modulus of elasticity to conventional design strength A and B. On the other hand, the values obtained in the reliability tests, coefficient of variability (CV) and coefficient of determination ($R^2$) are within the ranges for laboratory studies, so the data are reliable.

## Conclusions

The study shows that the effect of corn stubble ash (CSA) reinforced with cabuya fiber (CF) on the mechanical properties of concrete does not directly influence the mechanical properties, showing that it is not viable for structural concrete, but making it clear that it is possible to use these materials from areas of Peru as a sustainable use for non-structural concrete, the following conclusions of this study are presented below:

_ Workability is affected by the fact that plasticizers were not used; the unit weight showed a tendency to be less dense for all the combinations with CSA and denser with the hybrid combinations. The temperature is not an influential factor detrimental to the mixtures made, since they were made at room temperature (27 °C).

_ The optimum temperature for obtaining corn stover ash was 500 °C, obtaining an increase in compressive strength of 2.85%. The optimum percentage of CSA was 7% in substitution of cement, where it affected the increase in compressive strength for conventional design A by 2.7%, and for design B by 4.4%, respectively.

- There is no stable relationship between compressive strength and unit weight in its fresh state, since in the latter condition it showed higher values with the hybrid mix, but in its hardened state it showed low strengths.
- The optimal hybrid mixture of CSA + CF does not directly influence the mechanical properties of the concrete, since the bond between the ash and the fiber is not completely compromised. Which is recommended to be used for non-structural concrete for design strengths of 17.5 MPa and 14 MPa, respectively.
- According to the main findings, it has been determined that the optimum incineration temperature of corn stover has a significant influence on the concrete. As a result, a substantial improvement in mechanical properties is observed when using an optimum percentage of 7% CSA (corn stover ash), which makes it viable for use in structural concretes. However, it was found that the hybrid mixture of CSAoptimal + CF (corn stover ash + Cabuya fiber) did not achieve the expected strength. Nevertheless, this combination can be used in the manufacture of non-structural concretes, which opens the possibility of using them in the construction of sidewalks, sardinels or other low-strength components in order to promote sustainable construction using local materials, as well as being relevant from an environmental point of view.

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