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# Effects of incorporating granite powder in the mechanical properties of concrete

**Keywords:** concrete, granite powder, compressive strength, flexural strength, workability

## Introduction

The use of recycled materials in the production of concrete is an issue that has generated interest among many researchers for the purpose of improving the environment (Najaf & Abbasi, 2022a).

The subject under study has been of interest to other authors, and engineering studies have been carried out internationally in Pakistan, the researchers focused on the problem of granite powder (GP) produced in the granite processing industry, which is fatal to humans and not disposable due to limited disposal sites (Zhang, Ji, He & He, 2019). Researchers propose that GP could be valuably incorporated as a partial replacement for sand in concrete so as not to harm the environment, health, and thus avoid shortages to meet the sand demand (Zafar, Javed, Khushnood, Nawaz & Zafar, 2020; Ghouchani, Abbasi & Najaf, 2022). Adding Iran to this, (Amani, Babazadeh, Sabohanian & Khalilianpoor, 2019), incorporating the GP at 10% as a partial replacement for sand increases its compressive strength by

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up to 11% compared to its standard design of 210 kg·cm$^{-2}$ (Prokopski, Marchuk & Huts, 2020). Similarly, in another study, GP was incorporated at 28.4% and 45% as a partial replacement for the sand for a design of 210 kg·cm$^{-2}$ where the resistance was increased by 19% and 25% compared to the standard design, demonstrating an effect positive in both early strength and quality of concrete, as well as strength after 90 and 180 days of hardening (Ghorbani et al., 2019; Najaf & Abbasi, 2022b). Respect for the environment and the profitability of residual GP make it an acceptable and sustainable alternative construction material, indicating an enormous potential for GP as a replacement for natural fine aggregate (Singh, Khan, Khandelwal, Chugh & Nagar, 2016; Najaf & Abbasi, 2022a).

In Brazil, the GP produces a great environmental impact, due to the high demand for extraction of ornamental rocks, especially granite; the production of ornamental stones is at a very high level, reaching 9.3 M t in 2013; of this total, 4.6 M t are only granite; the final disposal of this waste has caused serious environmental problems; for this reason, the researchers are looking for ways to put this waste to use (Almeida, Soares & Matos, 2020). They carried out temperature tests incorporating the GP at 17% in a design of 210 kg·cm$^{-2}$, consequently, the fresh concrete is not affected by the incorporation of the GP, keeping it in the ambient temperature range. They also carried out high temperature tests illustrating a behavior of a higher the temperature and the faster the cooling process, resisting up to 600°C without affecting the concrete (dos Santos & Rodrigues, 2016). The workability was also analyzed with 30% and 50% GP in a 210 kg·cm$^{-2}$ concrete, evidencing a reduction in water absorption; consequently, its workability was affected to the highest percentage, showing a dry consistency and a slump of 1″ at 50% GP (Cordeiro, de Alvarenga & Rocha, 2016).

In India the GP is proposed as a good alternative to using natural sand in the preparation of concrete, obtaining up to a 10% increase in flexural strength for 210 kg·cm$^{-2}$ concrete containing 50% GP (Singh, Nagar & Agrawal, 2016). Researchers recommend that concrete incorporated with the GP by natural fine aggregate up to 30% for use in all structural applications, added GP at 10%, 20%, 30%, 40% and 50% by weight of sand in the concrete 210 kg·cm$^{-2}$, obtaining an optimal result at 30% GP, because it improves the mechanical properties of the concrete by up to 20% in the compressive strength, and even the results obtained for the GP at 50% are also acceptable, but they observe a reduction in other properties, mainly in its resistance to bending and workability (Jain & Sancheti, 2022). In Thailand, researchers incorporated the GP at 20%, 30% and 50% as a partial replacement for sand for a 254 kg·cm$^{-2}$ concrete, obtaining losses of 8%, 12% and 20%, respectively, in its flexural strength, evidencing that increasing the percentage of GP decreases the resistance to bending (Tangaramvong, Nuaklong, Khine & Jongvivatsakul, 2021). In another study, the tests for the incorporation of granite powder at 4%, 10% and 15% GP also achieved this tendency to decrease its resistance by up to 8% with respect to its standard design of 210 $kg \cdot cm^{-2}$ (Shwetha, Kumar, Dalawai, Anadinni & Sowjanya, 2022). Regarding its workability, the GP was incorporated at 20% and 40% in a 210 $kg \cdot cm^{-2}$ concrete, the results of slump reduced from 3″ to 1″, therefore they indicate that the workability of the concrete was also proportionally affected when incorporating higher amount of the GP (Gupta & Vyas, 2018; Taji et al., 2019). Consequently, finding the percentage of optimal substitution of sand by the GP can open new paths in sustainable construction techniques and reduce the detrimental effect on the environment due to waste disposal (Özcan & Koç, 2018; Najaf, Orouji & Ghouchani, 2022).

This study aims to analyze the impact of the incorporation of the granite powder (GP) as a partial replacement of the sand in the concrete in the following percentages 10%, 15%, 20% and 30% to carry out a mixed design of 210 $kg \cdot cm^{-2}$ and density of 2.4 $kg \cdot m^{-3}$ since it is the design mostly used in conventional constructions, seeking to find an optimal proportion to increase its mechanical properties where the geotechnical characteristics of the aggregates were identified, beams and concrete specimens were elaborated; the results of bending and compression tests were compared at 7, 14 and 28 days of setting between the standard concrete and the concrete incorporated with GP. It is concluded that the optimal result was at 20% GP, where the compressive strength increases by 13%, while its flexural property and workability are in an optimal range according to the stipulated parameters, allowing an important use regarding this waste in the construction industry, thus contributing to recycling, environmental quality and the development of using new materials.

## Material and methods

For this research, the study population covered the set of concrete design specimens according to the established construction standard $f'_c$ = 210 $kg \cdot cm^{-2}$. The sample consisted of 45 specimens and 45 concrete beams, with 9 samples per design. Standard concrete specimens and beams $f'_c$ = 210 $kg \cdot cm^{-2}$, concrete incorporated with GP at 10%, 15%, 20% and 30%. The fine GP was obtained from the granite cutting factories, Lima, the 1/2 stone and sand for the design of test tubes was obtained from the Cantera la Cría in Lambayeque (Peru) and the cement used in the present investigation is the cement portland type MS (Peru). Figure 1 shows the flowchart of processes carried out in research.

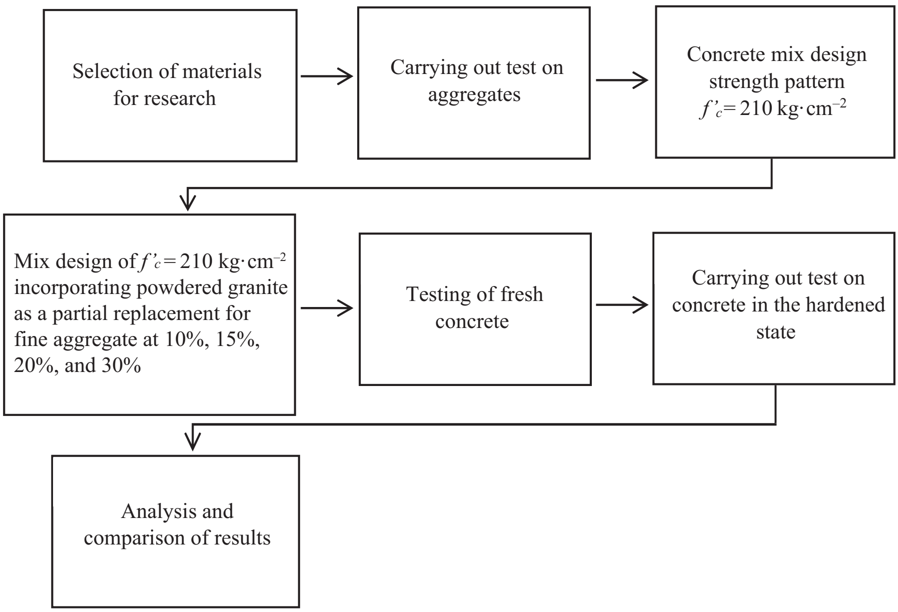


FIGURE 1. Process flow diagram

Source: own work.

# Tests

## Fine, coarse and GP aggregates geotechnical characteristics

To determine the geotechnical characteristics of the aggregates to be used in the mixed design (ASTM International [ASTM], 2015c), the following tests were carried out in the laboratory.

The fine aggregate is produced in a natural or artificial manner, it is the rocky material that passes through the standard 3/8-inch mesh and is retained in No 200; while the coarse aggregate is the rock material that does not pass through the No 4 mesh, this aggregate is produced by the natural or mechanical crushing of the stones; these have to comply with all the specifications mentioned in the current regulations (ASTM, 2015e). The aggregates for this study were obtained from natural quarries in Peru. Table 1 shows the results of the tests carried out to find the physical properties of the fine aggregates, coarse aggregates and GP.

TABLE 1. Aggregate geotechnical characteristics

| Parameter | Coarse aggregate | Fine aggregate | Granite powder |
|---|---|---|---|
| Nominal maximum size | 1″ | 1/4″ | 1/4″ |
| Fineness module | – | – | 0.53 |
| Moisture content | 0.0087 | 0.039 | 0.0032 |
| Dry loose unit weight [$g \cdot cm^{-3}$] | 1 419 | – | – |
| Compacted unit weight [$g \cdot cm^{-3}$] | 1 504 | – | – |
| Percent wear [%] | 0.211 | – | – |
| Salt content [%] | 0.0004 | – | – |
| Chloride content | 0.000106 | – | – |
| Sulfate content | 0.000068 | – | – |
| PE bulk (dry basis) | 2 678 | 2 574 | 2 798 |
| PE bulk (base saturated) | 2 705 | 2 609 | 2 808 |
| Pe apparent (dry basis) | 2 752 | 2 667 | 2 828 |
| Percentage of absorption [%] | 0.0101 | 0.0135 | 0.0037 |
| Sand equivalent | – | 0.364 | – |
| Salt content [%] | – | 0.0007 | – |
| Chloride content | – | 0.000134 | – |
| Sulfate content | – | 0.000087 | – |
| Fineness module | – | 2.78 | – |

Source: own work.

The GP used in this study was obtained from the granite ornamental stone cutting factories, Figure 2 shows the GP with 0.53 fineness modulus used for the study before being incorporated into the mix.

FIGURE 2. Granite powder

Source: own work.

## Specimens and beams preparation for a standard mix design

After the analysis of the aggregates, the mixture design was carried out for the resistance of 210 kg·cm$^{-2}$ of the standard concrete, the data of which are shown in Table 2, which illustrates the content of materials to be used according to the weight proportion.

TABLE 2. Proportion in weight standard design

| Resistance [kg·cm$^{-2}$] | Cement [bag] | Fine aggregate | Coarse aggregate | w/c |
|---|---|---|---|---|
| 210 | 1 | 2.2 | 2.4 | 0.53 |

Source: own work.

## Concrete mixture preparation with GP addition

Taking the standard design, 10%, 15%, 20% and 30% fine granitic aggregate is incorporated as a partial replacement for the sand in the concrete. Table 3 shows the mix designs in weight proportion incorporating the fine granite.

TABLE 3. Weight ratio of granite as a partial replacement for fine aggregate

| Mix design | Resistance [kg·cm$^{-2}$] | Cement [bag] | Fine aggregate | Coarse aggregate | w/c | Aggregate granite |
|---|---|---|---|---|---|---|
| Design + 10% GP | 210 | 1 | 1.98 | 2.4 | 0.53 | 0.22 |
| Design + 15% GP | 210 | 1 | 1.87 | 2.4 | 0.53 | 0.33 |
| Design + 20% GP | 210 | 1 | 1.76 | 2.4 | 0.53 | 0.44 |
| Design + 30% GP | 210 | 1 | 1.54 | 2.4 | 0.53 | 0.66 |

Source: own work.

## Tests on fresh concrete

### *Abrams cone – slump test*

The Abrams cone is an instrument that is applied to fresh concrete in order to obtain its fluidity or plasticity, the test consists of filling a cone-shaped metal mold with standardized dimensions, the process consists of forming three layers that will later be rammed with rods giving 25 blows, so that later the mold can be removed and the settlement of the fresh concrete can be measured (ASTM, 2015a).

*Temperature*

It consists of determining the temperature in the fresh concrete, it is influenced by the mixing energy, the environment and the heat released due to the reaction of the cement. The temperature must be between 10° and 32°C, an increase in the temperature will make the mixture mature faster, so it is one of the most important parameters (ASTM, 2015f; ASTM 2015g).

## Tests on concrete in hardened state

*Compression strength test*

It is carried out to verify if the prepared mixture meets the $f'_c$ requirements for which it was designed, where a vertical force is applied until the concrete specimen fails. It is performed after 7, 14 and 28 days (ASTM, 2015b). For this study, the compression test was carried out on cylindrical concrete specimens, with standard measurements of 150 × 300 mm. Figure 3 shows the compressive strength test using the hydraulic press.

FIGURE 3. Compressive strength concrete test
Source: own work.

*Flexural strength test*

The test consists of testing concrete beams, but without reinforcement where a vertical load is applied in the center in order to find the rupture modulus of the concrete, this is determined according to the type of failure that originates in the sample and generally ranges between 10% and 20% of the compressive strength (ASTM, 2016). For this study, concrete joists measuring 545 × 120 × 120 mm were made. Figure 4 shows the flexural strength test applied to the concrete joists.

FIGURE 4. Flexural strength concrete test
Source: own work.

# Results and discussion

## Comparison of the physical properties of standard concrete and concrete incorporating GP as a partial replacement for sand

The test results on the standard concrete of 210 kg·cm$^{-2}$ and the designs incorporating the GP at 10%, 15%, 20% and 30% in its fresh and hardened state were compared.

In its fresh state, the slump test was carried out in order to analyze the workability of the concrete (ASTM, 2015f). Figure 5 shows the average results of each design, the settlement is reduced to a higher percentage of the GP making it less workable, up to 20% has the optimal workability necessary for molding and its use in various structures, while at 30% it has a very low workability and dry consistency. Table 4 shows the consistency classification according to its workability.

The results obtained are in line with Sharma, Kumar, Kumar, Thomas and Gupta (2017) who incorporated the GP at 20% and 40% for a design of 210 kg·cm$^{-2}$, their slump results reduced from 3″ to 1″, the decreasing trend in the slump was also noted by Cordeiro et al. (2016). The workability was analyzed with 30% and 50%

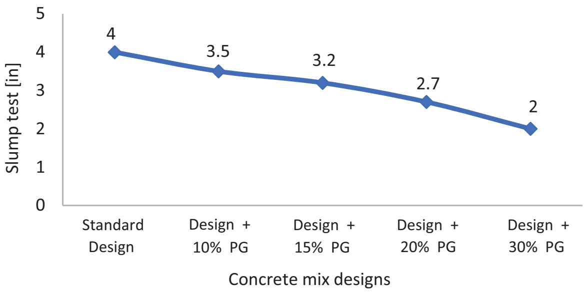


FIGURE 5. Slump test to determine workability
Source: own work.

TABLE 4. Consistency rating

| Consistency | Slump | Workability |
|---|---|---|
| Dry | 0″ to 2″ | little workable |
| Plastic | 3″ to 4″ | workable |
| Fluid | > 5″ | very workable |

Source: ASTM (2015a).

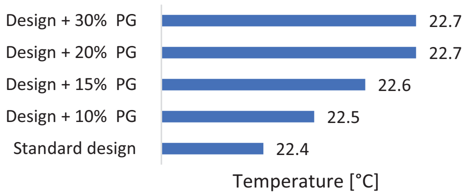


FIGURE 6. Temperature test
Source: own work.

GP in a 210 kg·cm$^{-2}$ concrete, demonstrating a reduction in water absorption, getting a dry consistency and a slump of 1″ at 50% GP.

The temperature test was performed in its fresh state with a digital thermometer at the time of pouring the concrete (ASTM, 2015f). Figure 6 shows the temperature of different designs, demonstrating that there is no negative effect when incorporating granite powder.

The maximum temperature reached by this study was observed for the concrete incorporated with the GP and is linked to the time of pouring and ambient temperature, and according to the ACI it mentions that in order to make a mixture design we have to have an adequate temperature that is not too high, in which the temperature used did not reach 25°C, which is within an acceptable range (ASTM, 2015d). The same behavior is obtained by Calmeiro and Rodrigues (2016), who carried out temperature tests incorporating the GP at 17% in a design of 210 kg·cm$^{-2}$. As a consequence, fresh concrete is not affected by the incorporation of the GP, maintaining the ambient temperature range. What is more, they also carried out high temperature tests showing a behavior where the higher the temperature, the faster the cooling process, resisting up to 600°C without affecting the concrete.

In its hardened state, the compressive strength test was applied, where 9 concrete specimens were made for each design, where its average strength was determined in kg·cm$^{-2}$ afer 7, 14 and 28 days from setting; all the designs with the GP obtained a higher resistance with respect to the standard concrete, reaching

275.4 kg·cm$^{-2}$ after 28 days as the highest average compressive strength in the design incorporated with 30% GP as partial replacement of the sand, subsequent 20% GP with 268.6 kg·cm$^{-2}$, Figure 7 shows the means of compressive strength versus time, where it can be seen that the higher the percentage of granite, the higher the compressive strength.

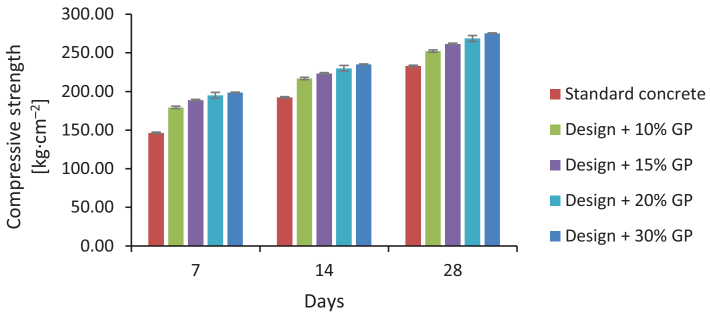


FIGURE 7. Variability of compressive strength at 28 days according to 7, 14, 28 days
Source: own work.

The results obtained are in line with Ghorbani et al. (2019) who achieved an improvement in their compressive strength by incorporating the GP at 10%, increasing up to 11% with respect to their standard design, as well as Prokopski et al. (2020) incorporated the GP at 28.4% and 45% as a partial replacement for sand for a 210 kg·cm$^{-2}$ design, increasing resistance by 19% and 25% compared to the standard design; confirming the trend, Jain and Sancheti (2022), added the GP at 10%, 20%, 30%, 40% and 50% by weight of sand in the concrete 210 kg·cm$^{-2}$, obtaining an optimal result at 30% GP because it improves the mechanical properties of the concrete up to 20% of its resistance to compression and even the results obtained for the GP at 50% are acceptable, but a reduction in other properties can be observed, the results reaffirm an improvement directly proportional to a higher percentage of GP.

The flexural strength test was applied, where 9 concrete joists measuring 15 × 15 cm were made for each design, determining their rupture modulus in kg·cm$^{-2}$ after 7, 14 and 28 days from setting, the results showed that a higher percentage of the GP incorporated in the design reduces the bending, complying with the parameters of minimum bending in the concrete up to the design of 20% GP, while the 30% design does not meet the parameters because the minimum rupture modulus must be between 10 and 15% of the compressive strength of the concrete (ASTM, 2016; National Ready Mixed Concrete Association [NRMCA], 2021).

Figure 8 shows the rupture modulus averages after 28 days of curing with respect to each design carried out, where a tendency to decrease with a higher percentage of the GP can be seen, with the lowest result being 26 kg·cm$^{-2}$ belonging to the 30% GP design.

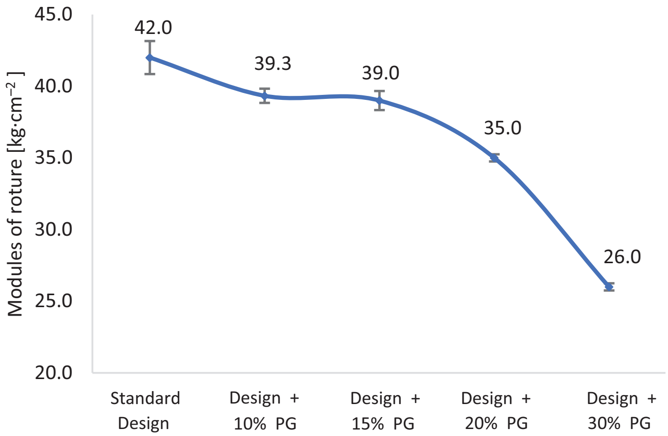


FIGURE 8. Flexural strength standard concrete vs concrete incorporated with GP after 28 days from setting

Source: own work.

The trend is also manifested in the results of Tangaramvong et al. (2021) who incorporated 20%, 30% and 50% of the GP as a partial replacement of the sand for a 254 kg·cm$^{-2}$ concrete, obtaining losses of 8%, 12% and 20%, respectively, in its resistance to bending, thus evidencing that increasing the percentage of the GP decreases the resistance to bending. Shwetha et al. (2022) carried out tests of GP incorporation at 4%, 10% and 15% GP in a 210 kg·cm$^{-2}$ concrete and also achieved this tendency of decreasing its resistance by up to 8% with respect to its standard design. All results contradict the reports made by Singh et al. (2016), who demonstrated a 10% increase in flexural strength for 210 kg·cm$^{-2}$ concrete containing 50% GP.

## Optimal dosage for the incorporation of GP as a partial replacement for sand

After evaluating the properties of the concrete of the different designs made, the proposed tests and results were obtained using standards such as ACI and ASTM. Concrete incorporating fine granite powder at 20% as a partial replacement for sand in concrete has been proposed as the optimal design, due to its results being within the ranges established by different regulations, the proportions of the materials are shown in Table 5. After 28 days, the 20% GP design obtained a compressive strength of 268.6 kg·cm$^{-2}$ growing by 13% with respect to the standard concrete, a 3″ slump entering the workable mix range with a plastic consistency and a flexural strength within the ranges recommended by the ASTM C293 standard (ASTM, 2016), the modulus of rupture being 13.04% of its compressive strength.

TABLE 5. Design optimal 20% GP

| Mix design | Resistance [kg·cm$^{-2}$] | Cement content | Fine aggregate content | Coarse aggregate content | Aggregate granite content | Water content |
|---|---|---|---|---|---|---|
| Design + 20% GP | 210 | 1 | 1.76 | 2.4 | 0.44 | 19.9 |

Source: own work.

However, the 30% GP design obtained a higher compressive strength, reaching 275.4 kg·cm$^{-2}$ after 28 days from setting, increasing the compressive strength by 18.2% with respect to the standard concrete, but this result is overshadowed by its other properties, such as the 2″ slump, which is not very practical, having a dry consistency, and a modulus of rupture of 26 kg·cm$^{-2}$, being a result smaller than the minimum recommended flexural strength, by the ASTM C293 standard, which recommends that it should be between 10% and 15% of the compressive strength (ASTM, 2016; Sharma et al., 2017). For this reason, the 20% GP design has been proposed as the optimal dosage since it meets all the parameters stipulated in this study.

## Conclusions

When evaluating the properties of the 210 kg·cm$^{-2}$ standard concrete and the designs incorporating GP as a partial replacement of the sand in the following percentages: 10%, 15%, 20% and 30% in its fresh state, a reduction in slump with a greater amount of GP was indicated, resulting in slumps of 3.5″ to 2″ compared to the 4″ obtained with the standard concrete; the temperature has not been affected since it was maintained according to the time of pouring, reaching a maximum temperature of 24°C.

The tests carried out in its hardened state show an increase in the compressive strength with a higher percentage of GP, where an increase of up to 17% was obtained in the 30% GP design with an average strength of 272.5 kg·cm$^{-2}$ and an average of 262.33 kg·cm$^{-2}$ at 20% compared to the 233 kg·cm$^{-2}$ standard concrete increasing up to 13%; in its flexural strength the standard concrete obtained an average rupture modulus of 40 kg·cm$^{-2}$,while the concrete with granite powder up to the 20% GP design complies with the recommended ranges of flexural strength of 35 kg·cm$^{-2}$, illustrating that the higher the percentage of granite powder, the lower the flexural strength.

It is proposed as a 20% optimal GP design with a water-cement ratio of 0.53, since it managed to improve the compressive strength up to 13%, with respect to the flexural strength an average rupture modulus of rupture of 35 kg·cm$^{-2}$ was evidenced complying with the parameters of the minimum flexural strength in structures where it is recommended that the bending should be between 10–15% of the compressive strength. What is more, good results in its workability were indicated, and according to its temperature characteristics, this design can be applied in the development of structural elements without having an adverse effect on them.

## References

Almeida, K. S. D., Soares, R. A. L. & Matos, J. M. E. D. (2020). Efeito de resíduos de gesso e de granito em produtos da indústria de cerâmica vermelha: revisão bibliográfica [Effect of gypsum and granite residues on products from the red ceramic industry: literature review]. *Matéria (Rio de Janeiro)*, *25* (1), e-12568. https://doi.org/10.1590/s1517-707620200001.0893

Amani, A., Babazadeh, A., Sabohanian, A. & Khalilianpoor, A. (2019). Mechanical properties of concrete pavements containing combinations of waste marble and granite powders. *International Journal of Pavement Engineering*, *22* (12), 1531–1540. https://doi.org/10.1080/10298436.2019.1702662

ASTM International [ASTM] (2015a). *Slump of portland cement concrete* (ASTM C143). West Conshohocken: ASTM International.

ASTM International [ASTM] (2015b). *Standard test method for compressive strength of cylindrical concrete specimens* (ASTM C39/C39M). West Conshohocken: ASTM International.

ASTM International [ASTM] (2015c). *Standard test method for particle-size analysis of soils* (ASTM D422). West Conshohocken: ASTM International.

ASTM International [ASTM] (2015d). *Standard test method for relative density (specific gravity) and absorption of coarse aggregate* (ASTM C127-15). West Conshohocken: ASTM International.

ASTM International [ASTM] (2015e). *Standard test method for sieve analysis of fine and coarse aggregates* (ASTM C136). West Conshohocken: ASTM International.

ASTM International [ASTM] (2015f). *Standard test method for temperature of freshly mixed hydraulic cement concrete* (ASTM C1064). West Conshohocken: ASTM International.

ASTM International [ASTM] (2015g). *Standard test method for temperature of freshly mixed hydraulic cement concrete* (ASTM C1064/C1064M-08). West Conshohocken: ASTM International.

ASTM International [ASTM] (2016). *Standard test method for flexural strength of concrete (using simple beam with center-point loading)* (ASTM C293). West Conshohocken: ASTM International.

Cordeiro, G. C., Alvarenga, L. M. S. C. de & Rocha, C. A. A. (2016). Rheological and mechanical properties of concrete containing crushed granite fine aggregate. *Construction and Building Materials*, *111*, 766–773. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2016.02.178

Ghorbani, S., Taji, I., Brito, J. de, Negahban, M., Sahar, G., Tavakkolizadeh, M. & Davoodi, A. (2019). Mechanical and durability behaviour of concrete with granite waste dust as partial cement replacement under adverse exposure conditions. *Construction and Building Materials*, *194*, 143–152. https://doi.org/10.1016/j.conbuildmat.2018.11.023

Ghouchani, K., Abbasi, H. & Najaf, E. (2022). Some mechanical properties and microstructure of cementitious nanocomposites containing nano-$SiO_2$ and graphene oxide nanosheets. *Case Studies in Construction Materials*, *17*, e01482. https://doi.org/10.1016/j.cscm.2022.e01482

Gupta, L. K. & Vyas, A. K. (2018). Impact on mechanical properties of cement sand mortar containing waste granite powder. *Construction and Building Materials*, *191*, 155–164. https://doi.org/10.1016/j.conbuildmat.2018.09.203

Jain, K. L. & Sancheti, G. (2022). Effect of granite fines on mechanical and microstructure properties of concrete. *Advances in Concrete Construction*, *13* (6), 461–470. https://doi.org/10.12989/acc.2022.13.6.461

Najaf, E. & Abbasi, H. (2022a). Impact resistance and mechanical properties of fiber-reinforced concrete using string and fibrillated polypropylene fibers in a hybrid form. *Structural Concrete Journal of the fib*, *2022*, 1–14. https://doi.org/10.1002/suco.202200019

Najaf, E. & Abbasi, H. (2022b). Using recycled concrete powder, waste glass powder, and plastic powder to improve the mechanical properties of compacted concrete: cement elimination approach. *Advances in Civil Engineering*, *2022*, 9481466. https://doi.org/10.1155/2022/9481466

Najaf, E., Orouji, M. & Ghouchani, K. (2022). Finite element analysis of the effect of type, number, and installation angle of FRP sheets on improving the flexural strength of concrete beams. *Case Studies in Construction Materials*, *17*, e01670. https://doi.org/10.1016/j.cscm.2022.e01670

National Ready Mixed Concrete Association [NRMCA] (2021). *CIP 16 – Flexural strength of concrete. Alexandria, VA: National Ready Mixed Concrete Association*. Retrieved from: https://eaglerockconcrete.com/wp-content/uploads/concrete-in-practice-16pr.pdf [accessed 30.09.2022].

Özcan, F. & Koç, M. E. (2018). Influence of ground pumice on compressive strength and air content of both non-air and air entrained concrete in fresh and hardened state. *Construction and Building Materials*, *187*, 382–393. https://doi.org/10.1016/j.conbuildmat.2018.07.183

Prokopski, G., Marchuk, V. & Huts, A. (2020). The effect of using granite dust as a component of concrete mixture. *Case Studies in Construction Materials*, *13*, e00349. https://doi.org/10.1016/j.cscm.2020.e00349

Santos, C. C. dos & Rodrigues, J. P. C. (2016). Calcareous and granite aggregate concretes after fire. *Journal of Building Engineering*, *8*, 231–242. https://doi.org/10.1016/j.jobe.2016.09.009

Sharma, N. K., Kumar, P., Kumar, S., Thomas, B. S. & Gupta, R. C. (2017). Properties of concrete containing polished granite waste as partial substitution of coarse aggregate. *Construction and Building Materials*, *151*, 158–163. https://doi.org/10.1016/j.conbuildmat.2017.06.081

Shwetha, K. G., Kumar, C. M., Dalawai, V. N., Anadinni, S. B. & Sowjanya, G. V. (2022). Comparative study on strengthening of concrete using granite waste. *Materials Today: Proceedings*, *62*, 5317–5322. https://doi.org/https://doi.org/10.1016/j.matpr.2022.03.389

Singh, S., Khan, S., Khandelwal, R., Chugh, A. & Nagar, R. (2016). Performance of sustainable concrete containing granite cutting waste. *Journal of Cleaner Production*, *119*, 86–98. https://doi.org/https://doi.org/10.1016/j.jclepro.2016.02.008

Singh, S., Nagar, R. & Agrawal, V. (2016). A review on Properties of Sustainable Concrete using granite dust as replacement for river sand. *Journal of Cleaner Production*, *126*, 74–87. https://doi.org/10.1016/j.jclepro.2016.03.114

Taji, I., Ghorbani, S., De Brito, J., Y. Tam, V. W., Sharifi, S., Davoodi, A., & Tavakkolizadeh, M. (2019). Application of statistical analysis to evaluate the corrosion resistance of steel rebars embedded in concrete with marble and granite waste dust. *Journal of Cleaner Production*, *210*, 837–846. https://doi.org/10.1016/j.jclepro.2018.11.091

Tangaramvong, S., Nuaklong, P., Khine, M. T. & Jongvivatsakul, P. (2021). The influences of granite industry waste on concrete properties with different strength grades. *Case Studies in Construction Materials*, *15*, e00669. https://doi.org/https://doi.org/10.1016/j.cscm.2021.e00669

Zafar, M. S., Javed, U., Khushnood, R. A., Nawaz, A. & Zafar, T. (2020). Sustainable incorporation of waste granite dust as partial replacement of sand in autoclave aerated concrete. *Construction and Building Materials*, *250*, 118878. https://doi.org/10.1016/j.conbuildmat.2020.118878

Zhang, H., Ji, T., He, B. & He, L. (2019). Performance of ultra-high performance concrete (UHPC) with cement partially replaced by ground granite powder (GGP) under different curing conditions. *Construction and Building Materials*, *213*, 469–482. https://doi.org/10.1016/j.conbuildmat.2019.04.058

## Summary

**Effects of incorporating granite powder in the mechanical properties of concrete.** This study analyzes the effects of the incorporation of the granite powder (GP) as a partial replacement of the sand in the concrete in percentages of 10%, 15%, 20% and 30% to carry out a mix design of 210 kg·cm$^{-2}$. Seeking to find an optimal proportion to increase its mechanical properties where the geotechnical characteristics of the aggregates were identified, workability, temperature, beams and concrete specimens were elaborated. The results of bending and compression tests were compared after 7, 14 and 28 days from

setting between the standard concrete and the concrete incorporated with the GP. It is concluded that the optimal result was at 20% GP with 268.6 $kg \cdot cm^{-2}$, where the compressive strength increases by 13%, while its flexural property rupture modulus of 35 $kg \cdot cm^{-2}$ and workability are in an optimal range according to the stipulated parameters, thus allowing an important application for this waste in the construction industry, therefore contributing to recycling, environmental quality and the development of the usage of new materials.