HIGH-PERFORMANCE MIXTURE FOR DOPING CONSTRUCTION WASTE AGGREGATES

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ABSTRACT
The construction industry is considered the sector of human activities that consumes the most natural resources, generating considerable environmental impacts, including the generation of construction waste. An alternative to this problem is to use this construction waste (RCC) in concrete. Studies show favorable results for this application, but attention must be paid to the limitations of the material, such as heterogeneity in composition, lower mechanical resistance, and greater water absorption. To correct these deficiencies, the doping technique can be applied, which consists of impregnating the aggregate with high-performance grout to alter its structure. Thus, this work addresses the study of the high-performance grout used in the doping of RCC aggregates to produce structural concrete. For this purpose, the recycled aggregate was characterized and the study of the high-performance grout was carried out, varying the proportion of superplasticizer additive and silica fume. After the results, it can be concluded that the doping procedure with high-performance grout proved to be efficient in reducing the porosity of the RCC aggregate, allowing the use of material that currently has no commercial value as an alternative aggregate in the preparation of structural concrete.

Keywords: Waste. High-performance grout. Doping technique. Structural concrete. Environment.

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INTRODUCTION

The construction industry increasingly consumes natural resources, most of which have a limited useful life; and the generation of construction waste accompanies this growth, generating, in turn, direct impacts on the environment. Projects that minimize or solve such problems must be designed in a way that reduces this waste and consequently reduces the environmental impacts of this activity (FERREIRA, 2022).

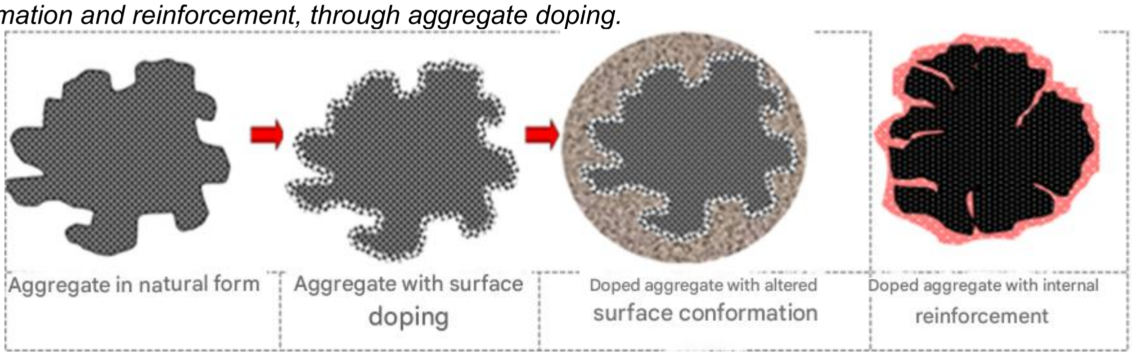
Abritta (2019) states that the scarcity of crushed stone deposits and the great demand for natural aggregates by the construction industry, with the consequent increase in waste generation, lead to the process of reformulating the production chain of this industrial activity, mainly the waste generated. Measures that establish guidelines for the management of construction waste (RCC) emerge, considering its reduction through the use of the material generated.

The use of recycled materials in the composition of new concrete has been investigated to assess the reduction of environmental impacts and the generation of quality products that are economically viable for civil construction, with analyses of concrete strength emerging with the use of alternative aggregates, such as RCC replacing natural aggregate, with behavior and applicability being evaluated (SOUZA, 2020).

Rabello (2015) evaluated the axial compression strength of concrete specimens, varying the percentage of mass replacement of RCC by conventional aggregate at levels of 0, 25, 50, 75, and 100%. The reference sample (0% RCC) reached a strength of 21.49 MPa at 28 days of age. With 25% replacement, the resistance dropped to 8.26 MPa, and with 75% RCC to 8.21 MPa, representing a drop of around 60%, which can be attributed to the excessive porosity of the test specimens made with recycled aggregate.

Thus, in the scenario of reusing RCC and the need to overcome its deficiencies, the aggregate doping technique emerges (Figure 1).

Figure 1 – Modification of the transition zone (TZ) at the paste/aggregate interface, change in surface conformation and reinforcement, through aggregate doping.



Source: Trigo (2012).

According to Trigo (2012), the technique consists of establishing the initial impregnation of the deficient aggregate with materials that react with other binders, modifying the texture of the material, or establishing a connection bridge between it and the binders that may be used, or providing reinforcement of the aggregate itself through its internal doping by filling the existing pores.

By providing the doping of an aggregate, through its “armor” with a high-quality matrix, it becomes possible to use aggregates previously considered unknown to concrete (Trigo, 2012).

Research carried out since 2002 at the Laboratory of Advanced Cement-Based Materials at the São Carlos School of Engineering (University of São Paulo) indicates that there is great potential for applying the material doping technique to increase the performance of concrete properties (Liborio and Fagury (2002); Silva and Liborio (2002); Liborio et al (2003); Silva and Liborio (2005); Trigo, Rebmann, and Liborio (2010); Trigo, Conceição, and Libório (2010); Trigo (2012)). Trigo (2012) states that, in concrete made with the doping technique, it is possible to observe improvements in the characteristics of the matrix-aggregate ZTI, such as a reduction in both the amount of calcium hydroxide (CH) and porosity, CH being a fragile compound formed during cement hydration, in addition to the formation of a large amount of additional hydrated calcium silicate (C-S-H), a more resistant hydrated product.

In his research, Trigo (2012) evaluated the doping technique by applying high-performance grout to lateritic aggregates. The application of the technique reduced the porosity of the laterite grain by more than 35%, demonstrating the efficiency of doping in plugging the surface pores of the aggregate. In terms of mechanical strength, the doping technique resulted in an average gain of 28% in compressive strength for concrete made with laterite. The author states that the increases in strength are a reflection of improvements in the paste/aggregate transition zone, confirmed in microscopic tests, representing the possibility of using many alternative aggregates that have been little or not at all explored until now.

Other materials that can potentially be used to replace the coarse aggregate commonly used in structural concrete, in addition to RCC, stand out, namely: marble waste, waste from oil well drilling, electric furnace slag, rolled gravel, and granite.

Araújo (2018) studied the physical and mechanical properties of concrete made with marble waste as a replacement for the coarse aggregate of granite gravel, in percentages of 5% and 10%, performing simple compression strength and water absorption tests. The results showed that the addition of 5% of marble waste promoted a gain of 4.53% in the compression strength test at 28 days of age, achieving a strength higher than the characteristic strength (fck) of 20 MPa used in the dosage. When replacing 10% of marble waste with granite aggregate, there was a 7.14% increase in strength, a fact that can be attributed to the packing of aggregate particles in the concrete (Araújo, 2018).

Santos (2018) evaluated the performance of grout manufactured with waste from oil well drilling as a partial replacement for natural aggregates, in terms of properties in the fresh and hardened states. The waste contents evaluated were 10% and 20%, with mass replacement of conventional coarse aggregate (gravel 0). The results showed that the addition of 10% waste did not change the strength, while the mix with 20% replacement showed a higher strength (12.8%) when compared to the reference mix at the age of 28 days, increasing from 41.49 MPa to 46.80 MPa. Thus, for Santos (2018), it is feasible to use 20% of residue as a partial replacement for coarse aggregate, since in addition to meeting workability, it has shown to have superior resistance to the reference mix.

Evangelista (2016) studied the technical and environmental feasibility of using electric furnace slag (EFS), a residue produced in semi-integrated steel mills, as a replacement for coarse aggregate in the production of concrete paving pieces (pavers). Based on the results, Evangelista (2016) states that the use of EFS, in proportions of 25% and 50%, met the regulatory requirements. For higher proportions, mixes that meet the required requirements should be tested.

Silva (2022) evaluated concrete made with rolled gravel and granite gravel in fresh and hardened states. The author observed that, at 28 days of age, the concrete containing rolled gravel exhibited 28.72% higher compressive strength values when compared to that containing granite gravel. The author explains that to maintain the same workability of the concrete, it is necessary to use more water when using granite, justifying the drop in compressive strength. Nest and aspect, the aggregate doping technique can be an alternative to the problem presented, since it provides a change in the conformation of the aggregate.

Martins and Oliveira (2020) studied concretes with granite cutting waste (RCG) from civil construction. The authors concluded that the addition of RCG brings gains in strength with the complete curing period of the concrete, since at 14 days of age the reference mix presented higher strength values than the mixes with addition. The authors explain that the cohesion between cement and granite coarse aggregate is not complete at the beginning of curing, due to the smooth surfaces of the RCG; which can be corrected with the application of the doping technique.

Given the above, it is important to study doping in alternative aggregates, such as RCC, which, despite having a high potential for use due to its availability, presents deficient characteristics, such as high porosity; a factor that often restricts its use in structural concretes.

Thus, this work seeks to study a high-performance grout capable of reinforcing and improving the matrix of alternative aggregates, making them suitable for use in structural concrete.

MATERIALS AND METHODS

Initially, the characterization tests of the aggregates were carried out. The granulometry was done by sieving according to NBR 17054:2022. From the result of this analysis, two important factors for the dosage study were taken, the fineness modulus and the maximum diameter of the coarse aggregate of RCC. To determine the specific mass, water absorption, and unit mass, the standards NBR 16917:2021 and NBR 16972:2021 were followed. The powdery material test followed the recommendations of NBR 16973:2021.

Next, the dosage study of the doping grout of the coarse aggregates was carried out. To obtain a high-performance grout, High Initial Strength Portland Cement (CPV-ARI) and silica fume were used as binders. Silica fume was used at a content of 10%, as suggested by Trigo (2012). To obtain low water-to-grout ratios, a superplasticizer additive was used, with contents of 0.4% to 1.6% of the cement mass being studied, to obtain a consistency suitable for impregnation of the aggregates.

The study of the grout was based on the mini-slump test of the truncated cone (Monte, 2003), which evaluates the additive content and the grout spreading area, making it possible to create a curve and determine the optimum percentage of superplasticizer additive. The homogenization of the mixture and the order of placement of the materials followed the study by Trigo (2012).

Once the high-performance grout had been determined with a consistency suitable for impregnating the coarse aggregates, a test was performed to determine the mixture's setting times by NBR 16607/2018. This test is valuable since inadequate levels can delay the setting, making it difficult to impregnate the material with the grout.

Next, some RCC aggregate grains were selected to proceed with impregnation/reinforcement with the high-performance grout, i.e., application of the doping technique. After applying the technique, images of the aggregates were taken in natural conditions (without doping) and doped (with high-performance grout) to verify the efficiency of the impregnation.

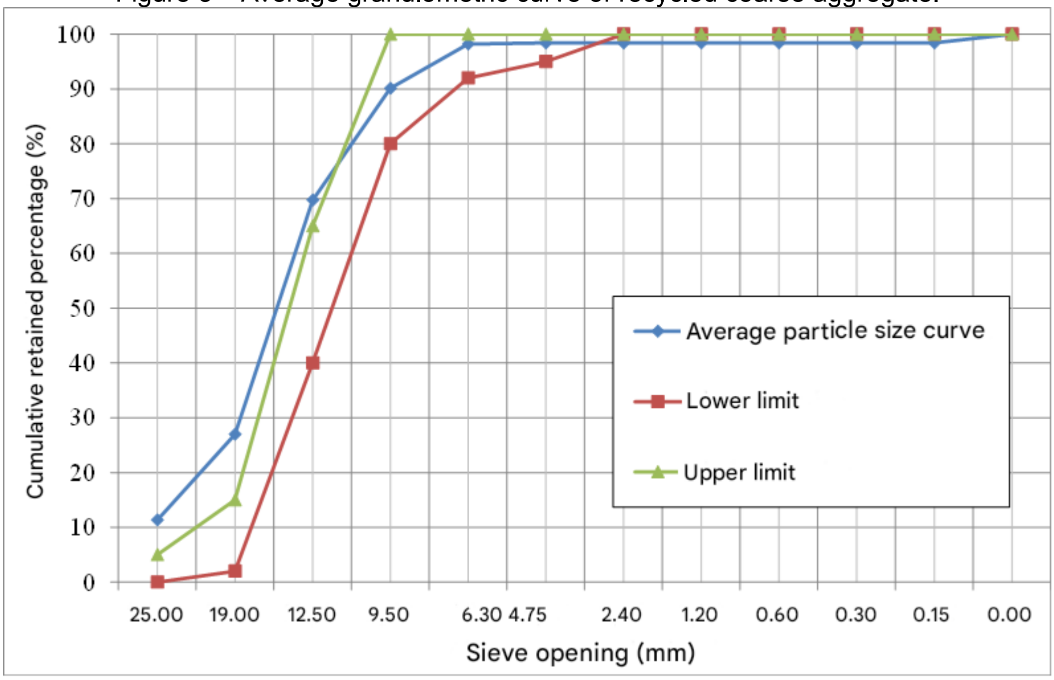
RESULTS AND DISCUSSION

The granulometry test of the recycled coarse aggregate was performed on three different samples to obtain the average between the results and the acceptability of the test. Figure 2 shows the RCC sample used in the work and Figure 3 refers to the average granulometric curve of the aggregate, with the maximum diameter of the RCC being 25 mm and the fineness modulus equal to 7,07.

Figure 2 – Coarse aggregate of RCC studied in the work.

Source Authors.

Figure 3 – Average granulometric curve of recycled coarse aggregate.



Source: Authors, 2025

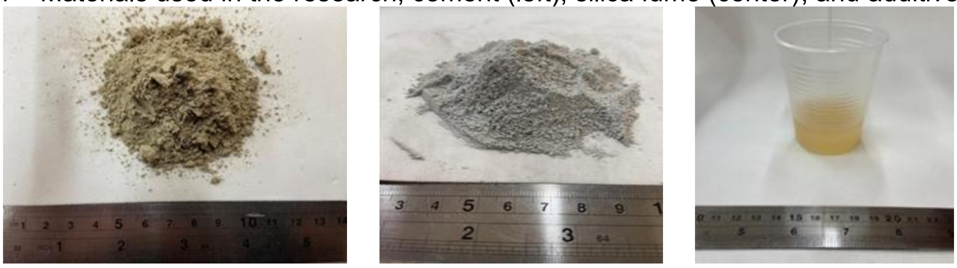
The average absolute specific mass of the coarse aggregate of RCC was 2.44 g/cm3, approximately 13% lower than the specific mass of a natural stone, which is around

2.80 g/cm3. This difference is mainly due to the presence of mortar adhered to the aggregate, which increases the porosity of the aggregate.

The results of the absolute specific mass of the binders were provided by their respective manufacturers. The cement used was CPV ARI, from the brand CSN Cimentos, with an absolute specific mass of 3.02 g/cm³. Regarding the silica fume, one from the brand Methatec was used, with an absolute specific mass of 2.20 g/cm³.

It was decided to use a 3rd generation superplasticizer additive, from the brand BASF, based on polycarboxylate, whose density is 1.07 g/cm³. The binders and additives are shown in Figure 4.

Figure 4 – Materials used in the research, cement (left), silica fume (center), and additive (right).



Source: Authors, 2025

Regarding the loose and compacted unit masses of the recycled coarse aggregate, the average values found were 976.41 kg/m³ and 999.37 kg/m³, respectively.

After determining the composition of the coarse recycled aggregate, by NBR 15116:2021, and obtaining its classification as ARCO (Recycled Concrete Aggregate), the absorption test was performed, recommended by NBR 16917:2021, in which an average value of 18.5% was reached. The result does not meet the 7% limit established by NBR 15116:2021, a factor that can be changed after doping. The increase in absorption can be attributed to the greater porosity of the material when compared to that of the natural coarse aggregate. Once the use of High Initial Strength Portland Cement (HIN-ARI) and silica fume at a content of 10% as binders had been defined, different levels of superplasticizer additive were evaluated to obtain low water to grout ratios and a consistency suitable for impregnating the aggregates. Thus, additive levels of 0.4%, 0.8%, 1.2%, and 1.6% of the cement mass were studied using the Kantro test, or mini-slump of the truncated cone. The mini-slump method was developed by Kantro (1980) and adopted in some national and international studies to determine the consistency of cement pastes with superplasticizer additives. This method consists of a truncated cone mold and a glass plate. After removing the mold, two orthogonal diameters of the paste are measured with a caliper. The average of the two measured diameters is calculated, and then the spread area of the paste is obtained (MONTE, 2003, p. 23-95).

The equipment used in this work is shown in Figure 5. The helical propeller coupled to the drill was used in the process of mixing the materials of the syrup.

Figure 5 – Equipment used in the research.

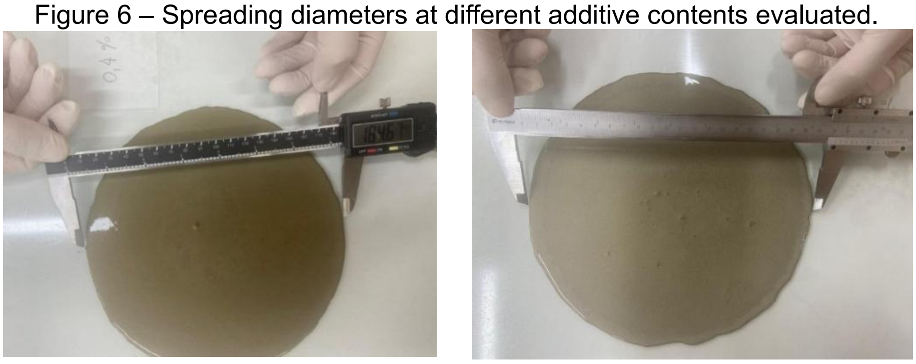
PVC conical trunk mold Analog caliper Drill with helical shank

Source: Authors, 2025

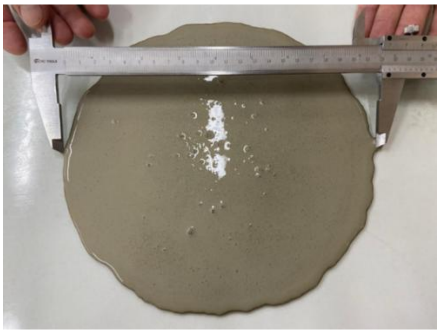
Before starting the Kantro test, the consumption of materials for the high-performance grout was determined, considering the silica fume content of 10% according to Trigo (2012), as well as the water/binder ratio (w/b) set at 0.35, which resulted in 0.9:0.073:0.35.

To define the additive content, the mini-cone slump test was performed on a flat and level bench, at a temperature of 24 degrees, on a glass plate greased with release oil. The mixing order of the materials followed the study by Trigo (2012). Figure 6 shows the different diameters obtained according to the additive content evaluated.

Figure 6 – Spreading diameters at different additive contents evaluated.



Content 0,4% Content 0,8%



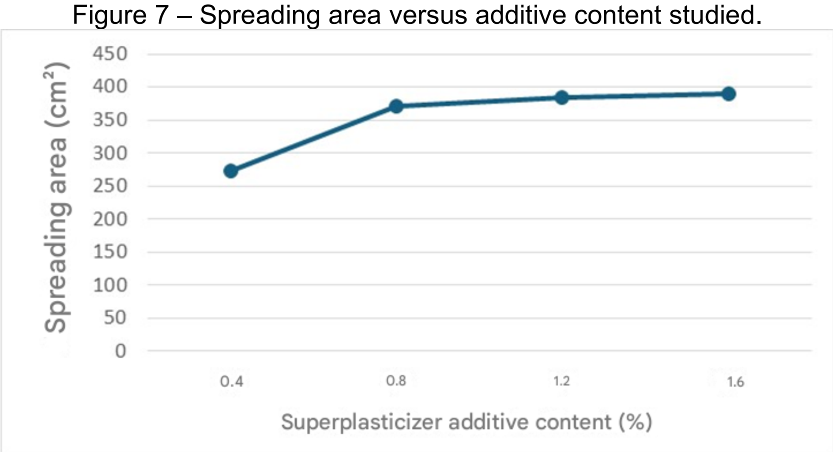
Content 1,2% Content 1,6%

Source: Authors, 2025

Thus, with the average diameter values obtained, it was possible to determine the approximate spreading areas of each paste, according to the percentage of additive in the mixture. Figure 7 shows the results of the “spreading area versus superplasticizer content” curve. Analyzing the results, it can be seen that there was a significant increase in the spreading area when increasing the additive content from 0.4% to 0.8%. On the other hand, contents greater than 0.8% contributed practically no gain in spreading, indicating an optimum content of no more than 0.8%.

Therefore, to choose the additive content to be used in the doping mixture, one should base oneself not only on the maximum spreading achieved but also on the lowest loss of spreading over time and the lowest interference in the setting. Therefore, the research continued by performing the setting time test, which followed the provisions of NBR 16607/2018. A Vicat apparatus and a truncated conical mold were used, as seen in Figure 8.

Figure 7 – Spreading area versus additive content studied.



Source: Authors, 2025

Figure 8 – Test to determine the setting times of the doping solution.

Source: Authors, 2025

Table 1 shows the start and end times of the doping grout setting, considering the different superplantifying additive contents evaluated. It can be noted that contents higher than 1.2% resulted in end-of-setting values higher than 8 hours, making them inadequate for the coarse aggregate doping process.

The 0.4% content was the one that resulted in the shortest setting time (the desired condition in this research), however, it did not guarantee perfect dispersion of the particles and adequate doping of the coarse aggregate; a reflection seen in the Kantro test.

The explanation for choosing a shorter setting time is related to the aggregate doping process, more precisely with the concern regarding the permanence of the doping grout in the aggregate after it is mixed with the other constituents of the concrete. It is considered that the closer to the start of the grout setting this mixing is carried out, the less chance there is of the impregnation being removed by the friction of the grains.

Table 1 – Results of setting times of high-performance grouts made with CP V-ARI and different superplasticizer additive contents.

Catching time	Additive content (%)			
(minutes)	0.4	0.8	1.2	1.6
Start	197	366	394	432
End	375	434	536	544

Source Authors

Thus, based on the mini-slump tests of the truncated cone and setting time, it was concluded that the additive at a content of 0.8% relative to the mass of the binder was the most suitable for both dispersing the particles, without causing exudation of the mixture, and for not causing excessive delay in the setting of the cement. Furthermore, this content does not compromise the viability regarding the production time of the doped concrete, since the mixing of the concrete (previously doped aggregate and other constituent materials) will occur in 366 minutes (6 hours and 6 minutes).

After completing the high-performance grout dosage study, and evaluating the conditions and efficiency of the doping grout, some RCC aggregate grains were selected and impregnated/reinforced with the high-performance grout.

Figure 9 shows the images of the aggregates in natural (without doping) and doped (with high-performance grout) conditions. It can be observed that the most significant change is in the surface conformation of the grain, which tends towards a more spherical shape, and in the reduction of surface pores. The spherical shape and smaller quantity of surface voids can represent an increase in the fluidity of concretes made with doped aggregates.

A larger quantity of aggregate was also doped to evaluate the efficiency of the mixture in a concrete mixer and the quantity of grout to be used in the impregnation. The high-performance grout was initially prepared, with the materials being inserted into the concrete mixer following the order of placement prescribed by Trigo (2012). Then, the coarse aggregates of RCC were added, which were mixed to dope them. After this, the material was passed through a sieve to remove the excess grout, thus completing the process of impregnating the aggregate. Figure 10 shows the steps of doping the RCC in a concrete mixer.

Figure 9 - RCC grains before (top row) and after impregnation with syrup (bottom row).

Source: Authors (2025)

Figure 10 – Preparation of high-performance grout (top row) and doping of RCC aggregate (bottom row).

Source: Authors (2025)

CONCLUSIONS

As outlined in the introductory text, the mineral sector faces challenges related to the availability of natural resources, especially those located in or near urban areas. The reduction in the possibilities of exploiting these mineral resources raises concerns about the guarantee of future supply. At the same time, the construction industry is responsible for the significant generation of waste, most of which is not recycled. In this context, it is essential and urgent to develop a technique that improves the performance of low-quality aggregates or aggregates previously considered unsuitable for concrete production.

Therefore, this work presents the development of a high-performance grout through the control and mini-slump tests of the truncated cone, in addition to the setting time test preceded by tests to characterize the aggregate by determining its granulometry, fineness modulus, fines content, and absolute and unit specific mass, where the ideal additive content of 0.8% for the grout was determined. Thus, the efficiency of the technique of doping aggregates with high-performance grout was proven in terms of reducing the porosity of the RCC aggregate through doping with large quantities presented during the work, making it possible to use a discarded material as an alternative material in the preparation of structural concretes.

For future research, it is recommended to mold test specimens using RCC already treated with the doping technique with different substitutions for the conventional coarse aggregate to establish the viability of the technique due to the possibility of reducing the use of natural coarse aggregate in structural concretes and its possible complete replacement.

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