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REGULAR ARTICLE

Analysis of concrete characteristics with the incorporation of construction waste aggregates

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Abstract

In order to reuse civil construction materials, research is carried out to obtain an efficient recycled concrete, promoting sustainability. The objective of this work is to compare the compressive strengths of the concrete specimen, with conventional and recycled aggregates, as well as the influence of granulometry on the strength and physical properties of the aggregates. For this purpose, aggregates from civil construction waste were incorporated into the concrete, replacing part of the coarse aggregates. Specimens were made with the following replacement percentages: 0%, 5%, 10%, and 15%, for multiple comparisons. The control group had no replacement of conventional aggregates by recycled ones (0%). The following tests were carried out: granulometric, density, water absorption, compressive strength, and slump test. Recycled concrete presents itself as a viable option in non-structural concretes, presenting greater efficiency in the compressive strength test at granulometry of 4.75 – 9.50 mm, with 15% incorporation.

Keywords

Concrete; Construction; Sustainability

Introduction

Since ancient times, concrete has been used by humans to build housing. The evolution of this material over time can be seen as always seeking to adapt itself to the needs of civil construction. As such, plain concrete has high compressive strength and low tensile strength. Comparatively, steel has good compressive and tensile strength, but is more expensive than concrete. Aiming at a better performance of the material, concrete is combined with steel, conferring mechanical strength, and making it possible to use it with a structural function (Sunita., 2021).

According to Bauer (1995), the simple compressive strength is used to evaluate the quality of concrete, being extremely important to curing control. It is important to emphasize that knowing the values of compressive forces that concrete resists to is essential for design in civil construction. Concrete can be considered a composite material containing cement, mineral additives, water, aggregates, and chemical additives, so its rheological properties depend on the quantity and quality of each constituent used in the mixture, as well as their interactions. In general, the increase in paste volume causes an increase in the slump value and a reduction in yield stress and plastic viscosity (Amario et al. 2021). In fact, progress was made in relation to the physical-chemical characteristics of concrete, however, the aggressiveness of the materials to the environment was not treated with priority.

Cement is the second most consumed material in the world, right after water. For and because of that, the environment suffers several damages, such as the release of atmospheric gases in the production of cement, which corroborates with the greenhouse effect. The removal of non-renewable natural materials such as clinker, sand, and gravel also directly harm the environment (Mehta & Siddique, 2016). In order to reduce the extraction of non-renewable materials, the importance of reusing materials appears as one of the main topics in the 21st century (Amario et al, 2021).

Studies show that concrete recycling has been developed with the intent of protecting natural resources and eliminating

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waste, using as a source readily available concrete or aggregate to obtain new concrete, as well as for other uses. Approximately 850 million tonnes of waste are generated in demolition and civil construction annually in the European Union alone, which represents 31% of total EU waste production (Hassan et al., 2021).

Aggregates have received attention in recent decades due to the scarcity of natural aggregates and their ecological appeal. According to the incorporation percentage of recycled aggregates and the product quality, the compressive strength of concrete may vary. The civil engineer is responsible for indicating the most appropriate construction materials for the execution of the work, always looking for the highest quality concrete at the lowest price (Alqarni et al., 2021).

Aiming at sustainability, research involving the recycling of construction waste is increasingly frequent. Currently, civil construction waste does not have an efficient destination, since it is not often reused and frequently discarded on large scales. The production of recycled concrete has been studied in order to reuse waste in different forms, materials, and origins. With this premise, the incorporation of large aggregates from civil construction waste in the production of concrete proposes a material with less damage to the environment and equivalent resistance.

The present research had as general objective to compare the properties of density, water absorption, and granulometry of recycled aggregates with conventional aggregates. The specific objective was to understand how the granulometry and the incorporation of recycled aggregates in different percentages and curing periods influence the compressive strength of concrete.

Materials and methods

To carry out the research, conventional materials for making concrete were acquired; cement CP II-E32 (most used cement in the region of Lavras), medium sand, conventional gravel 0 (4.75 – 9.50 mm grain size), and conventional gravel 1 (9.50 – 19.00 mm grain size), obtained in a building material house in the city of Lavras, Minas Gerais State, Brazil. In addition to these, recycled aggregates were used, partially replacing conventional aggregates.

The recycled aggregates were collected at the rubble recycling station, located on road BR-040, Pampulha neighbourhood, in Belo Horizonte city, Minas Gerais State, Brazil. The materials were classified as ceramic, metallic, and polymeric aggregates. They were names according to NBR 10004 (ABNT, 2004) as Class II-Inert and by Conama (2002) and as I-Class A. After gross separation, a selection was carried out manually for the removal of remaining organic and metallic materials, according to NBR NM 10007 (ABNT, 2004).

To determine the granulometry of the materials, the sieving of the recycled aggregates was performed at the Civil Construction Materials Laboratory of the Lavras University Centre (UNILAVRAS). Construction and demolition waste (CDW) does not have a technical standard for methodological characterization of the material, so this step was performed according to Jesus et al. (2019). Then, a second sieving of the material was executed, to separate the granulometries used in the research, through an electric sieve of greater power and dimension.

In this work, 3 granulometries are present: the acronym G-1 refers to the material, which after being sieved, resulted in a granulometry of 4.75 – 9.50 mm; G-2 resulted in a granulometry of 9.50 – 19.00 mm, and G-3 is the mixture of 50% of G-1 with 50% of G-2, resulting in a granulometry of 4.75 – 19.00 mm.

The maximum characteristic dimension and the fineness modulus were found in accordance with NBR 7211 (ABNT, 2019). In order to compare the results with similar works, the average of the fineness modulus of the recycled aggregates with the conventional ones was calculated for each studied granulometry.

A small amount of the recycled aggregates was separated and transported for the density test, at the Experimental Unit in Wood Panels (UEPAM), on the campus of the Federal University of Lavras (UFLA). The recycled aggregates were submerged for 24 hours in water, then surface dried and weighed. Then, the recycled aggregate was weighed while submerged and then oven dried and weighed again. The entire procedure mentioned above was carried out in accordance with NBR 16917 (ABNT, 2021).

The proportion of the concrete mix was defined, according to Silva (1974), as 1.04 coarse aggregate: 0.7 sand: 0.4 cement: 0.21 water. Then, the moulding of the specimens began. Four specimens were used by composition, totalling thirty-two specimens by granulometry. Two curing periods were used, 21 and 28 days, as shown in Table 1.

Table 1. Identification of treatments.

Treatment	Granulometry	Curing time	Incorporation
1	4.75 - 9.50	21	0%
2		21	5%
3		21	10%
4		21	15%
5		28	0%
6		28	5%
7		28	10%
8		28	15%
9	9.50 - 19.00	21	0%
10		21	5%
11		21	10%
12		21	15%
13		28	0%
14		28	5%
15		28	10%
16		28	15%
17	4.75 - 19.00	21	0%
18		21	5%
19		21	10%
20		21	15%
21		28	0%
22		28	5%
23		28	10%
24		28	15%

The necessary amounts of each material were separated according to the trace. These were inserted into the concrete mixer in the following order: crushed stone, recycled aggregate, sand, cement, and water. For the homogenization of the concrete, the mixer was turned on for an average period of 5 minutes.

Then, Slump Test was performed according to NBR 16889 (ABNT, 2020).

Subsequently, the concrete was inserted into cylindrical moulds with a dimension of 10 cm in diameter and 20 cm in height, with the classification of the trace delimited by labels. After 24 hours, the specimens were demoulded and immersed in a curing tank with a saturated solution of calcium hydroxide at 23 ± 2°C. The entire moulding and curing process of the specimens was carried out in accordance with NBR 5738 (ABNT, 2016).

After removing the specimens from the saturated solution, the compression test was performed on a CI Model Press (Solocap brand), with an error of ± 1%. The entire process was executed in accordance with NBR 5739 (ABNT, 2018).

With the results of the compressive strength, statistical analyses were performed in the R software. The experiment was balanced with four treatments and four replications. To perform comparisons between treatments, an analysis of variance (ANOVA) was performed, as well as tests to verify data normality and homogeneity of variances. After finding significant differences between treatments, Tukey's Test of multiple comparisons was applied to verify which groups differed from each other. All tests were performed at a 5% significance level.

Results and discussion

Grain analysis

Table 2 presents the results of the granulometric test, for recycled and conventional aggregates.

Table 2. Granulometry of coarse aggregates.

G-1 (4.75 – 9.50 mm)	25.00 mm	19.00 mm	12.50 mm	9.50 mm	6.30 mm	4.75 mm	Bottom
Aggregate recycled (g)	3.13	9.03	46.80	474.37	642.97	303.37	20.33
Aggregate conventional (g)	3.76	16.80	213.07	523.57	364.00	218.30	160.50
G-2 (9.50 – 19.00 mm)	25.00 mm	19.00 mm	12.50 mm	9.50 mm	6.30 mm	4.75 mm	Bottom
Aggregate recycled (g)	38.00	484.17	720.37	213.87	32.80	8.89	1.90
Aggregate conventional (g)	202.27	727.83	456.14	50.93	22.20	9.30	31.33

For G-1, we have the predominant granulometry of 6.30 mm in recycled aggregate, and 9.50 mm in conventional aggregate. In relation to G-2, the predominant granulometry in the recycled aggregate is 12.5 mm, and 19 mm for the conventional aggregate.

Table 3 presents the characteristic maximum dimension and the characteristic fineness modulus of the aggregates.

Table 3. Maximum characteristic dimension and fineness modulus referring to granulometries.

Granulometry (mm)	Maximum characteristic dimension (mm)	Fineness modulus
G-1 (Recycled aggregate)	12.50	2.15
G-2 (Recycled aggregate)	25.00	4 .18
G-1 (Conventional Aggregate)	19.00	2.31
G-2 (Conventional Aggregate)	25.00	4.60

The maximum characteristic dimension for G-1 of recycled aggregate is 12.50 mm, and for conventional is 19.00 mm, while for G-2, both recycled and conventional aggregates are 25.00 mm (the maximum characteristic dimensions of the aggregates coincide).

The average fineness modulus of aggregates referring to G-1 (recycled aggregate) and G-1 (conventional aggregate) present an average value of 2.23, with a variation of 0.08. The average referring to G-2 (recycled aggregate) and G-2 (conventional aggregate) have an average value of 4.39, with a variation of 0.21.

These results differ slightly from the results found by Fonseca et al. (2018), where the analysis of the technical feasibility of incorporating recycled aggregates in concrete found average values of fineness modulus equal to 7.05, with a variation of 0.22.

Figures 1a, 1b, 1c, and 1d present the granulometric distribution of aggregates referring to G-1, recycled aggregate and conventional aggregate, as well as G-2, recycled aggregate and conventional aggregate, respectively. These are described through the ratio Percentage passing (%) by Diameter of grains (mm).

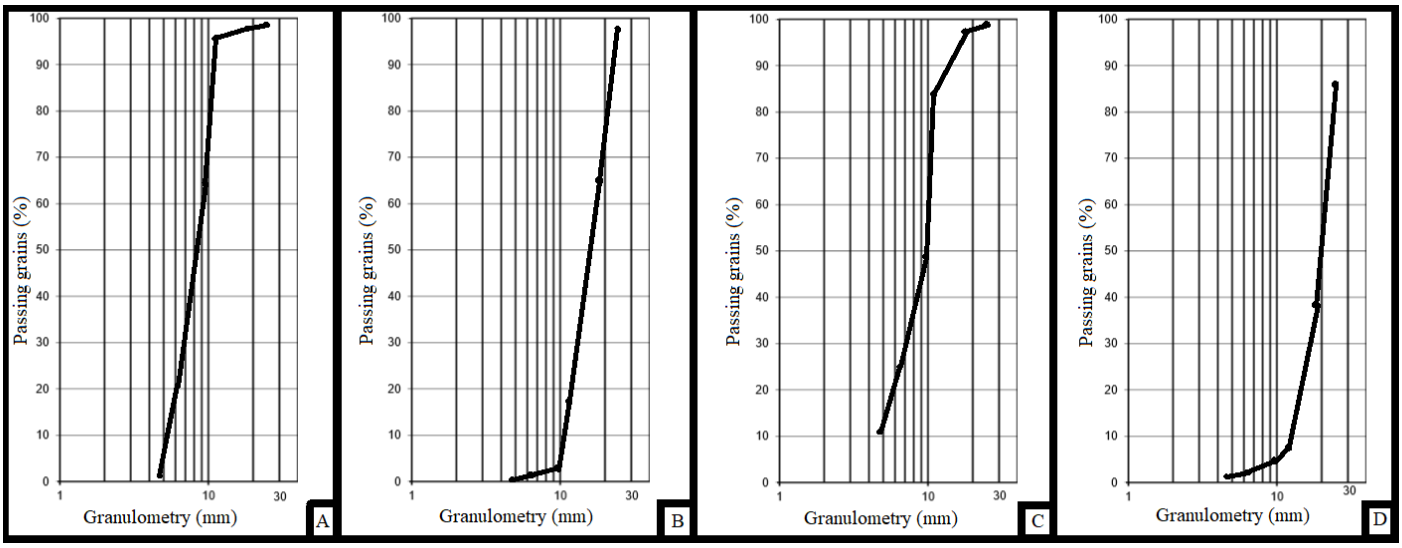

Figure 1. Aggregate granulometric distribution.

Based on the granulometric distribution curves, it is correct to state that all four types of granulometry present uniform distribution.

Density test

The results of the density test of recycled aggregates are shown in Table 4, bellow.

Table 4: Density test of recycled

Recycled aggregates	Saturated aggregate (g)	Submerged aggregate (g)	Dry aggregate (g)
G- 1 (4.75 - 9.50 mm)	3208.41	1800.06	2941.70
G-2 (9.50 - 19.00 mm)	3196.38	1806.26	2992.73

With the previous results, it was possible to find the densities and water absorption of the material, described in Table 5.

Table 5. Densities and water absorption of recycled aggregates.

Characterization	Recycled aggregate (4.75 - 9.50 mm)	Recycled aggregate (9.50 - 19.00 mm)
Density of dry aggregate (kg/m³)	2130.00	2160.00
Density of saturated aggregate on dry surface (kg/m³)	2280.00	2300.00
Apparent density (kg/m³)	2580.00	2520.00
Water absorption (%)	6.95	6.55

Note that the density of the recycled aggregate of granulometry 4.75 – 9.50 mm is 2130 kg/m^3 and water absorption is 6.95%. For recycled aggregates of granulometry 9.50 – 19.00 mm, the density is 2160 kg/m^3 and water absorption is 6.55%.

Table 6 presents the values of relative density and water absorption of recycled and natural (conventional) aggregates from the research by Limbachiya et al. (2000).

Table 6. Relative density and water absorption of aggregates

Property	Recycled aggregate		Natural aggregate	
Physical characteristics	10 - 20 mm	5 - 10 mm	10 - 20 mm	5 - 10 mm
Relative density (kg/m³)	2410.00	2400.00	2600.00	2600.00
Water absorption (%)	4.90	5.20	2.50	2.50

The results obtained for water absorption and density are in agreement with the work by Limbachiya et al. (2000), where the study of the use of recycled aggregates in high-strength concrete presented values close to those found in this research. According to the aforementioned author, recycled aggregate has approximately 7 to 9% less density and twice as much water absorption when compared to conventional aggregate, due to the material being more porous.

Slump Test

The results of the slump test are described in Table 7, bellow.

Table 7. Medium truncated cone slump test (Slump Test).

Granulometry (mm)	Treatments	0%	5%	10%	15%
G-1 (4.75 - 9.50)	21 days	20.00 mm	35.00 mm	25.00 mm	28.00 mm
G-2 (9.50 - 19.00)	21 days	32.00 mm	32.00 mm	34.00 mm	34.00 mm
G-3 (4.75 - 19.00)	21 days	50.00 mm	45.00 mm	18.00 mm	32.00 mm
G-1 (4.75 - 9.50)	28 days	40.00 mm	50.00 mm	35.00 mm	40.00 mm
G-2 (9.50 - 19.00)	28 days	30.00 mm	35.00 mm	40.00 mm	40.00 mm
G-3 (4.75 - 19.00)	28 days	78.00 mm	52.00 mm	54.00 mm	53.00 mm

To compare the results with other references, the table adapted from Ripper (1995) was used. Foundations and reinforced walls, with a consistency ranging from 'firm' to 'plastic', found reference values of 30 mm – 70 mm of slump.

Comparing the values found with Ripper (1995), all samples meet the specified workability, except for the following: 4.75 - 9.50 mm at 21 days with 0%, 10%, and 15%; 4.75 - 19.00 mm at 21 days with 10%; and 4.75 – 19.00 mm at 28 days with 0%. However, the difference is within the tolerance limits of 2 cm, being interpreted as a variation in the amount of porous materials (varying to a smaller amount of porous materials, in this case), which absorb more water, resulting in an increase in slump.

Frontte et al. (2017), studying the insertion of recycled aggregates, noticed that the values of the slump test decreased, since the recycled materials used were dry, and because they are porous, they absorbed water from the concrete, reducing its workability. In the case of this research, the slump values remained with an average difference of 5 to 10 millimetres, as they presented materials with higher and lower porosity, promoting a balance between the used aggregates.

Compressive strength tests

Figure 2 shows the mean strength results of treatments with a curing period of 21 days. The graphs show the standard deviation of the tests performed.

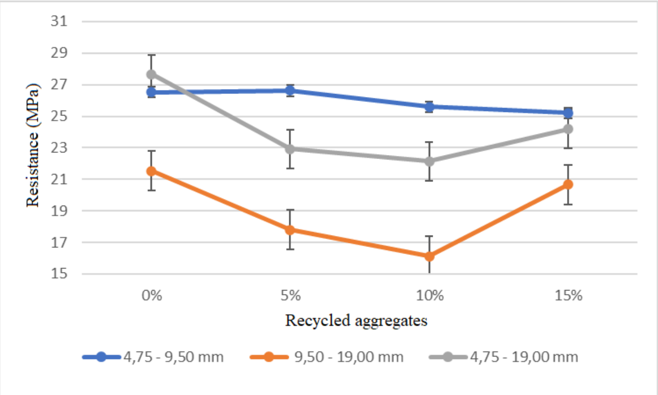

Figure 2: Mean strength (in MPa) of treatments with 21 days cure.

A progressive loss of strength can be observed in Figure 2, when comparing the percentages of 0%, 5% and 10%. However, when comparing 10% with 15% incorporation, there is a gain in strength for granulometries 9.50 – 19.00 mm and 4.75 – 19.00 mm. It is essential to point out that the granulometry 4.75 – 9.50 mm presents greater resistance than the other two granulometries studied, with 4.75 – 19.00 mm presenting intermediate resistance and 9.50 – 19.00 mm showing inferior resistance.

Figure 3 shows the mean strength results of treatments with a curing period of 28 days. It is observed that the compressive strength decreased when incorporating 5% and 10% of recycled coarse aggregates in the concrete. However, when comparing 10% with 15% incorporation, there is a gain in strength for the three types of granulometry. As occurred at 21 days of curing, the highest average strength was also observed in the granulometry of 4.75 – 9.50 mm.

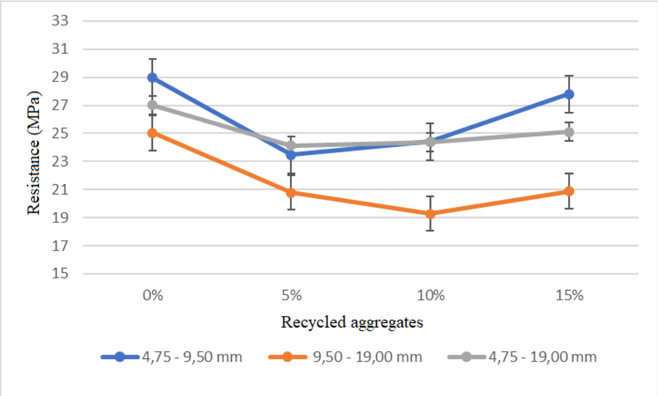

Figure 3. Average strength (in MPa) of treatments with 28 days cure.

When studying the recycling of concrete as coarse aggregate, McNeil and Kang (2013) found a 15% reduction in compressive strength when replacing the same percentage in recycled aggregates. In the case of this research, when performing the same comparison, values of reduction of the average compressive strength of approximately 4%, 7%, and 17% were found for granulometries 4.75 – 9.50 mm, 4.75 – 19, 00 mm, and 9.50 – 19.00 mm, respectively.

Statistical analysis

Table 8 presents the analysis of variance (ANOVA) referring to the compressive strength of the specimens.

Table 8: ANOVA results referring to the compressive strength of the treatments.

Treatment	Period	p-value
4.75 – 9.50 mm	21 days	0.1270
	28 days	0.0030*
9.50 – 19.00 mm	21 days	0.0068*
	28 days	0.5210
4.75 – 19.00 mm	21 days	0.3340
	28 days	0.5090

* Significant at 5% significance level by the F test.

The treatments with 21 days of curing referring to the granulometries of 4.75mm - 9.50 mm and 4.75 mm - 19.00 mm, as well as the ones with 28 days of curing referring to the granulometries 9.50 mm – 19.00 mm and 4.75 – 19.00 mm have a p-value > 0.05. Hence, there is no significant difference between the treatments tested, that is, the resistance values are statistically equal.

The treatments with 21 days of curing referring to granulometry of 9.50 - 19.00 mm and with 28 days referring to granulometry of 4.75 - 9.50 mm present statistical significance ($p < 0.05$). Therefore, there is a difference between the treatments tested, which is to say the resistance values are statistically different. For these treatments, Tukey's Test was performed to identify which concentrations differ in mean strength (Table 9).

Table 9. Tukey's Test for mean strengths of treatments.

Percentage of reused aggregate	4.75 – 9.50 mm. 28 days	9.50 – 19.00 mm. 21 days
0%	28.95 MPa A	21.52 MPa D
5%	23.46 MPa B	17.80 MPa DE
10%	24.42 MPa BC	16.12 MPa E
15%	27.80 MPa AC	20.67 MPa D

* Treatments with the same letters do not differ from each other at the 5% level of significance by Tukey's Test.

Table 9 shows that there is no significant difference between the control group and the 15% concentration, between the 5% and 10% concentrations, as well as between the 10% and 15% concentrations. The other combinations differ from each other.

It can be seen from Table 9 above that the concentrations of 0%, 5%, and 15% showed no significant difference between them. The resistance of the 10% concentration was statistically equal to the 5% concentration and different from the others.

Regarding compressive strength, it is recommended for granulometry 4.75 – 9.50 mm, at 28 days of curing, the use of 15% of recycled aggregate, since its compressive strength does not differ statistically from the control group. Regarding the granulometry of 9.50 – 19.00 mm, at 21 days of curing, it was observed that the compressive strength for the replacement of 5% and 15% did not show statistical difference from the control group.

In the research carried out by Bedoya and Dzul (2015), the following percentages of recycled aggregate in concrete were compared: 0%, 25%, 50%, and 100%. In relation to the 25%, there was an explicit loss of resistance of approximately 2.5% at 28 days and 2% at 91 days. According to Goldschmidt (2018), when incorporating 20% of recycled aggregates, a gain of 6MPa (about 20%) in compressive strength was found, when compared to 10% incorporation. When comparing the data of this research with the ones from the authors mentioned above, we found results close to 10% and 15%, and observed a resistance gain between 15% and 20%. Thus, this concrete presents good performance, meaning that its use in non-structural concrete is viable.

Conclusions

The tests performed revealed that recycled aggregates have lower density and higher water absorption when compared to conventional aggregates. Regarding workability, the values obtained from the slump test remained within the normal range.

Comparing the three studied granulometries, the option that confers greater resistance to compression is that of 4.75 – 9.50 mm. With intermediate strength, a granulometry of 4.75 – 19.00 mm was found. Finally, the granulometry of 9.50 – 19.00 mm showed the lower value of strength among all.

Recycled aggregates present themselves as a viable option for use in concrete, specifically in incorporation percentages of 5%, 10%, and 15% in granulometries of 9.50 – 19.00 mm and 4.75 – 19.00 mm. For granulometry of 4.75 – 9.50 mm, it is recommended to use 15% of recycled aggregate incorporation, since it does not differ from the control group in terms of compressive strength.

As a focus for future research, the aim is to investigate which incorporation of recycled aggregates is optimal, requiring studies of incorporation percentages between 15% and 25%. It is also proposed to study the economic feasibility of incorporating the material and the influence of chemical additives aiming at increasing the mechanical performance of recycled concrete.

Therefore, the concrete produced through recycled aggregates, in the specified proportions and granulometry, presents itself as a viable option for use in non-structural concrete.

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