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Influence of Cocoa Pod Ash on the Strength and Abrasion Properties of Concrete

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ABSTRACT

This paper investigates the compressive strength and abrasion properties of concretes incorporating cocoa pod ash (CPA) as partial cement replacement. Cocoa pod was calcined to ash at 600^0 C for 5 hours and sieved through 75 microns. Concrete mix of 1:2:4 was prepared at 0.5 w/b ratio and cement content was replaced with CPA at 0%, 5%, 10%, 15% and 20% separately in concrete mixes identified as CPAC0, CPAC5, CPAC10, CPAC15 and CPAC20 respectively. Oxide composition of CPA gave the sum of (SiO_2 + Al_2O_3 + Fe_2O_3) to be 72.04%. Slump of fresh concrete increased with increase in CPA content due to its likely hygroscopic nature. The setting times were longer in CPA pastes than in PLC paste. The results of the compressive strength at 7, 14, 28 and 56 days were determined while abrasion was investigated at 28 and 56 days. Results indicate that CPA can confidently replace cement in concrete up to about 15% by weight with favorable results and no deleterious effects relating to strength and abrasion.

Key words: Abrasion, Cement, Cocoa pod ash, Compressive strength, Concrete, Replacement

Abbreviations: CPA, cocoa pod ash; CO_2, carbon dioxide; SCM, supplementary cementitious materials; LoI, loss on ignition,

I. INTRODUCTION

The demand for cement-based materials is increasing with the growing industrialization and population. Concrete as the most used building material, faces some challenges: pollution and wastes generated through the activities of cement plants, indiscriminate harvesting of natural resources. The process of cement production is responsible for the release of about 8% of total CO_2 generated in the world [1]. This is highly harmful to human beings and the environment.

Many studies are now geared towards development of suitable cement substitutes and a remedy to reduce or avoid the use of cement. The common groups or classes of studies searching alternative to cements are the investigation involving natural pozzollans that are mainly derived from volcanic magma materials and the use of organic materials that are industrial by-products. A great attempt to contest shortfall of cement is the development of alternative binders targeting to reduce the environmental impact of construction, application of higher proportion of waste pozzollans and to improve concrete performance [2, 3].

Supplementary Cementitious Materials (SCM) are mostly integrated in concrete mix to minimize cement contents, improve fresh state properties especially workability, increase strength, enhance durability and ultimately reduce cost [2, 4]. One common class of SCM is the pozzolan family. Pozzolan is defined as a siliceous material which by itself possesses no cementitious properties but in processed form and finely divided form, react in the presence of water with lime, to form compounds of low solubility having cementitious properties [5]. Many existing structures in the advanced countries were built with the use of pozzolan-cement composites. Researches have reported that the performance of most agricultural wastes ash as pozzolans depend on the type and quantity of amorphous silica content such ash contains which further relies on the duration and temperature of the calcination process [6, 7].

Cocoa Pod is the hard husk that covers the cocoa beans (Theobroma cacao). The pod is a waste from agricultural product which is usually left to decay naturally or seldom burnt. It constitutes about a fourth part of the total fruit mass. Many agricultural wastes like rice husk, groundnut husk, palm kernel husk and many others have been researched as partial cement replacement in concrete but literature is very sparse on concrete incorporating cocoa pod ash. This study aims to investigate some structural properties of concrete containing cocoa pod ash (CPA).

II. MATERIALS AND METHODS

i. Materials

The materials used in this study were locally sourced construction materials in Ado Ekiti, Ekiti State, South West Nigeria.

a. Cocoa Pod Ash (CPA)

Cocoa pods were obtained from cocoa farm in Ago Aduloju, a suburb area of Ado Ekiti Local government of Ekiti State. The pods were sun-dried, and burned to ash in a foundry furnace at Obasanjo Engineering Innovation Centre, The Federal Polytechnic, Ado Ekiti. The calcination was done at a temperature of 600 degree Celsius for a period of 5 hours. The ash was then sieved through 75 microns.

b. Cement

Portland limestone cement CEM II B-L (32.5 N) produced by Dangote Cement complying with [8] was used. The required bags of cement were purchased in one batch from the local construction market in Ado Ekiti, Ekiti State, South West Nigeria.

c. Fine Aggregate

The fine aggregate used is clean and continuous graded Fine River sand with specific gravity of 2.75 and fineness modulus (FM) of 1.82. The particle size distribution of the sand used is shown Figure 1.

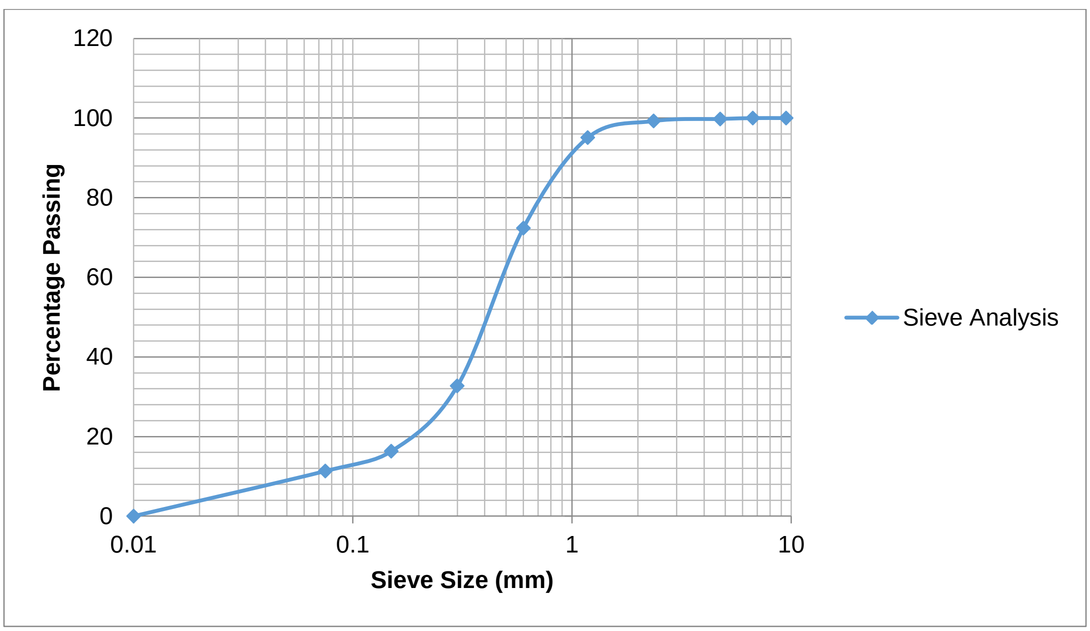

Figure 1: Particle Size Distribution Curve of the Sand

d. Coarse aggregate

The coarse aggregate used was granite of size 20mm. The granite was sourced from a quarry in the locality.

e. Water

Potable water from the School of Engineering bore hole was used to prepare the concrete.

ii. Methods

a. Oxide Composition

The oxide composition of the cocoa pod ash (CPA) and the cement were determined by using AAS Buck scientific 210VGP and Flame Photometer FP 902GP at Chemistry Department of Afe Babalola University, Ado-Ekiti (ABUAD), Nigeria in accordance with [9] for oxides present and especially the amount of Silica, Ferric oxide and Alumina present in them.

b. Mix design

The proportions of the concrete constituents are presented in Table 1 below. The table specifies the mix design of the CPA concrete made with water/ binder ratio of 0.5. A concrete mix ratio of 1:2:4 was adopted for the preparation of the CPA concretes. The fine and coarse aggregates contents were kept constant. CPA content of 0%, 5%, 10%, 15% and 20% replaced the cement content in the mix. This levels of replacement was adopted based on work done by previous researchers such as [10, 11, 12] among others who shave used agricultural wastes as cement replacement in concretes. A blend of the cement and the CPA percentage is referred to as the binder in this study. The experimental specimens are identified as shown in the Table 1.

Table 1: CPA Concrete Constituents Proportioning

Specimen identification	**CPA replacement level (%)**	**Cement content**	**Cocoa pod ash (CPA) content**	**Fine Aggregate (kg)**	**coarse Aggregate (kg)**
CPAC0	0%	13.885	0	27.7771	55.54
CPAC5	5%	13.190	0.694	27.7771	55.54
CPAC10	10%	12.496	1.388	27.7771	55.54
CPAC15	15%	11.802	2.082	27.7771	55.54
CPAC20	20%	11.108	2.777	27.7771	55.54

iii. Fresh State Tests

a) Slump

Immediately after mixing, fresh state tests were conducted on the CPA concrete mixes. The workability of CPA concrete was determined by conducting the slump test. The height of fall of the concrete is measured as the slump value.

b) Setting Times

The initial and final setting times of the binder (cement and CPA) were determined using the Vicat needle method

c) Curing method of the CPA concrete

After the production of the concrete, it was scooped into steel cube molds and compacted in 2 layers to avoid voids in the test specimens. The filled cubes were left on plane flat surface to avoid any form of disturbances. The concrete cubes were demolded 24 hours after casting and were placed inside a tank filled with water for curing in the laboratory. Curing was done till the testing ages of 7, 14, 28 and 56 days.

d) Hardened state tests

The tests performed on hardened concretes were compressive strength and abrasion tests in accordance with acceptable standard codes of practice.

III. Results and Discussion

i. Oxide composition

The oxides composition of the cocoa pod ash (CPA) and that of the cement is shown in Table 2. The sum of the major oxides for pozzolanic reaction (SiO_2 + Al_2O_3 + Fe_2O_3) is found to be 72.04% in CPA. This is greater than 70% and 50% stipulated by [14] ASTM C618 "Classification of Pozzolans" for Classes F and N pozzolans respectively.

Moreover, the SO_3 content of CPA is 2.08% which is considerably below the maximum permissible value of 5% recommended by the standard. Also, the loss on ignition (LoI) for the CPA is 5.01% which is less than the maximum permissible value of 10%. The LoI indicates that there are unburnt carbon content in the ash. The result designates CPA as highly pozzolanic according to the comparison presented in Table 3 below.

Table 2: The Chemical Composition of CPA and Cement

Constituent Oxide	% Composition in CPA	% Composition in Portland limestone Cement (PC)
Silica Oxide (SiO_2)	59.42	20.13
Aluminum oxide (Al_2O_3)	11.10	5.78
Ferrous oxide (Fe_2O_3)	1.52	2.35
Calcium oxide (CaO)	8.42	64.01
Magnesium oxide (MgO)	5.21	1.19
Sulphite (SO_3^{-2})	2.08	3.53
Loss on Ignition (LoI)	5.01	1.60

Table 3: Comparison of the ASTM C618 chemical requirements and CPA Pozzolanic composition

(Summary of the ASTM C618 (2008) for pozzolan classification)

	Class			
Chemical Requirement	N	F	C	GHA
SiO_2 + Al_2O_3 +Fe_2O_3 min. %	70	70	50	72.04
SO_3, max. %	4	5	5	2.08
Moisture Content max %	3	3	3	-
Loss on ignition, max %	10	6^A	6	5.01

ii. Fresh state results

a. Influence of CPA on concrete slump

The result of the slump test is presented in Table 4 and Figure 2. The result shows that the slump of the fresh concrete containing cocoa pod ash (CPA) increased with increase in CPA content. The respective slump values for CPAC0, CPAC5, CPAC10, CPAC15 and CPAC20 are 14 mm, 15.50 mm, 16.40 mm, 17.80 mm and 19.20 mm. This observation can be attributed to the effect of the fineness of the binder and the possibility that CPA is hygroscopic in nature.

Table 4: Slump Test Result for CPA Concrete

CPA concrete ID	% CPA replacement	w/b	Height of cone (mm)	Height of slump concrete (mm)	Slumps (mm)
CPAC0	0 %	0.5	300	286.00	14.00
CPAC5	5%		300	284.50	15.50
CPAC10	10%		300	283.60	16.40
CPAC15	15%		300	282.20	17.80
CPAC20	20%		300	280.80	19.20

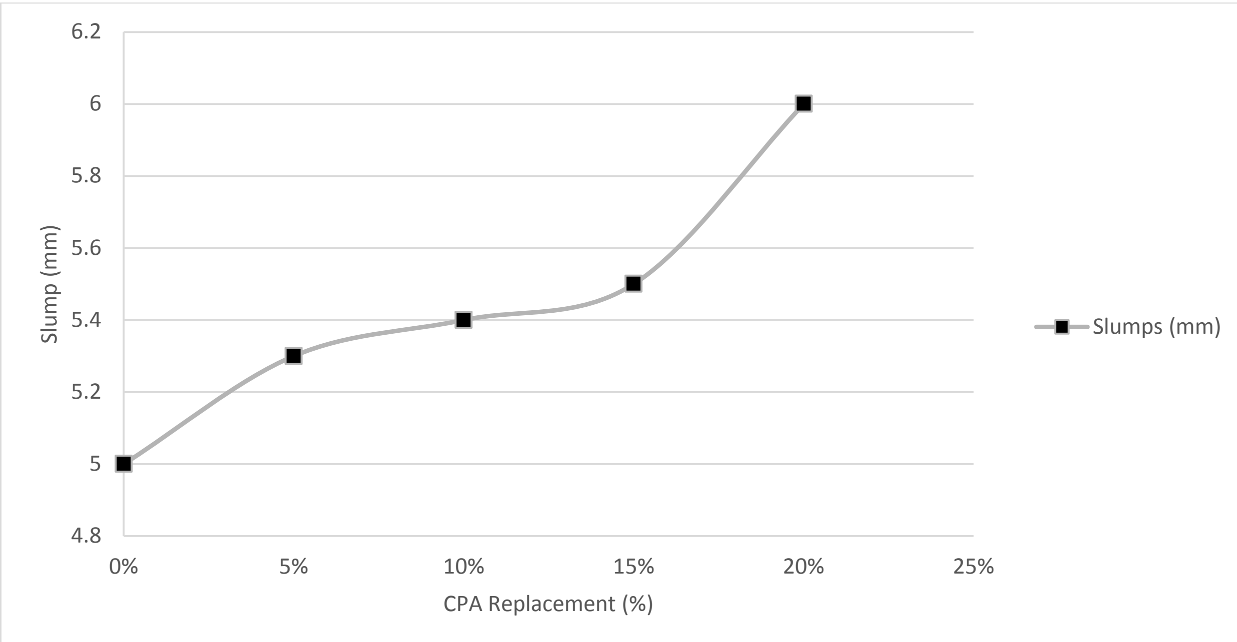

Figure 2: Slump result for CPA Concrete

b. **Effect of CPA on setting time**

The setting times of the binders (CPA and cement) is shown in Figure 3. The result shows that both initial and final the setting times of concretes containing CPA were longer than that of conventional concrete without CPA. The initial setting time of CPAC0 was 86 minutes while that of CPAC5, CPAC10, CPAC15 and CPAC20 were 100, 118, 129 and 177 minutes respectively. The final setting time of CPAC0 was 143 minutes while corresponding final setting times for CPAC5, CPAC10, CPAC15 and CPAC20 were 173, 206, 215 and 248 minutes respectively. This indicates that CPA retards setting of concrete and it can be used in concrete that has to be transported over a long distance.

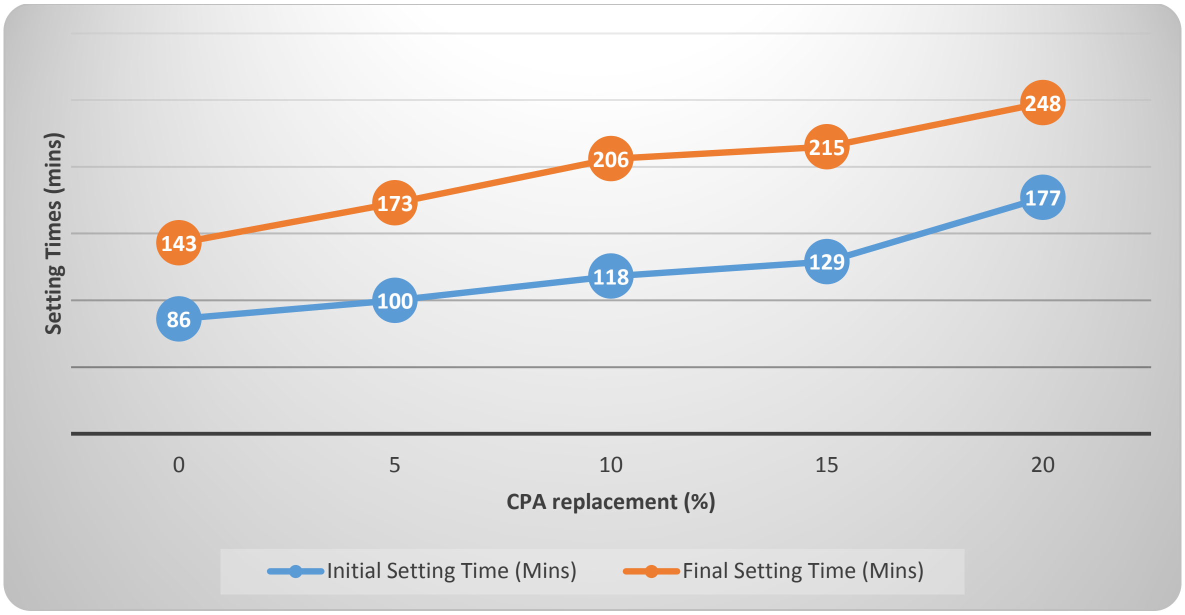

Figure 3: Initial and Final Setting Times of CPA Concrete

iii. Hardened state results

a. Compressive strength of CPA concrete

The result of the compressive strength of the CPA concrete is presented in Table 5 and Figure 4. The result shows that the compressive strength consistently increased as the age of the concrete increased irrespective of the level of CPA content in the concrete. For instance, the compressive strength of the CPAC5 were 13.83 N/mm^2, 14.39, 16.84 and 20.45 while that of CPAC20 were 11.25, 12.44, 13.68 and 15.60 N/mm^2 at the ages 7 days, 14 days, 28 days and 56 days respectively as considered in the study. This result is attributed to hydration through continuous curing.

Table 5: Compressive Strength of CPA Concretes

Specimen identification	CPA replacement level (%)	Compressive Strength of crushed cubes (N/mm^2)			
		7days	14days	28days	56 days
CPAC0	0%	14.55	15.24	16.40	18.84
CPAC5	5%	13.83	14.39	16.84	20.45
CPAC10	10%	13.61	13.93	16.23	19.80
CPAC15	15%	13.08	13.53	14.16	16.60
CPAC20	20%	11.25	12.44	13.68	15.60

At each age considered, it is noted that compressive strength improved with decrease in CPA replacement level. For instance, at age 28 days, CPAC20, CPAC15, CPAC10, CPAC5 and CPAC0 had 13.68, 14.16, 16.23, 16.84 and 16.40 N/mm^2 respectively. This performance is attributed to dilution effect.

It is also observed that the compressive strength of CPA5 and CPA10 at 56 days are higher than that of CPAC0 which earlier had highest strength value till 14 days of testing. The improvement in strength of concretes containing ash at the latter age is attributed to the fact that cement continues to hydrate and the silica from the pozzolan (CPA) reacts with lime produced as by-product of hydration of cement to form additional calcium-silicate-hydrate (C-S-H) that improves the binder performance and the compressive strength values at 56 days.

The progressions of the strength development beyond 28 days shows that the pozzolanic effect of CPA is more significant at latter ages of prolong curing. [13] observed similar trend when checking the strength of ternary blended cement sandcrete containing some agricultural by- products.

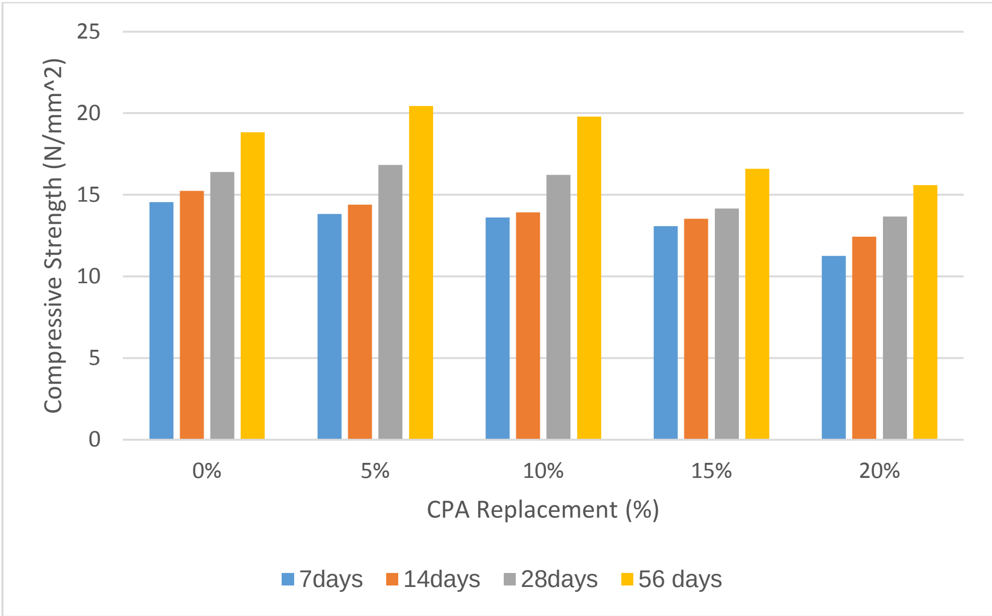

Figure 4: Comparison of compressive strength of CPA concrete

b. **Abrasion of CPA concrete**

The result of the abrasion is presented in Figure 5. It can be reasoned from the result that the abrasion of CPA concretes as well as the conventional concrete reduced with age. That is, as the curing age and compressive strength advanced, so the loss to abrasion reduced. The stronger concretes resisted the wear due to abrasion. For instance, the percentage loss due to abrasion at 28 days were 2.50, 2.57, 2.68, 2.73, 2.80 and the values at 56 days were 2.25, 2.29, 2.30, 2.48, 2.50 for concretes containing 0%, 5%, 10%, 15% and 20% CPA respectively. This behavior of CPAC0 (the conventional) is similar to that CPA concretes. There is notable relationship between the compressive strength obtained, curing age, abrasion resistance and percentage of CPA content.

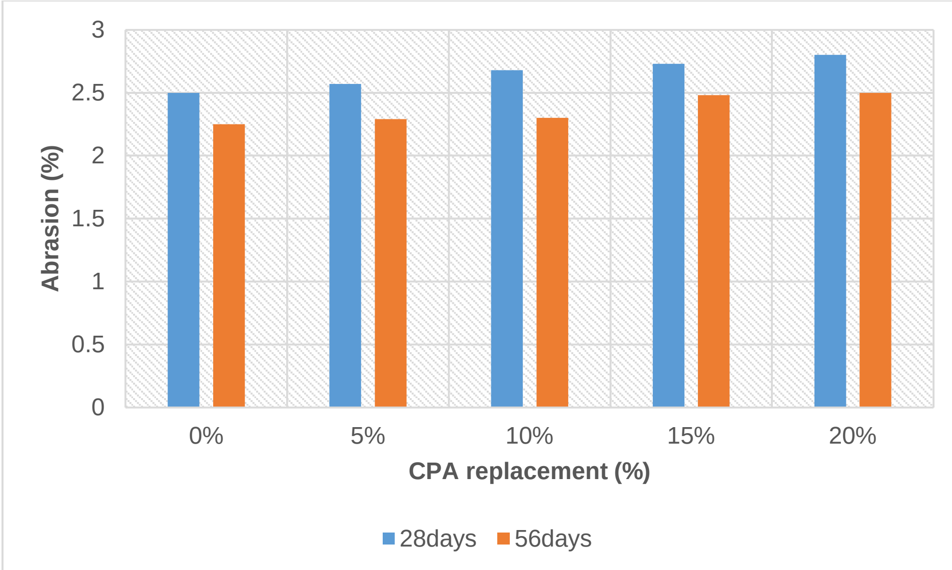

Figure 5: Abrasion of CPA concrete

IV. CONCLUSION

a. The sum of the major oxides for pozzolanic reaction (SiO_2 + Al_2O_3 + Fe_2O_3) is found to be 72.04% in CPA. This indicates that CPA is highly pozzolanic
b. Slump of the concretes increased with increase in CPA content due to the hygroscopic nature of CPA
c. The higher the CPA content, the longer the initial and final setting times
d. Compressive strength of the concretes improved with decrease in CPA replacement level and consistently increased as the age of the concrete increased irrespective of the level of CPA content in the concrete
e. There is notable relationship between the compressive strength obtained, curing age, abrasion resistance and percentage of CPA content.

V. FUTURE SCOPE

The future scope of this work should consider the durability of the concretes containing cocoa pod ash in some aggressive environments like chloride and sulphate rich environments.

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