Journal of the Korea Concrete Institute
Vol.17 No.1, pp.141~147, February, 2005

Fundamental Properties of Mortar and Concrete Using Waste Foundry Sand

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(Received, February 5, 2004; Accepted December 31, 2004)

Abstract

The development of automobile, vessel, rail road, and machine industry leads an increase of foundry production used as their components, which cause a by-product, waste foundry sand (WFS). The amount of the WFS produced in Korea is over 700,000 tons a year, but most WFS has been buried itself and only 5~6% WFS is recycled as construction materials. Therefore, it is necessary for most WFS to research other ways which can be used in a higher value added product. The study on recycling it as a fine aggregate for concrete or green sand has been in progress in America and Japan since 1970s and 1980s respaectively. In this study, two types of WFS were used as a fine aggregate for concrete. Nine types of concrete aimed at the specified strength of 30 MPa were mixed with washed seashore coarse sand in which salt was removed, and WFS and then appropriate mixture proportion of concrete was determined. Moreover, basic properties such as air contents, setting time, bleeding, workability and slump loss of the fresh concrete with WFS were tested and compared with those of the concrete mixed without WFS. In addition, both compressive strength of hardened concrete at each ages and tensile strength of it at the age of 28 days were measured and discussed.

***Keywords** : foundry sand, by-product, clay bonded sand, CO_2-silicate bonded sand, bleeding*

1. Introduction

As the concerns of environment have become higher, the Ministry of Construction & Transportation in Korea regulated the use of natural sand in civil construction, which brought out an undesirable influence on civil construction and ready mixed concrete company. As a result, it seems to be considerably short of sand needed in construction site.[4)] Hence this paper aims at recycling waste foundry sand (WFS) which has been usually done away with in foundry plants as a fine aggregate for concrete.

WFS is usually classified into clay bonded sand(CLW), furan resin bonded sand, CO_2-silicate bonded sand(COW), α -set sand, and resin coated sand etc. in accordance with types of foundry molds. The total amount of WFS is about 300 million tons a year, and the amount of the waste foundry sand produced in Korea is over 800,000 tons a year but most of WFS has been buried and in these days only 5~6% of WFS is recycled as construction materials.[1, 7)]

In addition, many problems such as site contamination, disposal cost and underground water pollution are occurred when it is buried under ground. The tipping fee reaches as high as $50 a ton, so the total cost of environmental compliance is rated-approximately 5% of the direct cost to produce a casting.

Therefore, many research have been done to change as a higher value added product. The study on recycling of WFS as a fine aggregate for concrete or green sand has been done in America and Japan since 1970s and 1980s respectively. In Japan, only 1.7% of WFS is buried and the rest of it is recycled; 86% of it as green sand and 12% as a fine aggregate for concrete.[2, 3)]

In this study, first of all, fundamental properties of CO_2-silicate bonded sand, clay bonded sand, and washed seashore coarse sand (WCS) of which salt was removed are

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evaluated. Then WFS is used as a fine aggregate for concrete. Concrete was *mixed with* WCS, COW and CLW aimed to be strength of 27 MPa. Moreover, basic properties such as air contents, setting time, workability and slump loss of the fresh concrete with COW and CLW were evaluated and compared with those of the controlled concrete without WFS. In addition, compressive strength of hardened concrete at each ages and its tensile strength at the age of 28 days were measured and investigated.

2. Experimental program

2.1 Materials

2.2.1 Cement

Table 1 shows chemical compositions and physical properties of Ordinary Portland Cement (OPC). Specific gravity is 3.15 and blain's fineness is 3,112 cm^2/g.

2.2.2 Aggregates

The chemical compositions and physical properties of CO_2 silicate bonded sand and clay bonded sand are as shown in Table 2.

Table 1 Chemical compositions and physical properties of cement

SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Ig. Loss (%)	Specific gravity	Blaine's Fineness (cm^2/g)
21.95	6.59	2.81	60.10	3.32	2.11	2.58	3.15	3,112

Table 2 Chemical compositions of waste foundry sand

Items / Types	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	Ig. Loss (%)
COW	84.30	5.95	0.42	0.85	0.16	1.01	5.61
CLW	90.41	2.62	3.71	0.33	0.52	-	-

COW : CO_2-silicated bonded sand, CLW : Clay bonded sand

WCS, COW and CLW are used as fine aggregates for concrete. The specific gravity and unit weight of COW and CLW are similar to each other but absorption and fineness modulus of them are different. Fine aggregates including COW and CLW are founded enough to be used as fine aggregate for concrete from the result of organic impurity test. Coarse aggregate which of maximum size is 25mm is used. The physical properties of coarse aggregates are shown in Table 3.

2.2.3 Chemical admixtures

The density of a calcium ligno sulphonate-based WRA and a neutralized resin-based AEA is 1.153 and 1.03 respectively. In this study, a calcium ligno sulphonate-based WRA is used to obtain appropriate slump. Chemical compositions and physical properties of chemical admixtures are shown in Table 4.

2.2 Mixture proportions

From the results of preliminary tests mortar mixed with 0~100% of COW and CLW respectively, COW and CLW replaced with natural fine aggregate of WCS from 0% to 50% were chosen and manufactured in accordance with KS L 5105 in mortar mixtures. Flow value was evaluated, and compressive strength was measured at the age of 3, 7 and 28 days. Mixture proportions of mortar were shown in Table 5.

In concrete mixture, compressive strength of concrete containing COW and CLW was 30MPa, the range of air content 4.5±1% and target slump 12±1.5cm. The concrete specimens in which COW and CLW were replaced as fine aggregates at the rate of 0, 20, 30, 40 and 50%, were manufactured. Compressive strength, elastic modulus and tensile strength of concrete with WFS were measured at the age of 3, 7, 28 and 56 days. Mixture proportions of concrete were shown in Table 6.

Table 3 Physical properties of fine and coarse aggregates

Items / Types	Specific gravity	Absorption (%)	Percentage of solids (%)	F.M.	Unit weight (kg/m^3)	Abrasion value (%)	Organic impurity
WCS	2.60	0.78	63.6	2.97	1,653	-	Good
COW	2.60	2.30	59.1	2.39	1,537	-	Good
CLW	2.62	1.12	58.7	1.40	1,539	-	Good
Coarse agg.	2.66	0.78	65.7	6.51	1,741	28.6	-

WCS : Washed seashore coarse sand

Table 4 Chemical compositions and physical properties of chemical admixtures

Items / Types	Main composition	Density at 20℃ (kg/ℓ)	Standard dosage (C× wt., %)	pH	Appearance
WRA	Calcium ligno sulphonate	1.153±0.005	0.5	8.0±1.0	Dark brown liquid
AEA	Neutralized resin	1.03±0.003	0.005	11.0±1.0	Transparent liquid

WRA : Water reducing agent, AEA : Air-entraining agent

Table 5 Mixture proportions of mortar

Types \ Items	W/C(%)	C(g)	W(g)	Sand (g)	
				WCS	WFS
Control	48.5	765	371	1874	0
COW10				1687	187
COW20				1499	375
COW30				1312	562
COW40				1124	750
COW50				937	937
CLW10	48.5	765	371	1687	187
CLW20				1499	375
CLW30				1312	562
CLW40				1124	750
CLW50				937	937

2.3 Testing methods

2.3.1 Harmful element analysis

Atomic absorption spectrophotometry and inductively coupled plasma spectroscopy were carried out to investigate whether COW and CLW that are industrial discharges have harmful effect on human body or not.

2.3.2 X-ray diffraction

For the purpose of investigating chemical compositions of COW and CLW, X-ray diffraction (XRD) analysis of powder sample passing over 150 ㎛ sieve was carried out. Measurement conditions were CuKα (Ni filter): 30kV, 20mA, scanning speed: 8°/min, full scale 7000cps, 2θ: 5° ~ 60°.

2.3.3 Setting time and bleeding of concrete

Setting time and bleeding of concrete containing WFS as fine aggregate were measured in accordance with KS F 2436 and KS F 2414 respectively.

2.3.4 Slump loss of concrete

Slump of concrete was measured in accordance with KS F 2402 at 0, 30, 60 and 90 min. after mixing in order to investigate the ratio of slump loss of concrete containing fine aggregate over elapsed time.

2.3.5 Compressive, tensile strength and elastic modulus of concrete

After ϕ10×20 specimens were manufactured and cured at standard curing condition, compressive strength was tested in accordance with KS F 2405, tensile strength was measured in accordance with KS F 2423 (testing method for splitting tensile strength of molded concrete cylinders) and elastic modulus were measured in accordance with KS F 2438.

3. Test results and discussions

3.1 Characteristic of waste foundry sand

3.1.1 Grading

In order to investigate the chemical compositions of COW and CLW, X-ray diffraction (XRD) analysis of powder sample passing over 150㎛ sieve was ~~is~~ carried out. Fig. 1 shows the results of XRD. While the most peak points of COW are silicate in this figure, that is, it seems that COW is consisted of silicate substances, CLW is composed of silicate, $Ca(OH)_2$, and $CaCO_3$ because of the difference of manufacturing method and processes of foundry molds. The particle size and shape of COW, CLW are smaller and angular compared to natural fine aggregate due to 1st, 2nd crush processes.

Fig. 2 shows the grading curves of fine aggregates. Fineness modulus of COW and CLW are 2.43 and 1.40 respectively, which is smaller than other natural fine aggregate. The fineness modulus of natural fine aggregate is in a range of 2.3~3.1 that is generally used for concrete, however, Fig. 2 shows that grading curves of COW and CLW are deviated from the standard grading curve. Therefore, the fineness of COW and CLW was controlled to make up for smaller fineness modulus by using WCS whose fineness is higher than that of COW and CLW.

3.1.2 Harmful element analysis

In the case of replacing COW and CLW for fine aggregate, atomic absorption spectrophotometry and inductively

Table 6 Mixture proportions of concrete

Types \ Items	G_{max}	Slump (cm)	Air (%)	W/C (%)	S/a (%)	Unit weight (kg/m³)					WRA (Cx%)	AEA (Cx%)
						W	C	S		G		
								WFS	WCS			
Control	25	12±1.5	4.5±1	50	41.4	165	330	0	748	1053	0.60	0.006
COW20					41.4			148	590	1063	0.70	0.008
COW30					41.1			220	513	1069	0.74	0.009
COW40					40.8			291	437	1074	0.80	0.010
COW50					40.6			361	361	1079	0.87	0.013
CLW20					41.5			151	603	1064	0.23	0.013
CLW30					40.5			221	516	1083	0.23	0.013
CLW40					39.5			288	431	1102	0.23	0.013
CLW50					38.5			351	351	1120	0.26	0.014

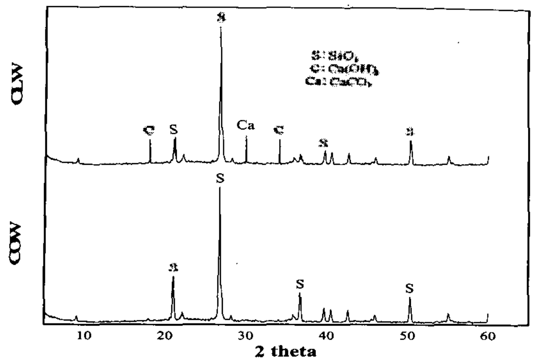

Fig. 1 X-ray Diffraction Analysis of WFS

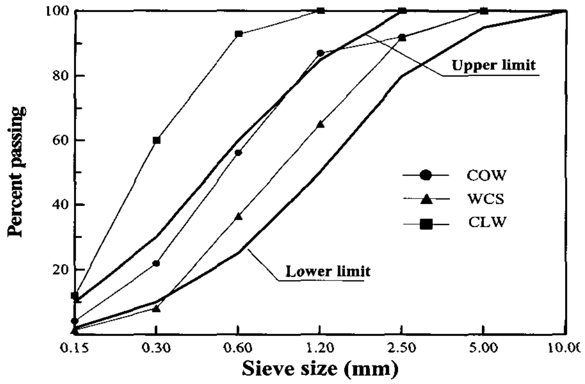

Fig. 2 Grading curve

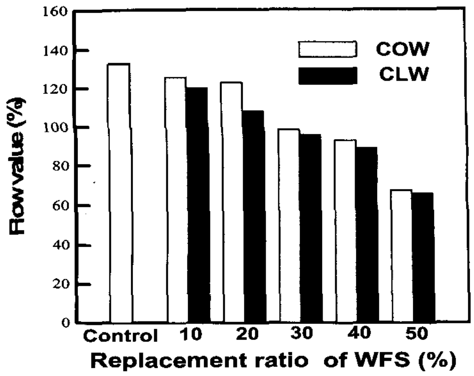

Fig. 3 Consistency of mortar

coupled plasma spectroscopy were also carried out to know whether COW and CLW have harmful element on human body, and the results are shown in Table 7. In this table extremely harmful cadmium (Cd) for human body was not detected and the content of arsenic.(As), chromium(Cr), copper(Cu) and lead(Pb) are found to be lower than limit value regulated in the wastes management law in Korea. Accordingly, in time using COW and CLW as fine aggregate for concrete, COW and CLW have no harmful effect on human body or environments.

3.2 Properties of mortar

3.2.1 Flow value

Fig. 3 shows the flow test results of mortar mixed with COW, CLW as fine aggregate. In this figure, flow value of mortar is very rapidly decreased with increase of the replacement ratio of COW and CLW regardless of types due to inappropriate size distribution, fineness modulus and particle shape of COW and CLW. However, the decreasing degree of flow value of mortar with CLW is a little bit higher than that with COW. The reason is that, due to the smaller particle size of CLW, mortar with CLW is more absorptive when mixed with water than mortar with COW.

3.2.2 Compressive strength

Fig. 4 shows the compressive strength of mortar according to the replacement ratio and the types of COW and CLW at the age of 3, 7, and 28 days. The compressive strength of mortar is decreased with increase of the replacement ratio of COW, CLW as same as in flow value. It is attributed to inappropriate size distribution, fineness modulus, and particle shape of COW, CLW compared to natural aggregates. In other words, the reason is that several properties of mortar replaced with WFS are decreased with increasing replacement ratio of COW and CLW.

3.3 Properties of concrete

3.3.1 Setting time

Setting time of fresh concrete mixed with COW, CLW of 0, 30 and 50% is shown in Fig. 5. In this figure, setting time of concrete with COW is a bit faster in accordance with increasing the replacement ratio of COW than that of control concrete. Because the increase of COW shortens the setting time of concrete due to rapidly setting by reaction of silicic acid sodium ($Na_2O{\cdot}nSiO_3$) encircled in the surface of WFS. On the other hand, setting time of concrete with CLW

Table 7 Harmful element analysis of COW and CLW

Items / Types	Al	As	Ba	Ca	Cd	Cr	Cu	Mg	Pb	Se	Zn
COW	6.389	0.058	ND*	13.268	ND	0.064	0.097	3.276	0.175	ND	0.814
CLW	54.316	ND	0.106	28.254	ND	0.069	0.196	16.262	0.335	ND	3.528
Limit value	-	<1.500	-	-	<0.300	<1.500	<3.000	-	<3.000	-	-

* : Non-detective

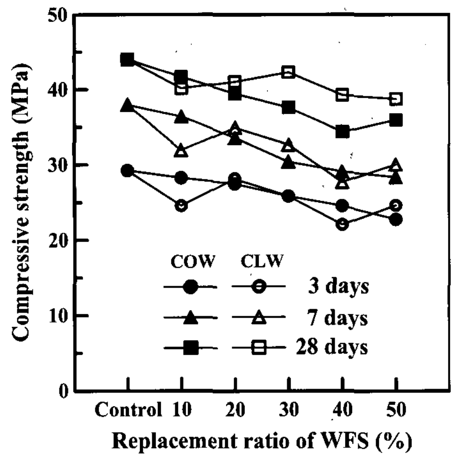

Fig. 4 Compressive strength of mortar

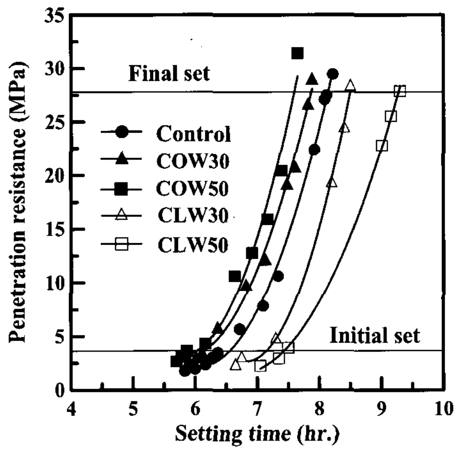

Fig. 5 Setting time of concrete

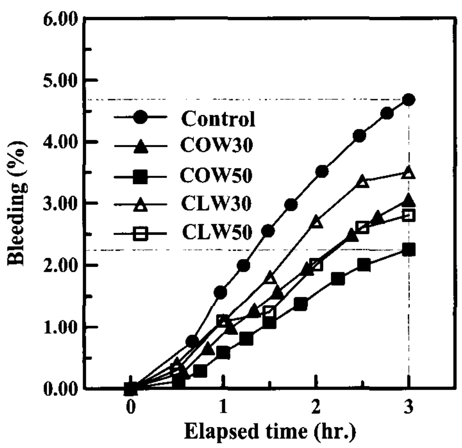

Fig. 6 Bleeding of concrete

is a bit slower with increase of the replacement ratio of CLW than that of control concrete. Because CLW has the property of holding water due to clay particles.

3.3.2 Bleeding

Fig. 6 shows the bleedings of fresh concrete. In this

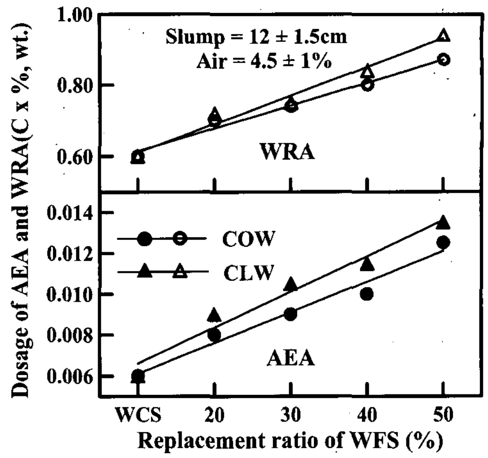

Fig. 7 Amount of WRA and AEA in concrete

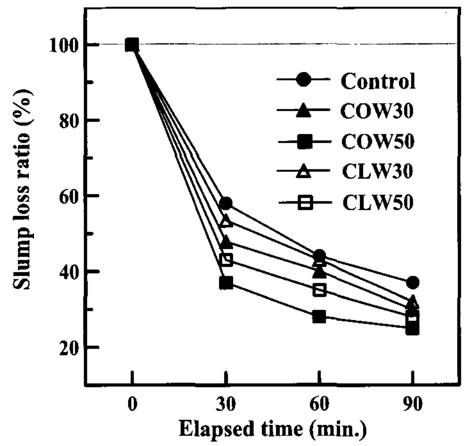

Fig. 8 Slump loss ratio of concrete

figure the bleeding of concrete with COW, CLW are decreased according to increasing replacement ratio of COW and CLW. In three hours, bleedings of concrete without COW and with COW 50% are 4.65% and 2.40% respectively. This reason is that fine particle absorbing mixing water is increased in accordance with increasing the amount of COW. However, the bleeding in case of concrete with CLW is a little higher than that of concrete with COW. The reason is that concrete with CLW has more retentive property of water due to clay particles.

3.3.3 Workability

Figs. 7 and 8 show the amount of AEA and WRA and the slump loss ratio of concrete mixed with WFS. In Fig. 7 the dosage of chemical admixtures is increased with increasing the replacement ratio of WFS by reason of poor grading, inferior particle of WFS. In Fig. 8 the slump loss ratio of concrete with CLW is lower than that of concrete with the COW owing to CLW's retentive property of water and due to rapidly setting by reaction of silicic acid sodium ($Na_2O{\cdot}nSiO_3$) encircled in the surface of WFS..

3.3.4 Mechanical properties

The compressive and tensile strength of concrete in accordance with replacement ratio of COW, CLW in W/C 50% at the age of 7, 28 and 56 days are shown in Fig. 9. The compressive and tensile strength are the highest in the case of concrete replaced with COW 30% irrespective of ages. It is attributed to minimize the porosity due to the reaction of silicic acid sodium encircled in the surface of COW.[5, 6)]

Meanwhile, on a certain occasion of concrete with CLW it is decreased with increasing replacement ratio of CLW. Fig. 10 shows the relationship between tensile strength & elastic modulus and compressive strength of concrete with COW and CLW. Tensile strength and elastic modulus of concrete is increased in proportion to compressive strength irrespective of the replacement of WFS.

It is indicated that linear relationship in concrete with COW is inclined to be similar to that in concrete with CLW as 83.3% of coefficient of determination in case of tensile strength to compressive strength, however, elastic modulus to compressive strength of concrete with COW and CLW makes different to each other, and coefficient of determination is 91.8% and 85.1% respectively.

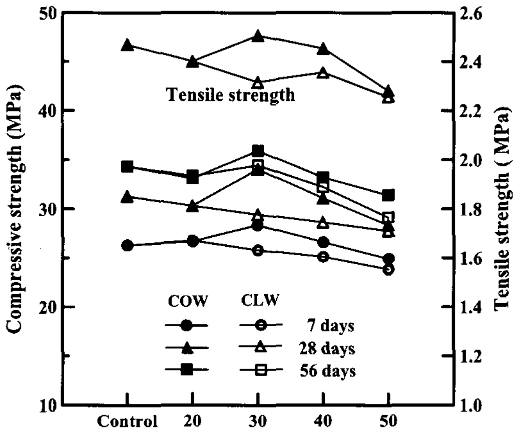

Fig. 9 Compressive and tensile strength of concrete

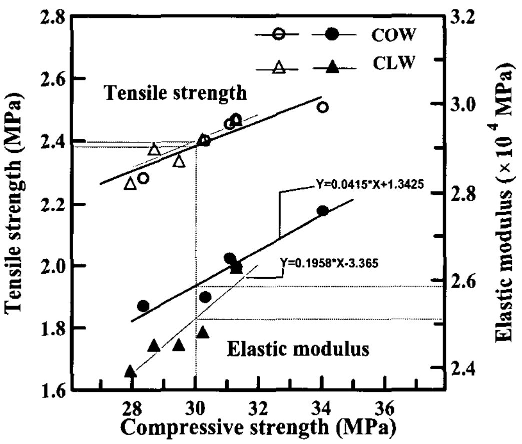

Fig. 10 Relationship between tensile strength and elastic modulus to compressive strength of concrete

This paper contains fundamental properties of concrete mixed with WFS, however, hereafter efflorescence problem of concrete mixed with WFS, and durability of concrete like freezing and thawing, carbonation for the sake of using WFS as fine aggregate for concrete will be evaluated.

4. Conclusions

Based on the results of this study, the following conclusions can be drawn:

1) Fineness modulus of COW and CLW are 2.43 and 1.40 respectively, which is smaller than that of WCS that is generally used as fine aggregate for concrete. Therefore, COW and CLW should be controlled to make up for smaller fineness modulus by using WCS that is higher than particle of COW and CLW.
2) Flow value of mortar is very rapidly decreased with increasing the replacement ratio of COW and CLW regardless of types due to inappropriate size distribution and particle shape of COW and CLW. But the decreasing degree of flow value of mortar containing with CLW is a little more than that with COW owing to higher absorption of mixing water.
3) The compressive strength of mortar is decreased with increasing the replacement ratio of COW, CLW. It is attributed to inappropriate size distribution, fineness modulus, and particle shape of COW, CLW compared to natural fine aggregates. In other words, several properties of mortar replaced with WFS are deteriorated according to increasing replacement ratio of COW and CLW.
4) Setting time of concrete with COW is a bit faster in accordance with increasing the replacement ratio of COW than that of control concrete due to the further promotion of the setting according to reaction of silicic acid sodium ($Na_2O{\cdot}nSiO_3$) encircled in the surface of WFS. Bleeding of concrete with COW, CLW are decreased according to increasing replacement ratio of COW and CLW.
5) In case of concrete mixed with COW of 30%, compressive and tensile strengths of concrete are higher than those of any other concrete without COW. In the case of concrete mixed with CLW, compressive and tensile strengths of concrete are a bit smaller than that of control concrete.

Acknowledgement

This research was supported by 2004th Research Institute of Industrial Science In Hanyang University. The financial support is gratefully acknowledged.

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