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Durability of Coconut Shell Concrete with Silica Fume

Hidayu Muri Abu Hussain [1], Noor Aina Misnon [2*], Faridah Hanim Khairuddin[2], Gunalaan Vasudevan[1], Nadia Zulkarnaen[2], Mohd Aiman Amzar Mohamad Pazli[2]

[1] Faculty of Built & Environment, Tunku Abdul Rahman University of Management and Technology, Kuala Lumpur
[2] Department of Civil Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, 57000, Kuala Lumpur

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ABSTRACT

Concrete is the most widely utilised construction material for construction. The largest portion of the volume in concrete comes from the coarse and fine aggregate. The constant removal of aggregates from natural sources has raised their cost and accelerated resource depletion. This study proposes the use of crushed coconut shells and silica fumes as replacements for aggregate and cement, respectively, to address the shortage of aggregate and the decarbonization of the environment. This study investigates the mechanical properties, durability (initial surface water absorption and carbonation resistance), and interfacial transition zone through microscopic examination of coconut shell concrete with 10% silica fume as a cement replacement. A microscopic examination was conducted to observe the bond between cement paste and coconut shells. 10% of silica fume as cement replacement has improved the strength of coconut shell concrete up to 20.3 N/mm^2. The durability of coconut shell concrete with silica fume is more reliable than coconut shell concrete itself since the coconut shell concrete has been filled with silica fume particles. Therefore, it was demonstrated that coconut shell concrete mixed with silica fume is an acceptable substitution for concrete.

1. Introduction

Concrete is the most used material in construction due to its good strength characteristics. The concrete production requires a mixing of cement, aggregates (fine and coarse) and water. The most strength in concrete is contributed by the aggregates which occupies most of the concrete volumes with cement paste as a binder. Due to the high demand of aggregate not only in construction industries but also infrastructure, electronics, and cosmetics, resulted in high activities of mining and extraction of the aggregates that led to the conflict in environment and humankind [1-2]. Meanwhile, cement industry was reported as a significant contributor to the worldwide carbon dioxide (CO2) emission with about 5% of CO2 emission globally [3].

Numerous numbers of research have been carried out to discover as much as potential sustainable material as an alternative for aggregate fraction in concrete production including utilization of agricultural wastes such as palm kernel shell, corn cob, and coconut shell [4–8]. Crushed coconut shell (CS) has been utilizing as aggregate replacement since its hardness is comparable to hardwood and its promising mechanical properties [7] [9-10]. The finding on mechanical properties of concrete with CS as aggregate replacement, namely coconut shell concrete (CSC) showed promising results when the compressive strength of the CSC satisfies minimum requirements of lightweight aggregate concrete for structural applications [11]. However, the high cement content is required to produce the CSC with desired strength [7]. Thus, substitution cement with pozzolana is proposed to reduce the cement content and improved the strength of the CSC. Silica fume (SF) was found to be the most reactive pozzolan and has advantages in concrete strength improvement [12-15].

In this study, the use of SF as cement replacement in CSC was investigated with the objective of determining the mechanical properties and durability of the CSC with SF and to examine the interfacial transition zone (ITZ) through microscopic examination.

2. Methodology

2.1 Sample preparation and experimental testing

A total number of 45 concrete samples were cast with a design mix ratio of 1:1.6:0.7 (cement: sand: aggregate/CS) and cement content of 480 kg/m^3 that was adopted from [Gunasekaran et al.5]. The water-cement ratio (w/c) used was 0.42. The target strength for the concrete mixture was 20 MPa. The type samples consist of normal concrete (NC) as the control sample, coconut shell concrete (CSC), and coconut shell concrete with 10% silica fume replacement (CSC + 10% SF). Table 1 shows the design mix proportion for 0.05 m^3 concrete volume of the concrete mixture.

The concrete constituents were Ordinary Portland cement (OPC), and river sand, crushed aggregate with a maximum size of 15 mm, and crushed coconut shell. The crushed coconut shell was collected from the wider region of Klang Valley with the range size of 5 mm to 15 mm. Subsequently, the crushed coconut shell was soaked in water for up to 24 hours prior to the concrete mixing. The process allows the crushed coconut shell to absorb water and provide saturated surface dry (SSD) conditions. The samples were plastic wrapped for curing process up to 28 days (see Figure 1).

Table 1
Design mix proportion for 0.05m^3 concrete volume

Type of sample	Cement	Sand	Crushed aggregate	Crushed coconut shell	Silica fume
NC	27	44	19	-	-
CSC	27	44	-	19	-
CSC + 10%SF	24	44	-	19	3

*All units in kilograms

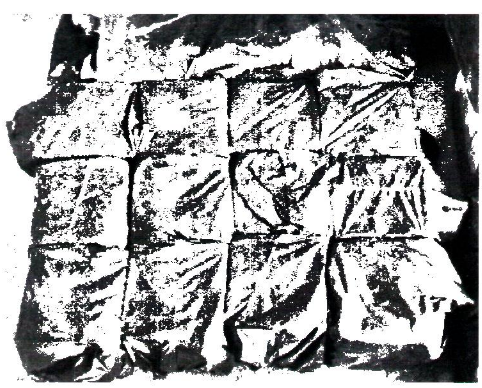


Fig. 1. Plastic wrapping curing

2.2 Laboratory Testing

2.2.1 Mechanical properties testing

Mechanical properties testing of the concrete samples consist of compression test, splitting tensile and flexural strength test. The compression test was conducted on 18 concrete samples with dimension of 150 mm x 150 mm x 150 mm at 7th and 28 days of curing period. The testing was conducted using universal testing machine (UTM) with a maximum capacity of 3000 kN according to BS EN 12390-3: 2009 [16].

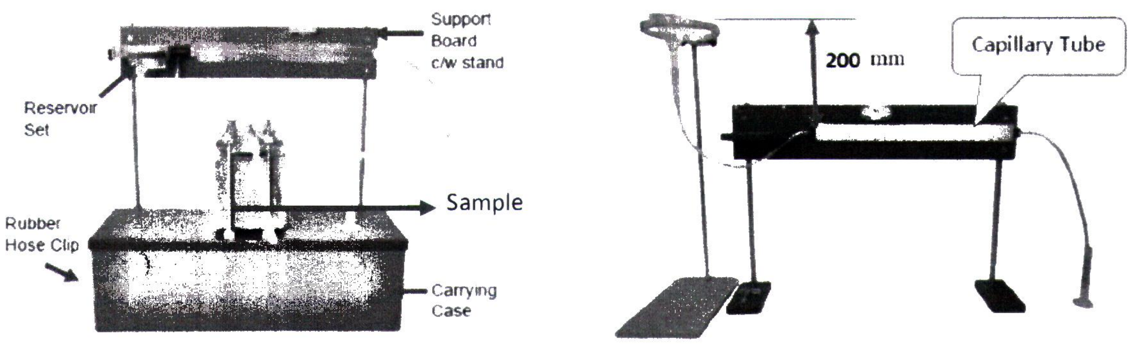
A total number of nine-cylinder samples with dimension of 150 mm diameter and 300 mm height were tested on splitting tensile strength in accordance with BS EN 12390-3: 2009 [17] after 28 days of curing period. Four point bending test was carried out to determine the flexural strength of the concrete samples at 28 days. The test was conducted on nine samples of concrete beamlets with size of 100 mm (W) x 100 mm (B) x 500 mm (L) according to BS EN 12390-3: 2009 [18].

2.3.3 Initial surface absorption test (ISAT)

The initial surface absorption test of the samples was conducted in accordance with BS 1881-206:1996. The test was carried out to assess the permeability of the concrete surface which provide information about the ability of the samples to absorb water. In this study, nine cube samples with dimension of 150 mm x 150 mm x 150 mm were tested at 28 days of curing. The test setup is shown in Figure 2. The reading was recorded at three intervals time i.e., 10 seconds, 30 seconds, and 60 seconds. The bore radius of the capillary tube, r (in millimetres) was calculated using the Eq. (1):

$$r^4 = KL/t \quad (1)$$

where K is a coefficient incorporating the viscosity of water and the geometry of the apparatus obtained from the values in Table 2, L is the length of the capillary tube (millimetre), and t is the mean time to collect 10 millilitres of water (seconds).



(a) (b)

Fig. 2. The test setup for ISAT (a) apparatus (b) calibration arrangement

Table 2
Coefficient of the viscosity of water

Water temperature (°C)	10	15	20	25	30
Factor, K	0.0167	0.0145	0.0128	0.0114	0.0100

2.3.4 Carbonation resistance test

The concrete carbonation resistance of the concrete samples was tested using an accelerated carbonation test according to ISO 1920-12:2015 [19]. The test was conducted in two conditions, i.e. controlled and uncontrolled environment. The concrete samples for controlled environment were kept in a chamber and were exposed with low rate of carbon dioxide gasses for up to five days while the samples were left outside in room temperature for uncontrolled environment exposure. The samples were sprayed with phenolphthalein to observe the carbonation depth. The percentage of colourless area which indicated the carbonated area was calculated to determine using a grid method (see Figure 3) and Eq. (2).

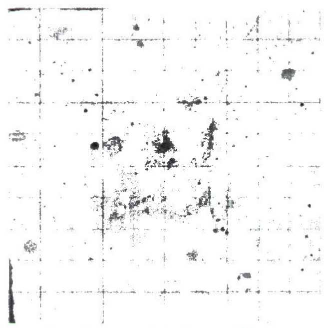
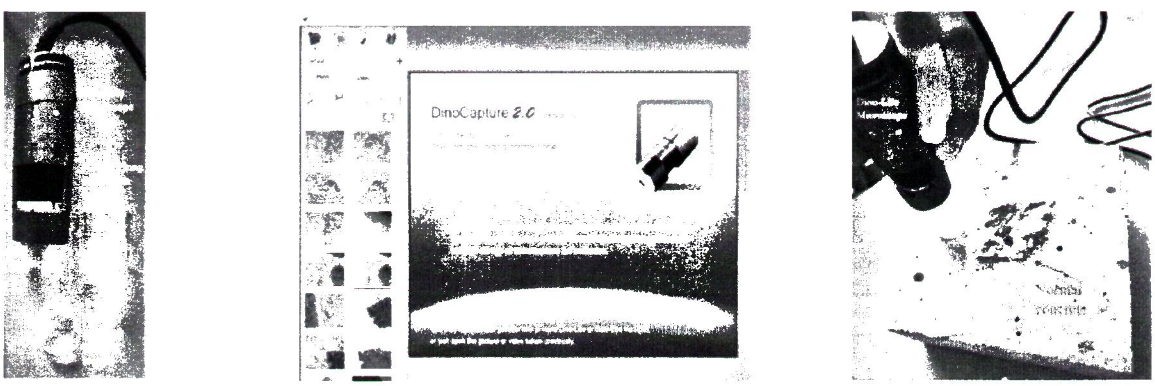


Fig. 3. Grid method with gridline 10 mm x 10 mm

Percentage of carbonated area, C (%) = area of colourless grid/total sample area x 100 (2)

2.3.5 Microscopic examinations

The ITZ of each type of samples was observed through the microscopic examination (ME) by using a Dyno-lite digital microscope as shown in Figure 4.



(a) (b) (c)

Fig. 4. Dyno-lite digital microscope (a) component (b) software interface (c) examination on concrete surface

3. Results

3.1 Density of samples

The density, ρ of the samples was calculated by dividing the mass (kg) with the volume (m^3) of the samples. Figure 5 shows the density of the samples at 1, 7 and 28 days of curing. All samples showed a similar pattern with density reduction between age of 1, 7 days and 28 days age of curing due to the loss of water for the hydration process until the samples achieved matured age at 28 days. Both CSC samples can be categorized as LWAC since the ρ were less than 2000 kg/m^3 at the age of 28 days of curing [20]. The mass reduction of CSC was expected since the crushed CS has lower bulk density when compared to the gravel [8]. Adding 10% SF in the CSC sample showed slight reduction in density at both 7 and 28 days of curing as result of replacing the cement content because SF has lower specific gravity and bulk density than cement [8].

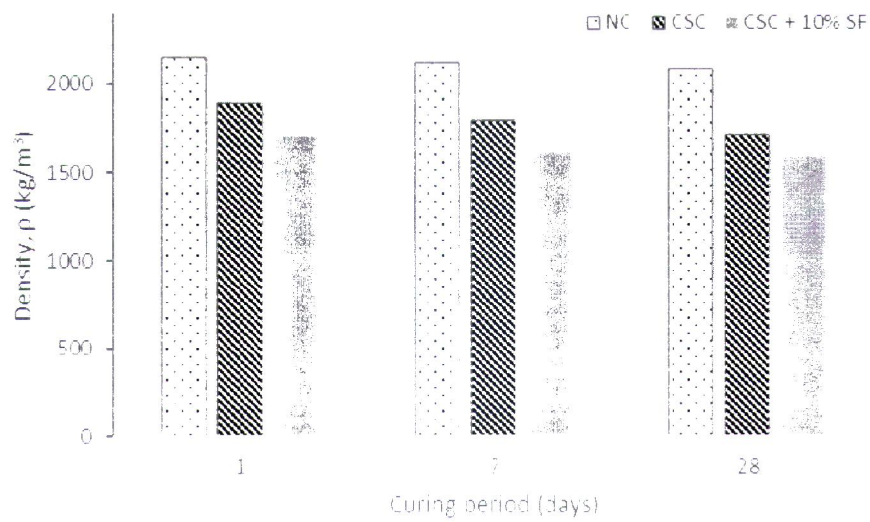


Fig.5. Density of the samples at 1, 7 and 28 days

3.2 Mechanical properties

Figure 6 shows comparison of compressive strength, f_c between all the samples at 7 and 28 days. All the samples showed that the f_c at 7 days achieved at least 70% of the ultimate strength at 28 days which agreed with the conventional concrete strength development. At the maturity age of the samples at 28 days, the f_c of CSC slightly decreased up to approximately 7% when compared to the NC. The f_c reduction was anticipated since the crushed CS has lower specific gravity [8] and led to weakening the concrete samples. However, substitution 10% cement with SF successfully to improve the f_c of CSC up to 20.3 MPa that comparable to the NC. It is notable that SF possess pozzolanic reaction by creating a compact and dense microstructure. All the samples satisfy the minimum requirement for f_c i.e., 17 MPa to be used as structural lightweight concrete [21]. The splitting tensile strength, f_t of the concrete sample is as shown in Figure 7. Replacement 10% of SF improved the f_t 5% and 15% when compared to the NC and CSC, respectively. The flexural strength, f_f of concrete provides fundamental information regarding to the behaviour of the concrete material under flexural stress. Figure 8 shows the results of FS for all the samples tested under four-points bending test. It is remarked that the replacement of crushed coconut shell reduced the f_f up to -7% when compared to the NC. Addition of 10% SF improved the f_f of CSC up to +11% and +2% relative to the NC samples.

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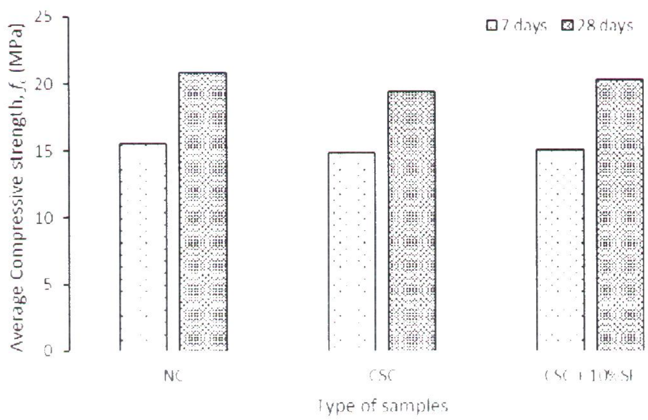


Fig. 6. Compressive strength of concrete samples

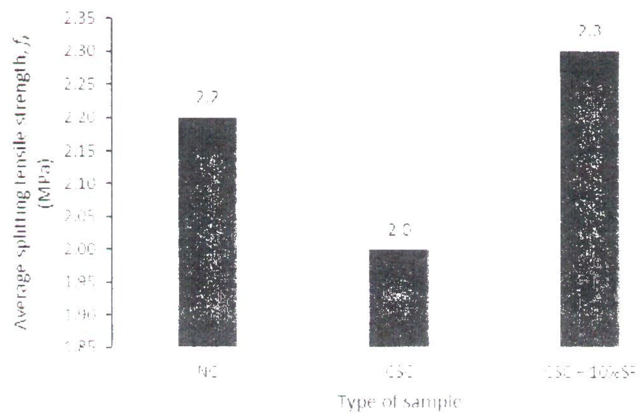


Fig. 7. Splitting tensile strength of the samples

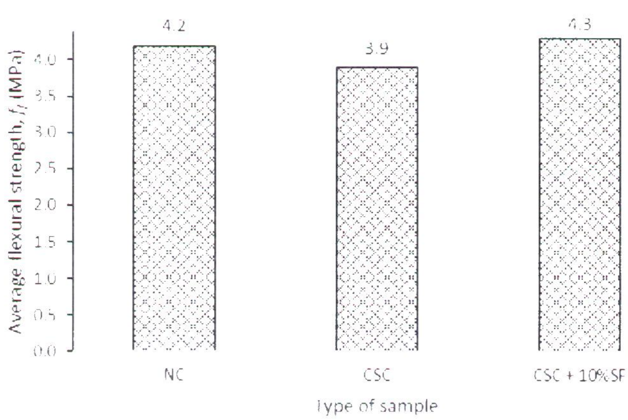


Fig. 8. Flexural strength of the samples

3.2 Initial Surface Absorption (ISAT)

The ISAT was conducted to assess the water absorption rate into the surface of the concrete samples by exposing water with a small head of pressure. The results indicate the permeability evaluation of the concrete samples. Figure 9 illustrates the initial surface absorption rate of the samples. The water absorption rate linearly increases with the time for all the concrete samples. This suggests that the concrete samples absorbed more water over longer periods of the interval time. The NC sample showed a higher water absorption rate relative to the CSC samples. The SSD condition of CS had a positive effect on the water absorption rate of CSC samples when the sample showed lower water absorption rate when compared to the NC samples. When employing SF, concrete is believed to have superior density and less porosity, which can lead to less water absorption. The use of SF to coconut shell concrete assisted in reducing the pores and gaps and preventing water from penetrating the samples.

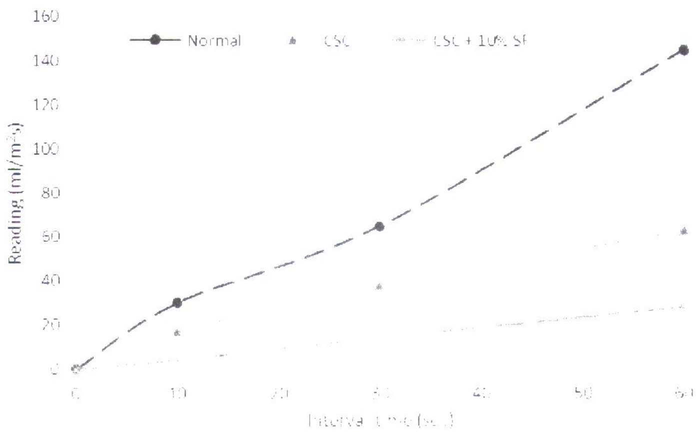
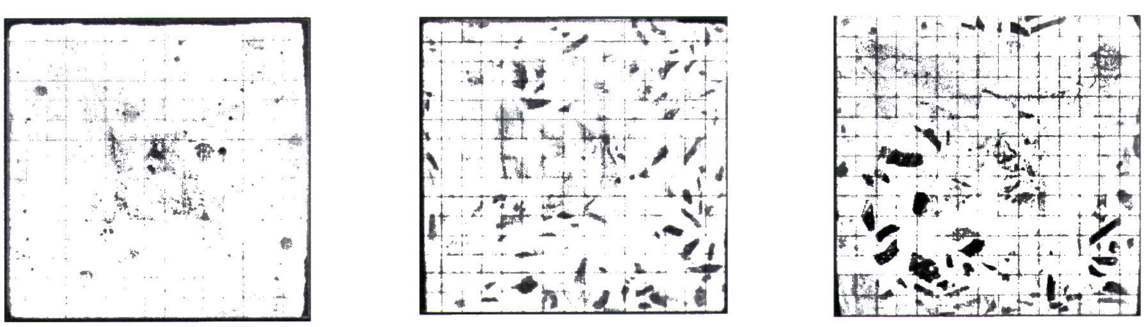


Fig.9. Water absorption rate of the samples for 60 seconds interval time

3.3 Carbonation Resistance

The reaction between CO2 in the atmosphere and the alkaline components of the concrete can be evaluated with carbonation test. In this study, the carbonation rate of concrete samples was presented as the percentage of the carbonated area (see Figure 10). The presence of purple color on the samples indicates that the area is not polluted with CO2. The NC samples showed the lowest carbonation rate with only 8% of the sample area polluted with CO2 (Figure 10a) while approximately 77% of the CSC sample area was carbonated (Figure 10b). Due to the high porosity of crushed CS, it allows more CO2 to penetrate the sample and consequently affects the carbonation rate. The CSC sample with 10% GGBS showed better result with only 13% of the area was polluted with CO2. In this situation, the CSC becomes denser and exhibits less permeability due to the pozzolanic reactions of SF.

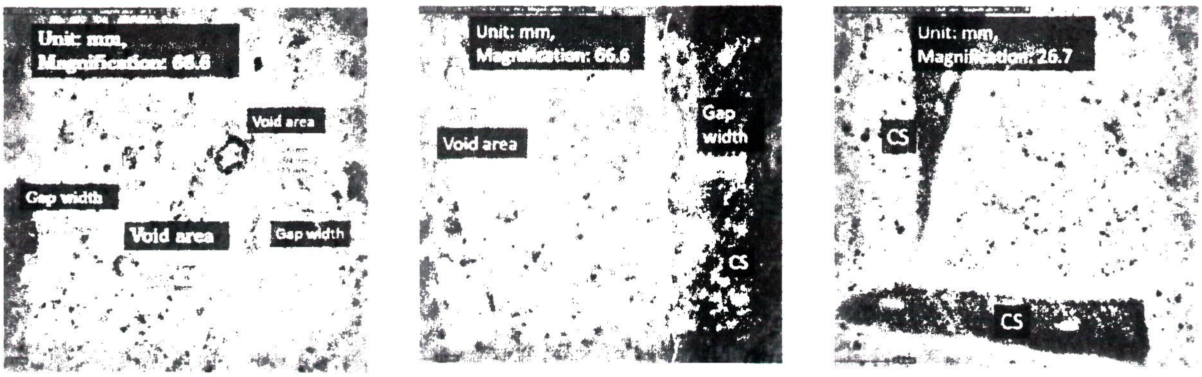


(a) (b) (c)

Fig. 10. Observation of (a) NC (b) CSC (c) CSC + 10% GGBS samples after carbonation test

3.4 Microscopic Examinations

The microscopic examination allows observation for the bond between the concrete matrix and identifying ITZ layer. A dense and well-compacted concrete mix minimizes the penetration of moisture and unwanted substances is suggested by the smaller length of the gap between the cement paste and aggregate and the small void areas. Figure 11 shows the microscopic view of the NC, CSC and CSC + 10% SF samples. Cement paste as cement hydration products can be observed well developed in all concrete samples. The NC showed more denser product (see Figure 11 (a)) when compared to the CSC samples (Figure 11(b) and Figure 11(c)) with the smallest gap between the gravel particle and cement paste. This suggests a strong bond which is also agreed with the f_c finding as previously discussed. The presence of small voids was also noticed in all concrete samples that might be affected from the inadequate compaction during the concrete mixing.



(a) (b) (c)

Fig 11: ITZ of (a) NC (b) CSC and (c) CSC+10%SF at 66.6x magnification

4. Conclusions

This study explores the potential of crushed CS to be utilized as coarse particles in concrete mix to produce LWAC. The mechanical properties and durability of CSC with addition of 10% SF as cement replacement was also studied. Microscopic examinations were carried out to gain more understanding in bonding structures between the concrete constituents. From the study, it can be inferred that:

i. The CSC is categorized as LWAC since the density is lower than 2000 kg/m^3 with promising mechanical properties was determined which are comparable to the NC.
ii. Incorporation 10% SF in CSC assists in strength improvement while reducing approximately 2% of the CSC density. The durability of the CSC was also showed better results with SF as cement replacement.
iii. A good bond between CS particles and cement paste was observed under microscopic examination with small gap was measured. Presence of SF showed better bonding and compact concrete matrix.

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