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Special Issue

Development of Dry Gunning Material with no Necessity of Drying Process for a Contribution to Carbon Neutrality

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1. Preface

The dry gunning method is broadly applied for repairing maintenance of environmental industry furnaces, such as general and industrial waste incinerators or biomass fuel power generation boilers, as well as nonferrous industry furnaces, such as aluminum melting furnaces or cement plants. Generally, in the applied dry gunning work, cement containing refractory material pneumatically transported by high-pressurized air is gunned with admixing water at the outlet of gunning nozzle. The gunned refractory body is densified by cement hydrate formation. Since water components in the gunned refractory body need to be removed by lengthy time drying, the overall repair maintenance period tends to be extended. In addition, because of heating with a gas burner by combusting biofuel like heavy oil, a large amount of CO_2 gas is emitted. For example, 50 hours of drying time is required after dry gunning repair maintenance on a mechanical stoker-type incinerator at A plant consuming 8.3 kl of A-type heave oil. When using 2.71 t-$CO_2 \cdot kl^{-1}$ of carbon dioxide emission factor of A-type heave oil[1], roughly 22 tons of CO_2 gas is emitted.

When a drying process is unnecessitated after dry gunning repair maintenance, CO_2 gas emission is expected to be reduced, contributing to the 13th issue of SDGs, i.e., "specific activities for climate change". In this regard, dry gunning refractory material which can be operatable just after ambient temperature curing, i.e., dry gunning refractory material with no necessity for a drying process, is developed in association with satisfactory performance in practical application. The details of newly developed dry gunning material are stipulated in the following sections.

2. Development of Dry Gunning Refractory Material with no Necessity for Drying Process

2.1 Outline of New Dry Gunning Refractory Material and its Effects

The reason for applying a drying process after repair work with conventional dry gunning refractory material is to remove the water component which is required for gunning operation. As a preventive measure for peel-off incidents of the gunned refractory body induced by explosive spalling, long-time steady drying is commonly applied so as not to increase internal vapor pressure unnecessarily. To realize dry gunning refractory material which does not need a drying process, the gunned refractory body should not be broken by explosive spalling even at quick heating in association with high permeability so as to suppress internal vapor pressure rise. For increasing permeability of the gunned refractory body, a refractory material system without cement as a binder is adopted. Considering possible explosive spalling caused by the poor mechanical strength of the cementless refractory body, the mechanical strength of the refractory body needs to be kept at a certain level.

As illustrated in Fig. 1, dry gunning refractory material is generally mixed with water at the outlet of gunning nozzle in gunning operation of conventional cement containing dry gunning refractory. Since gunning refractory material needs to be instantly coagulated by a coagulation agent, i.e., cement binder blended in refractory material which is dissolved into admixed water, the amount of admixed water at gunning nozzle

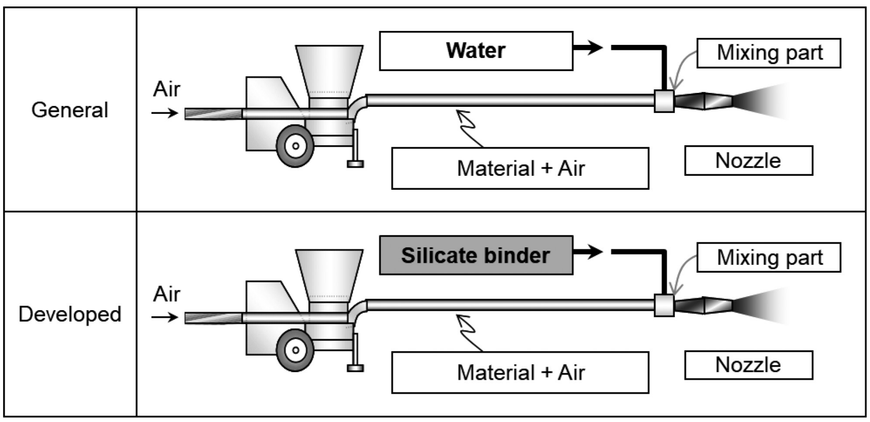

Fig. 1 Comparison of dry gunning operation between conventional and developed gunning material.

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Table 1 Blending compositions and major physical properties of conventional and newly developed dry gunning refractory material

Material	a	b	c	d
Type of binder	Cement	Powder silicate	Liquid silicate	
Chemical composition / mass%				
Al_2O_3	70	73	72	91
SiO_2	23	17	19	6
CaO	4			
Permanent linear change / %				
After firing 1400 ℃×3 h	-1.2	-2.7	-0.7	-0.4
Cold crushing strength / MPa				
After drying 110 ℃×24 h	31	4	18	15
After firing 1400 ℃×3 h	49	81	89	84

tends to be excessively increased. Furthermore, when the dissolution of a binder into admixed water is insufficient, the dispersibility of the binder in the gunned refractory body would deteriorate in association with the uneven structure of the gunned refractory body.

Taking these aspects into consideration, silicate water solution was applied, in place of water, for securing sufficient mechanical strength of the gunned refractory body. As indicated in the lower part of the illustration in Fig. 1, silicate water solution used as a binder in developed dry gunning refractory material can be supplied by a water feeding line which is used for water supply for gunning operation of conventional dry gunning refractory material. Thus, generally applied gunning machine works for newly developed dry gunning refractory material.

2.2 Characteristics of Binders and Gunned Refractory Bodies

Table 1 comparatively shows the blending compositions of conventional dry gunning material mixed with cement and newly developed dry gunning refractory material mixed with powder silicate or liquid silicate, along with the major physical properties of the gunned refractory body. The physical properties of the gunned refractory body were evaluated on a sample specimen which was prepared by casting gunning refractory mixture blended with a certain amount of binder into a mold with 160×40×40 mm of dimension.

It is apparent from Table 1 that the cold crushing strength of the sample specimen dried at 110 ℃ for 24 hours can be improved by exchanging the binder from powder silicate (binder b) to liquid silicate binder (binder c). Using another type of liquid silicate binder (binder d), which materializes a similar level of mechanical strength to the gunned refractory body sample specimen and is composed majorly of sintered alumina so as to endure high-temperature operation of environmental industry furnaces, the physical properties of its gunned refractory body sample specimen were compared with those of sample specimens with binder a (cement) or binder b (powder silicate).

3. Drying Property

3.1 Permeability

For preventing explosive spalling, it is efficient to increase permeability of the refractory body so as to lower water vapor pressure which is generated in the refractory body. Permeability of gunned refractory bodies containing binder a, b or d, which are dried at 110 ℃ for 24 hours or at 250 ℃ for 3 hours, is comparatively shown in Fig. 2. It is clarified that the permeability of gunned refractory bodies containing binder b or d is much higher than that of cement (binder a) containing gunned refractory body. It is inferred that the reason for the high permeability of gunned refractory bodies which do not contain cement (binder a) is that there is no calcium-aluminate hydrates in the refractory body.

3.2 Internal Water Vapor Pressure at Quick Drying

For estimating internal vapor pressure generated in binder d containing gunned refractory body at quick heating, a rapid drying experiment was conducted by plunging sample specimens, in which thermocouples and electrodes were embedded, into heated-up furnace. A schematic illustration for the rapid drying experiment is shown in Fig. 3, along with all the setups for the experiment. Anticipating an unlikely but possible incident of explosive spalling, a sample specimen was placed in

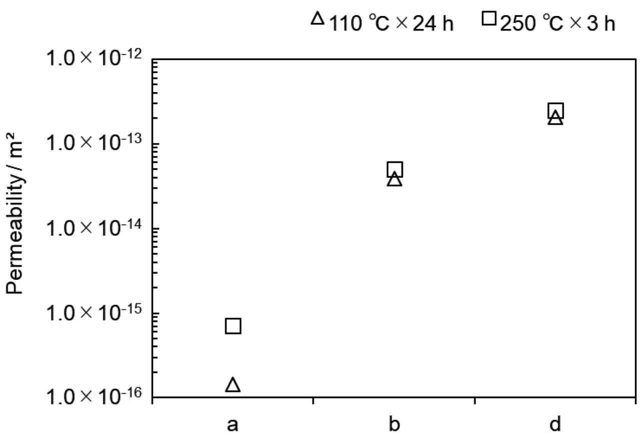

Fig. 2 Comparison of permeability of three types of gunned refractory bodies dried at 110 ℃ or at 250 ℃.

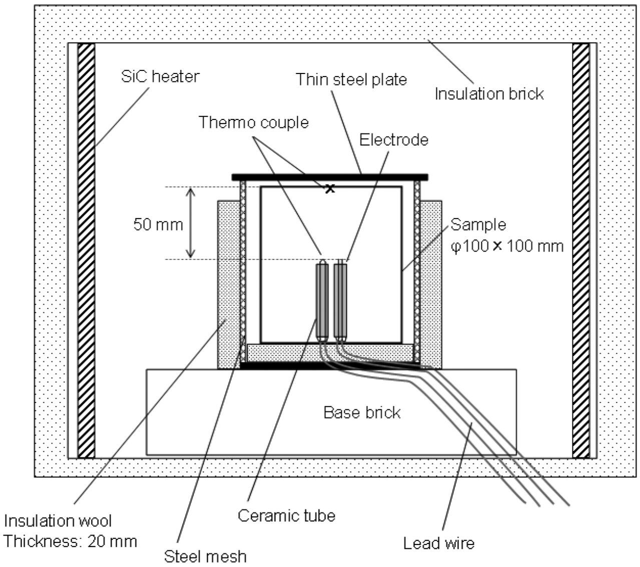

Fig. 3 Schematic illustration for rapid drying experiment for estimating internal vapor pressure generated in set-up sample specimen.

a cylindrical basket made of steel mesh, on whose side face and bottom base thermal insulation wool was installed so that the sample specimen would be heated up only from the upside. Taking into account their insulation and sealing properties, thermocouples and electrodes were run through ceramic tubes with tamping gaps with heat resistance shielding material. Embedded electrodes were used for measuring electric resistivity in the refractory body, with which water-containing state in the refractory body can be recognized. Since, at enough water-containing state, internal water pressure generally corresponds to saturated vapor pressure curve[2], internal vapor pressure can be estimated with electric resistivity and internal temperature measured by thermocouple[3].

As mentioned above, the sample specimen was fabricated with dry gunning refractory material with binder d shown in Table 1. The inner temperature of the heating furnace was kept at 650 ℃.

An example of the rapid drying experiment result is shown in Fig. 4. The internal temperature of the sample specimen was raised to around 100 ℃ at approximately 800 seconds of heating, and 100 ℃ of the internal temperature was kept up to roughly 1000 seconds of heating. Electric resistivity in this period was low, indicating enough water-containing state. Afterwards, electric resistivity in the refractory sample specimen was increased at 1350 seconds of heating. It suggests that the water-containing state at the central portion of the sample specimen where electrodes were embedded was lowered. It is clarified that the estimated value of vapor pressure, which is shown with the red-colored line in Fig. 4, was 0.04 MPa at most, too small vapor pressure in comparison with the mechanical strength of the refractory body to induce explosive spalling. After the rapid drying experiment, the sample specimen was cut into halves for observation on cross section. In fact, no initiated cracks were observed in cross section of the sample specimen.

3.3 Large Scale Rapid Drying Test

It was affirmed with above mentioned quick drying experiment that explosive spalling resistance of binder d containing dry gunning material is superior with quite small internal vapor pressure generated during drying. As a next step, a large scale rapid drying test was conducted in a manner shown by the schematic illustration and exterior photograph in Fig. 5 and Fig. 6, respectively, in which a series of operations from gunning to rapid drying were sequentially carried out, anticipating practical applications. Dry gunning refractory was gunned on the base refractory surface with over 200 mm of thickness. After curing at ambient temperature for 24 hours, the gunned refractory body was quickly heated up to 800 ℃ within

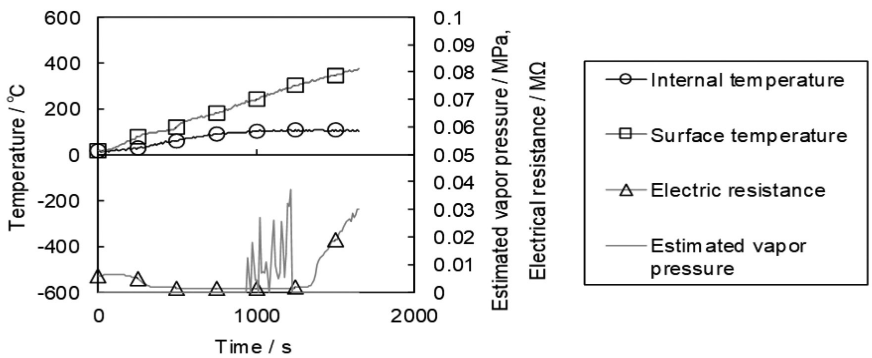

Fig. 4 An example of internal vapor pressure estimated with temperature and electrical resistivity in sample specimen.

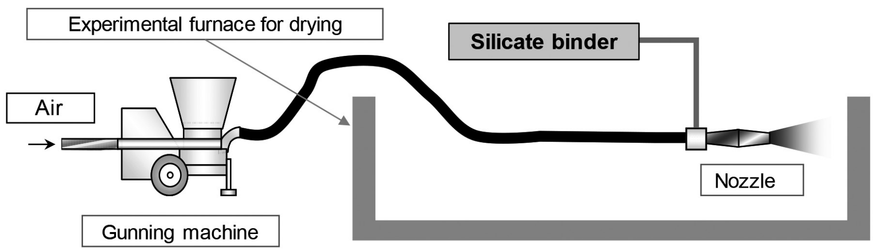

Fig. 5 Schematic illustration of large scale rapid drying test.

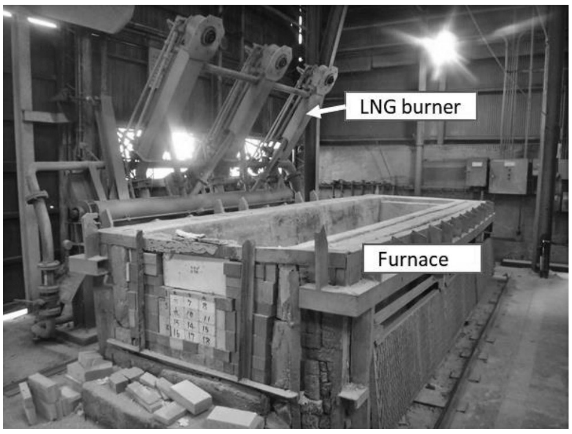

Fig. 6 Exterior photograph of large scale rapid drying test.

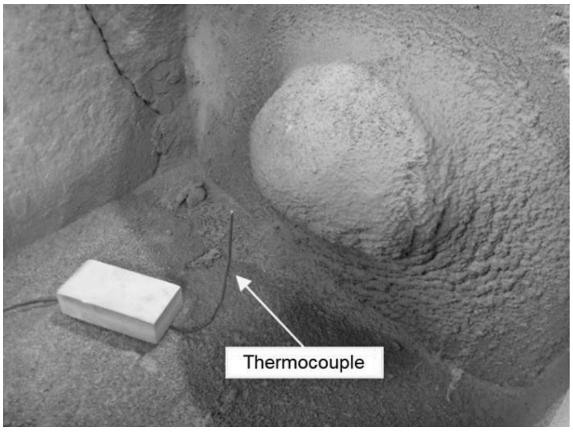

Fig. 7 External appearance of gunned body after quick heating to 800 ℃.

1 hour. The external appearance of the gunned body after quick heating is shown in Fig. 7. The gunned body exhibited quite a healthy state with no crack initiation or peel-off damages.

4. Adhesiveness to Base Refractory Surface

The adhesiveness of gunning refractory material onto base refractory surface is an important property which influences on the durability of the gunned body. Using adhesive shear strength measurement apparatus[4] illustrated in Fig. 8, the adhesive shear strength of new dry gunning material gunned onto alumina brick was evaluated at room temperature. Procedures of the adhesive shear strength measurement test are as follows;

(1) After setting a closure plate with an open window in its lower portion onto 60 %-Al_2O_3 composition Al_2O_3-SiO_2 brick, gunning material was gunned into the open window of the closure plate.

(2) The gunned body of gunning refractory material was heat-treated at 110 ℃, 800 ℃, 1000 ℃ and 1200 ℃ for 3 hours along with base Al_2O_3-SiO_2 brick and closure plate.

(3) After setting into the adhesive shear strength measurement apparatus, a heat-treated sample was pushed up by lifting jack, whose thrusting power was monitored and recorded.

Results of adhesive shear strength measurement on dry gunning materials with binder a, b and d are comparatively

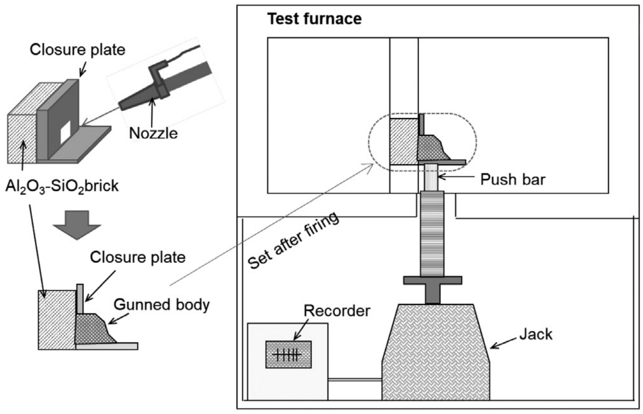

Fig. 8 Schematic illustration of adhesive shear strength measurement apparatus and gunned body sample preparation.

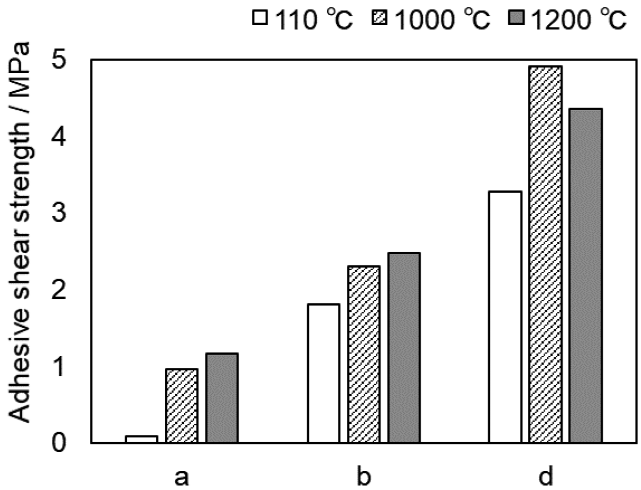

Fig. 9 Comparison of adhesive shear strength of three types of gunned refractory bodies heat-treated at 110 ℃, 1000 ℃ and 1200 ℃.

shown in Fig. 9. Adhesive shear strength of dry gunning materials with binder a (cement) was quite low and the heat-treated sample was sheared at the interface between base Al_2O_3-SiO_2 brick and gunned body. While dry gunning material with binder d (liquid silicate) exhibited high adhesive shear strength from low temperature to high temperature and the heat-treated sample was fractured inside the gunned body. It can be concluded that the adhesive shear strength of binder d containing gunning refractory material was much higher than the mechanical strength of its gunned body which was recorded as the shear strength of the heat-treated sample.

For verifying major factors for the high adhesiveness of binder d containing gunning refractory material, an observation was conducted for microstructure near the interface between base Al_2O_3-SiO_2 brick and gunning material in the gunned body sample heat-treated at 800 ℃. EPMA-observed microstructure is shown in Fig. 10. It was affirmed that Na element, one of the binder components, was evenly dispersed over 5 mm deep in base Al_2O_3-SiO_2 brick. It is inferred that, since Na element was not comprised in base Al_2O_3-SiO_2 brick, Na element detected in base brick derived from liquid silicate binder which infiltrated into base brick. It can be concluded that gunning material and

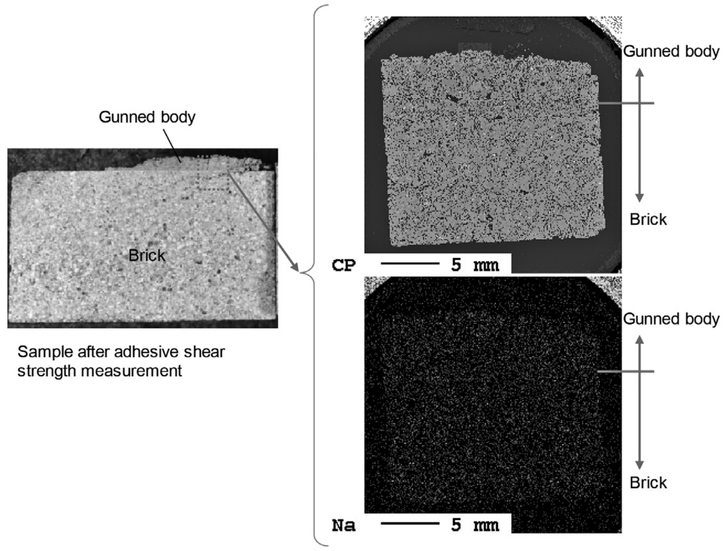

Fig. 10 EPMA-observed microstructure near interface between Al_2O_3-SiO_2 brick and gunning material.

surface area of base Al_2O_3-SiO_2 brick was strongly united by the anchor effect of liquid silicate binder, which was observed as quite high adhesive shear strength. It is expected that, since superior adhesiveness, which is much higher than that of cement containing gunning material, is materialized by new dry gunning material with liquid silicate binder, the durability of new repairing gunning material body installed on furnace base bricks would be remarkably improved in association with significant contribution to service life extension of furnaces.

5. Performance in Practical Application

Newly developed dry gunning refractory material blended with liquid silicate binder was practically applied at stoker-type industrial waste incinerator of A company. The inclined ceiling in a burning zone was selected as a maintained location with 30-40 mm of repairing gunned body thickness. A photograph of dry gunning operation is shown in Fig. 11. The adhesiveness of new gunning refractory material was better than that of conventional cement containing gunning refractory material with roughly 5 % of rebound loss. After curing at room temperature for 2 days, quick heating, which is usually adopted before furnace operation start-up, was applied, followed by normal operation with no explosive spalling incidents.

Figure 12 shows the surface condition of the gunned body 6 months after the incinerator operation. When adhering slag was partially removed, the white-colored gunned body was exposed with no trace of slag penetration. In comparison with conventional cement containing gunning refractory material, almost all of whose gunned body was peeled off after 6 months of the operation, no significant damage was observed on the gunned body of newly developed gunning refractory material. The superior protection effect for furnace body refractory was affirmed, which was materialized by the good adhesiveness of new gunning refractory material.

Fig. 11 Photograph of dry gunning operation in practical application.

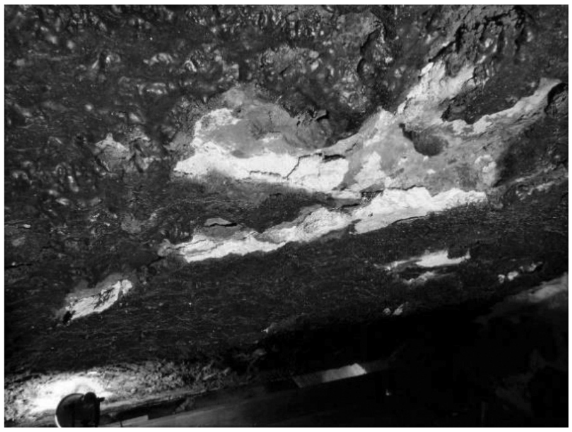

Fig. 12 Photograph showing surface condition of gunned body experiencing 6 months incinerator operation.

6. Conclusion

For dry gunning repairing maintenance on refractory relined in environmental industry furnaces or nonferrous industry furnaces, a newly developed operation method was established with liquid silicate binder containing dry gunning material which does not need a drying process after gunning operation. In practical application at stoker-type industrial waste incinerator of A company, an operation was resumed after room temperature curing for 2 days with no drying process. When compared with 50 hours of the drying process which is required for cement containing dry gunning refractory material, approximately 22 tons of CO_2 gas emission was suppressed, in association with remarkable saving of fuel consumption for the drying process. That is, it would greatly contribute to carbon neutrality (zero emission of CO_2 gas). In addition, since the overall repair maintenance period was shortened by 50 hours, the volume of waste which was loaded in the waste storage pit awaiting for treatment was reduced. Taking into account possible fire incidents caused by the ignition of oil-containing waste by its weighing pressure, such side effect contributes to the improvement of environmental accident prevention. In addition to direct benefits which were attained at customers' sites by the use of new dry gunning refractory material, it is expected that the contribution of new dry gunning material to SDGs as well as to zero emission of CO_2 gas would increase.

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