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FLEXURAL BEHAVIOUR OF COPPER SLAG AND FLY ASH CONCRETE- A CASE STUDY

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ABSTRACT

The present study encourages the use of waste materials copper slag (CS) and fly ash (FA) as supplementary cement replacement materials in concrete. The combined effect of copper slag and fly ash as a partial replacement of cement on flexural strength of concrete has been investigated. Fifteen mixes were prepared at different replacement levels of copper slag (0 to 20% @ increment of 5%) and fly ash (0 to 10% @ increment of 5%) with cement. Three prisms (150 mm X 150 mm X 700 mm) were casted and tested after 7 and 28-days of curing to determine the flexural strength (modulus of rupture) for each mix. It was observed that the flexural strength of concrete decreases as copper slag content increases for all curing ages. The reduction in flexural strength was minor (4.30% to 7.60%) up to 10% of copper slag but beyond 10% of copper slag, there was significant reduction (24.70% to 34.21%) in flexural strength. The addition of 5% and 10% fly ash with copper slag slightly reduced the flexural strength. It is recommended that 10% of copper slag can be used as combined with 10% of fly ash as maximum replacement of cement. The average flexural strength was within the permissible values in accordance with the design specifications.

INDEX TERMS: Copper slag, Flexural strength, Fly ash, Waste materials

INTRODUCTION

The emission of CO_2 to the environment is the largest driver of global warming. Cement industry is a major contributor in the emission of CO_2 as well as in using up high levels of energy resources in the production of cement. The production of cement releases greenhouse gas emissions both directly and indirectly. Cement industry accounts for around 5% of global CO_2 emissions, to reduce this effect researchers from all over the world are focusing on the different ways to utilization of different kind of wastes as a supplementary replacement materials. This waste utilization would not only be economical, but may also help protecting the environment. Industrial wastes, such as slag, fly ash and silica fume are being used as supplementary cement replacement materials [23].

Copper slag (CS) is a by-product obtained during the smelting and refining of copper. Copper slag is one of the materials that is considered as a waste material which could have a promising future in construction industry as partial or full substitute of either cement or aggregates [19]. During smelting, a molten pool of copper forms at the bottom of the furnace while a layer of impure metal form a less dense liquid floating on the top of the melted copper, which is the slag. The molten slag is discharged from the furnace at 1000–1300°C. Copper slag usually has a low content of calcium oxide (CaO), it exhibits pozzolanic properties. Due to its pozzolanic properties it reacts with the calcium hydroxide (CH), which is produced during cement hydration. Copper slag combines with CH to produce additional cementing compound calcium-silicate-hydrate (C-S-H), which is responsible for holding concrete together.

To produce every ton of copper, approximately 2.2-3 tons copper slag is generated [5]. In India three copper producers- Sterlite Copper, Birla Copper and Hindustan Copper produce approximately 6-6.5 million tons of copper slag annually at different sites [17]. Therefore, numerous contemporary researches have focused on the application of copper slag in cement and concrete production as a suitable path towards sustainable development. Many researchers have investigated the use of copper slag as partial replacement of aggregates in concrete. [1,2,4,14]. Some researchers have investigated the use of copper slag as partial replacement of ordinary Portland cement in concrete. The use of copper slag reduces the early age strength (1 day) while increasing it beyond 7 days [22]. The use of ground copper slag up to 15% by mass as a Portland cement replacement increased the strength significantly [3]. The addition of copper slag to cement increased its initial and final setting times [24]. The concrete batches with copper slag addition presented greater mechanical and durability performance [15]. Blends of copper slag with Portland cement generally possess properties equivalent to Portland cement containing fly ash [18]. The use of copper slag in cement and concrete provides potential environmental as well as economic benefits for all related industries, particularly in areas where a considerable amount of copper slag is produced.

Fly ash (FA) is a by-product from burning ground coal in electric power generating plants. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (both amorphous and crystalline) and calcium oxide. Both of these are endemic ingredients in many coal-bearing rock strata. Fly ash particles are generally spherical in shape and range in size from 0.5 µm to 300 µm. Based on reactive calcium oxide content, fly ash is divided into two types: siliceous fly ash and calcareous fly ash. India is a resourceful country for fly ash and it is estimated that 130-145 million tons of fly ash is generated by 70 major thermal power plants of which only 6-10 % is utilized by cement, construction and road industries [21]. In coming year (2016-17) it is expected that India will produce 300-400 million tons of fly ash per year which is approximately double the quantity it is produced now so the consumption should be increased subsequently [6]. Availability of consistent quality fly ash across the country and awareness of positive effects of using fly ash in concrete are pre requisite for change of perception about fly ash from a waste material to a resource material. The use of fly ash in concrete is propagated due to following reasons. First of all, the spherical shape of fly ash creates a ball bearing effect in the mix, improving workability without increasing water requirements [13]. The spherical shape of fly ash also improves the pumpability of concrete by decreasing the friction between the concrete and the pump line. Fly ash, as all pozzolanic materials do, generally increases concrete strength gain for much longer periods than mixes with Portland cement only [20]. The biggest reason to use fly ash in concrete is the increased life cycle expectancy and increase in durability associated with its use. During the hydration process, fly ash chemically reacts with the calcium hydroxide forming calcium silicate hydrate and calcium aluminate, which reduces the risk of leaching of calcium hydroxide and of concrete's permeability. The spherical shape of fly ash also improves the consolidation of concrete, which also reduces permeability. Fly ash in concrete provides better resistance to abrasion, chloride-ion penetration, salt scaling, freezing and thawing cycling than ordinary Portland cement [16].

Several researchers have studied the individual effect of addition of either copper slag or fly ash on the flexural strength of concrete. The studies dealing with combined effect of addition of copper slag and fly ash on the flexural strength of concrete are scanty. In this study, therefore, an attempt has been made to find the combined effect of addition of copper slag and fly ash on the flexural strength of concrete.

MATERIALS USED

Cement

Ordinary Portland Cement (OPC) of grade 43 from a single lot was used in the study. It was fresh and free from any lumps. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture. Cement conforming to specifications given in IS: 8112 [12] was used.

Fine aggregates

Fine aggregates were collected from Chakki River (Pathankot). It was coarse sand, brown in color. Specific gravity of fine aggregates was experimentally determined as 2.64. Fine aggregates confirming to grading zone II as per IS-383 [9] were used.

Coarse aggregates

The coarse aggregates used were a mixture of two locally available crushed stone of 10 mm and 20 mm size in 50:50 proportions. The aggregates were washed to remove dirt, dust and then dried to surface dry condition. The aggregates were grey in color, angular in shape and having specific gravity was 2.60. Coarse aggregates confirming to IS: 383 [9] were used.

Copper slag

It is a by-product obtained during the smelting and refining of copper. During smelting, a molten pool of copper forms at the bottom of the furnace while a layer of impure metal form a less dense liquid floating on the top of the melted copper, which is the slag. The molten slag is discharged from the furnace at 1000–1300°C. Copper slag obtained from Synco Industries Limited (Jodhpur, Rajasthan) was used in study. The physical and chemical properties of copper slag are given in Table 1 (Source: Synco Industries Limited, Jodhpur).

Table 1: Physical and chemical properties of copper slag

Sr. No.	Physical properties	Copper slag
1.	Particle shape	Irregular
2.	Appearance	Black & glassy
3.	Type	Air cooled
4.	Specific gravity	3.51
5.	Bulk density(g/cm^3)	1.9-2.4
6.	Hardness	6-7mohs
	Chemical component	**% of Chemical component**
1.	SiO_2	28%
2.	Fe_2O_3	57.5%
3.	Al_2O_3	4%
4.	CaO	2.5%
5.	MgO	1.2%

Fly ash

Fly ash is a by-product from burning ground coal in electric power generating plants. Fly ash obtained from Guru Nanak Dev Thermal Plant (Bathinda) was used in study. The physical and chemical properties of fly ash are given in Table 2 and Table 3 respectively (Source: Guru Nanak Dev Thermal Plant, Bathinda).

Table 2: Physical properties of fly ash

Sr. No.	Physical properties	Values	Requirements as per IS: 3812 [8]
1.	Specific gravity	2.22	-
2.	Fineness Blaine' specific surface (m^2/kg)	369.7	320 (Min)
3.	Lime reactivity — Average compressive strength (N/mm^2)	3.4	4.5 (Min)
4.	Particles retained on 45 micron IS sieve (%)	31	34 (Max)
5.	Soundness by autoclave test — Expansion of specimen (%)	0.23	0.8 (Max)

Table 3: Chemical properties of fly ash

Sr. No.	Chemical component	Values	Requirements as per IS: 3812 [8]
1.	$(SiO_2) + (Al_2O_3) + (Fe_2O_3)$ in percent by mass	91.02	70 (Min)
2.	Silicon dioxide (SiO_2) in percent by mass	86.72	35 (Min)
3.	Reactive silica in percent by mass	24.80	20 (Min)
4.	Magnesium oxide (MgO) in percent by mass	0.84	5 (Max)
5.	Sulphur trioxide (SO_3) in percent by mass	0.59	3 (Max)
6.	Sodium oxide (Na_2O) in percent by mass	0.50	1.5 (Max)
7.	Loss on ignition in percent by mass	2.3	5 (Max)

LABORATORY TESTING PROGRAM

Mix design and sample preparation

In this work, one control mix C1 was designed as per IS: 10262 [7]. Then 14 mixes were prepared other than control mix at different replacement levels of copper slag (0 to 20% @ increment of 5%) and fly ash (0 to 10% @ increment of 5%). Copper slag and fly ash were replaced with cement. The water/cement (w/c) ratio in all the mixes was kept at 0.43. Water content in each mix was 186 L/m^3. Fine aggregates (548.55 Kg/m^3) and coarse aggregates (1167.70 Kg/m^3) were constant in each mix. Mix proportions of concrete mixes are shown in Table 4. To determine the flexural strength (modulus of rupture) for each mix, three (150 mm X 150 mm X 700 mm) prisms were cast and tested after 7 and 28-days of curing. The flexural strength test was conducted in accordance with IS: 516 [11] using a simple beam with third point loading at a loading rate of 0.2 kN/s. The flexural strength test was conducted using a Universal Testing Machine (UTM).

Table 4: Mix proportions of different concrete mixes

Mix	W/C Ratio	CS %	FA %	CS (Kg/m^3)	FA (Kg/m^3)	Cement (Kg/m^3)
C1	0.43	0%	0%	0	0	432.56
C2	0.43	5%	0%	21.63	0	410.93
C3	0.43	10%	0%	43.26	0	389.3
C4	0.43	15%	0%	64.89	0	367.67
C5	0.43	20%	0%	86.52	0	346.04
C6	0.43	0%	5%	0	21.63	410.93
C7	0.43	5%	5%	21.63	21.63	389.3
C8	0.43	10%	5%	43.26	21.63	367.67
C9	0.43	15%	5%	64.89	21.63	346.04
C10	0.43	20%	5%	86.52	21.63	324.41
C11	0.43	0%	10%	0	43.26	389.3
C12	0.43	5%	10%	21.63	43.26	367.67
C13	0.43	10%	10%	43.26	43.26	346.04
C14	0.43	15%	10%	64.89	43.26	324.41
C15	0.43	20%	10%	86.52	43.26	302.78

RESULTS AND DISCUSSION

Flexural strength of concrete

Flexural strength of concrete was determined using three point loading system after 7 and 28 days of curing. The flexural strength of the specimen was determined in accordance with IS: 516 [11] using relation $f_b = PL/bd^2$ where, a = the distance between the line of fracture and the nearest support, b = measured width in cm of the specimen, d = measured depth in cm of the specimen was supported, and P = maximum load in kg applied on the specimen. The values of average flexural strength for different replacement levels of copper slag (0 to 20% @ increment of 5%) and fly ash (0 to 10% @ increment of 5%) at the end of different curing periods (7 days & 28 days) are given in Table 5. These values are plotted in Figure 1 to 3.

Table 5: Test results for flexural strength of concrete

Mixes	CS%	FA%	Flexural strength	
			7 days (N/mm^2)	28 days (N/mm^2)
C1	0%	0%	4.27	5.10
C2	5%	0%	4.20	4.97
C3	10%	0%	4.11	4.89
C4	15%	0%	3.71	4.41
C5	20%	0%	3.31	4.09
C6	0%	5%	4.13	4.95
C7	5%	5%	4.06	4.83
C8	10%	5%	3.94	4.79
C9	15%	5%	3.39	4.23
C10	20%	5%	2.87	3.86
C11	0%	10%	4.03	4.92
C12	5%	10%	3.88	4.81
C13	10%	10%	3.73	4.74
C14	15%	10%	3.27	4.21
C15	20%	10%	2.64	3.80

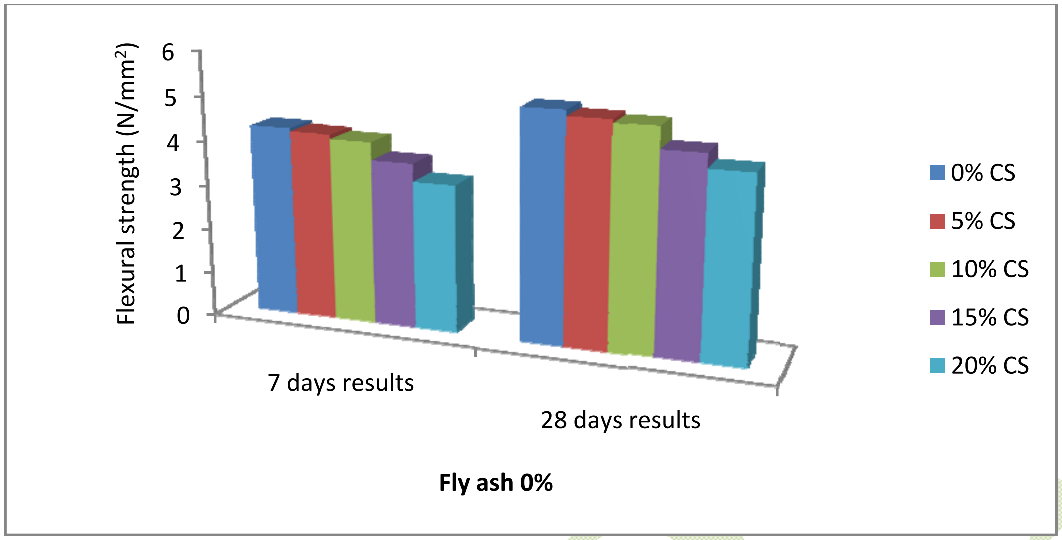

Figure 1: Flexural strength of concrete with different replacement levels of cement with copper slag for 0% fly ash

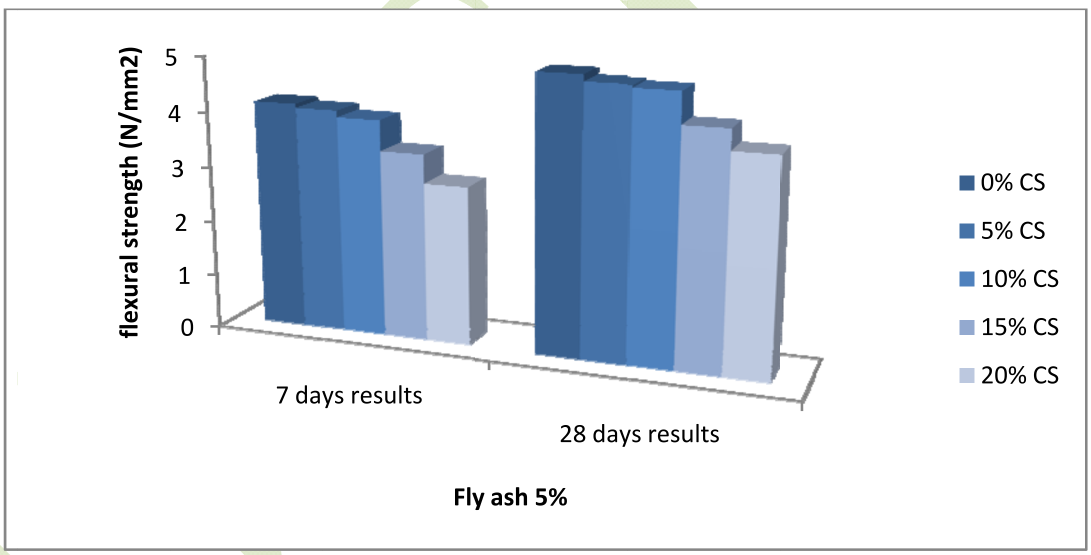

Figure 2: Flexural strength of concrete with different replacement levels of cement with copper slag for 5% fly ash

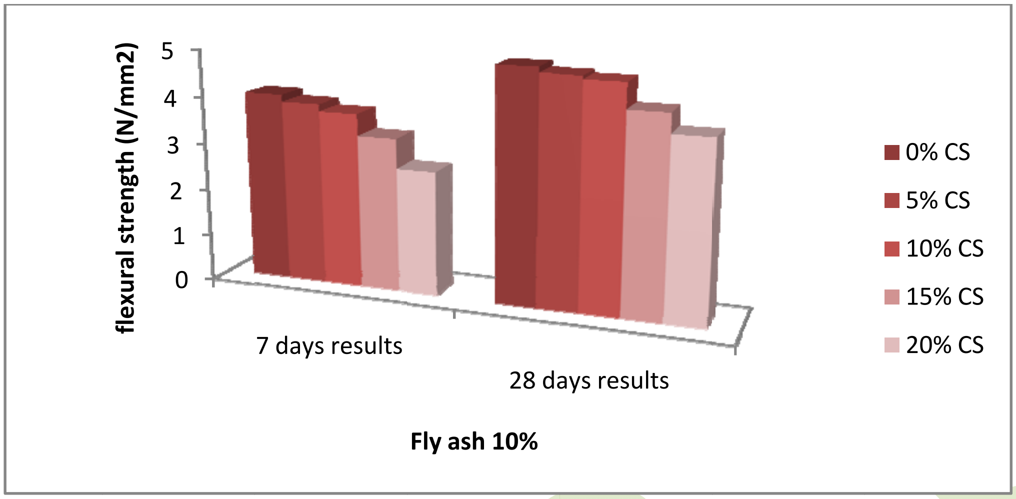

Figure 3: Flexural strength of concrete with different replacement levels of cement with copper slag for 10% fly ash

Figure 1 shows the variation of flexural strength of concrete with different replacement levels of copper slag with cement for 0% of fly ash. It can be observed that the flexural strength of concrete decreases as copper slag content increases for all curing ages. The same trend was observed for 5% of fly ash and 10% of fly ash in Figure 2 & 3. For 0% of fly ash, the percentage reduction in flexural strength for 5%, 10%, 15% and 20% of copper slag was 2.62, 4.30, 15.65 and 24.70 respectively after 28 days of curing. For 5% of fly ash the percentage reduction in flexural strength for 5%, 10%, 15% and 20% of copper slag was 5.60, 6.47, 20.57 and 32.12 respectively after 28 days of curing. For 10% of fly ash the percentage reduction in flexural strength for 5%, 10%, 15% and 20% of copper slag was 6.03, 7.60, 21.14 and 34.21 respectively after 28 days of curing. It can be seen that the reduction in flexural strength was minor up to 10% of copper slag but beyond 10% of copper slag, there was significant reduction in flexural strength. It can also seen that the flexural strength of concrete decreases as fly ash content increases for all curing ages. It can be observed that the addition of fly ash with 5% and 10% of copper slag slightly reduced the flexural strength of concrete. But when fly ash was used with 15% and 20% of copper slag, reduction was higher. It is recommended that 10% of copper slag can be used as combined with 10% of fly ash as maximum replacement of cement. The average flexural strength was within the permissible values in accordance with the design specifications. For design purposes, the flexural strength can be empirically taken as $0.7(F_{ck})^{.5}$ where F_{ck} is the 28-day characteristic cube compressive strength [10].

Development of prediction equation for flexural strength of concrete

It is well established that flexural strength depends upon the proportions of the copper slag and fly ash used. So an attempt has been made to relate the flexural strength with these parameters. Regression analysis was performed to generate the best fit equation for flexural strength.
The flexural strength of concrete is given as

$$\sigma_{cr} = 5.22 - 0.0548x_1 - 0.0196x_2 \qquad \text{(i)}$$

Where x_1= proportions of copper slag

x_2= proportions of fly ash

For the equation (i) , the coefficient of determination (r^2) is 0.89 and the correlation coefficient (r) is 0.95.

CHECKING OF THE DEVELOPED RELATIONSHIP

Equation (i) is used to find the flexural strength of the concrete mixes. Table 6 shows the estimated flexural strength using equation (i). The measured values of flexural strength are also shown in Table 6. Figure 4 shows the variation of estimated flexural strength and measured flexural strength for different mixes. ±10% error line is also drawn in the Figure 4. It is observed that 100% of values fall in the ±10% range.

Table 6: Measured and estimated flexural strength and for all mixes

Mixes	Measured Flexural Strength (N/mm^2)	Estimated Flexural Strength (N/mm^2)	% error
C1	5.10	5.22	+2.4
C2	4.97	4.95	-0.4
C3	4.89	4.67	-4.5
C4	4.41	4.39	-0.5
C5	4.09	4.12	+0.7
C6	4.95	5.12	+3.4
C7	4.83	4.85	+0.4
C8	4.79	4.57	-4.6
C9	4.23	4.3	+1.7
C10	3.86	4.03	+4.4
C11	4.92	5.02	+2.0
C12	4.81	4.75	-1.2
C13	4.74	4.48	-5.5
C14	4.21	4.20	-0.2
C15	3.80	3.93	+3.4

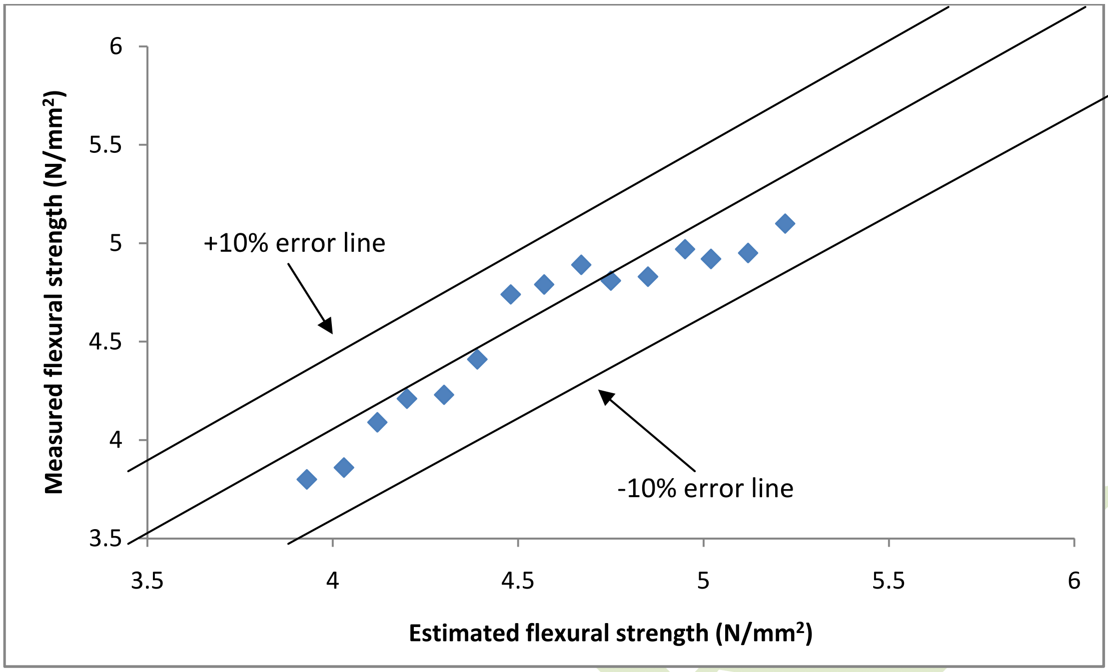

Figure 4: Variation of estimated flexural strength and measured flexural strength for different mixes

CONCLUSIONS

The following conclusions are drawn from this investigation:

- The flexural strength of concrete decreases as copper slag content increases for all curing ages. The reduction in flexural strength is minor up to 10% of copper slag but beyond 10% of copper slag, there is significant reduction in flexural strength.

- It can also see that the flexural strength of concrete decreases marginally as fly ash content increases for all curing ages. It is recommended that 10% of copper slag can be used as combined with 10% of fly ash as maximum replacement of cement.

- The average flexural strength was within the permissible values in accordance with the design specifications.

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