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Strength of Geopolymer Paste using a Ternary Blend of Fly Ash GGBFS and Silica Fume under Ambient Conditions

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ABSTRACT: In this paper, compressive strength (CS) of geopolymer paste has been studied under ambient conditions using locally available Class C fly ash, GGBFS and silica fume and a combination alkali activator, namely: NaOH and Na_2SiO_3. Two approaches were used for mix proportioning and 60 mixes of the paste were proportioned. It is found that all the mixes proportioned were workable and no adverse effects were observed within 30 minutes of mixing. It is found that the 'minimum voids' approach along with a constant fly ash – to – activator ratio (FA/AA) is the best approach for the design of geopolymer mixes, rather than a constant water- to- solid ratio (w/s). Further, the role of GGBFS and SF on the CS of the paste has also been highlighted.

Keywords: Fly ash (FA), GGBFS, Silica fume (SF), Alkali Activators, Mix design, Compressive strength, Geopolymer paste.

I.INTRODUCTION

Fast depletion of naturals resources and global warming are among the most important reasons that have led to focussed studies on the development and use of 'cement less' construction materials like geopolymer paste/mortar/concrete, during the last three decades. In recent years, the emphasis is on 'sustainability' and hence the use of industrial waste materials like FA, GGBFS and SF in developing geopolymer materials. However, studies on using ternary blend of the above materials, and their role in the strength and other characteristics of geopolymer paste etc., are rather rare. Several studies on geopolymer paste have been carried out recently using FA and GGBFS, in India and elsewhere [Kumar et al (2010); Kara et al (2014), Abdel – Gawwad and Abd El – Aleem (2015) and Ma et al (2019)]. However, the emphasis was on using a single activator, Class F fly ash, and evaluating the characterises at ambient and / or elevated temperature. Thus, there exists a necessity to address the interaction between FA and GGBFS at ambient temperature, using a combination of alkali activators on geopolymer paste.

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Further, a systematic study on mix proportion is also found to be rather limited. Hence, in this paper, interaction of Class C FA and GGBFS under ambient conditions and the effect of a proper mix design approach on the compression strength (CS) of geopolymer paste are studied and result presented.

II.EXPERIMENTAL

A Alumina Silicate Materials (ASM)

In this study, Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBFS), and Silica Fume (SF) were used. All the above three, taken together are referred to as Alumina Silicate Materials (ASMs). FA was obtained from the lignite-based thermal power station located at Neyveli, Tamil Nadu, India. GGBFS was obtained from a local steel plant. SF was obtained from a local commercial dealer, based in Chennai (Madras), India. The physical and chemical composition of all the above ASMs were obtained from a private research laboratory, using X-ray fluorescence (XRF) spectroscopy, excepting for SF, for which the chemical composition was provided by the manufacturer. The above results are given in Tables1 and 2. All the tests were done on the samples of FA and GGBFS passing through 63 microns' sieve, as the same samples were used for the experimental work.

Even though SiO_2 content is comparable among the ASMs used, Al_2O_3 in FA is nearly double in FA than GGBFS. This is expected to contribute for the early – age strength of the paste. On the other hand, CaO content in GGBFS is more than double in GGBFS, than in FA. Thus, the interaction of CaO along with SiO_2 is also expected to contribute to the strength utilising the water available in the AAs, especially, in the prevailing ambient conditions in the laboratory, thereby avoiding the need for an external source of heat energy for curing and attainment of strength.

B Alkaline Activators (AAs)

A combination of commercially available 98% pure sodium hydroxide (flakes) (NaOH) and sodium silicate (liquid gel) were used as alkali activators (AAs). NaOH flakes was dissolved in water for preparing NaOH solution. 10M (molar) NaOH solution was prepared by dissolving 306 grams of NaOH flakes in 694 ml of water, based on the recommended procedure by Raja mane & others (5). The chemical and physical properties of the above AAs are given in Tables 3and 4.

Table 1 Physical Properties of ASMs

Material	Physical state	Odour	Appearance	Bulk density (g/cc)	Particle size distribution(μm)				Specific gravity	Blaine specific surface (m^2/kg)
					d_{10}	d_{50}	d_{90}	d_{moy}		
Fly ash	Micronized power	Odourless	Grey colour powder	0.692	3.71	20.16	59.26	26.94	2.60	306
GGBS	Micronized power	Odourless	white colour powder	0.95	1.69	12.85	46.85	19.75	2.90	358
Silica fume	Micronized power	Odourless	white colour powder	0.76	-	-	-	-	2.63	-

Note: d_m- Mean diameter in (μm)

Table 2 Chemical Composition of ASMs (in percentage by weight)

Appearance /colour	Boiling point	Molecular weight	Specific gravity	Assay	Carbonate (Na_2CO_3)	Chloride (Cl)	Sulphate SO_2	Lead (Pb)	Iron (Fe)	Potassium (K)	Zinc (Zn)
Light yellow liquid (gel)	102ºC for 40% Aqueous Solution	184.04	1.6	97%	2%	0.01%	0.05%	0.00 %	0.00 %	0.10%	0.02 %

Note: LOI – Loss of Ignition

Table 3 Chemical and Physical Properties of Sodium Hydroxide (NaOH)

Materials	SiO_2	Al_2O_3	Fe_2O_3	$SiO_2+Al_2O_3+Fe_2O_3$	Ca O	MgO	Na_2O	K_2O	SO_3	TiO_2	LOI	Others	SiO_2/Al_2O_3	SiO_2/Na_2O
Fly ash	35.55	33.9	5.4	74.85	15.151	4.752	0.175	0.094	0.9514	1.9197	1.77	0.2353	1.05	203.14
GGBS	32.47	18	1.161	51.63	35.689	8.076	0.199	0.222	1.6341	0.5858	0.72	1.8603	1.8	163.16
Silica fume	99.886	0.043	0.04	0.001	0.001	0	0.003	0.003	-	-	0.015	-		

Note: The total percentage of ($SiO_2 + Al_2O_3 + Fe_2o_3$) is greater than 70% in the above FA Sample. Further, CaO content is greater than 10%. Hence, it is classified as class C FA according to ASTMC 6128 - 03 or cementitious FA according to IS3812 (2003).

Table 4 Chemical and Physical Properties of Sodium Silicate (Na_2SiO_3)

Chemical formula	Na_2O (%)	SiO_2 (%)	H_2O (%)	Appearance	Colour	Boiling point	Molecular weight	Specific gravity
Na_2SiO_3 colourless	15.9	31.4	52.7	Liquid(gel)	Light yellow	102ºC for 40% Aqueous Solution	184.04	1.53

Note: Properties as furnished by manufacture.

C Proportioning of Geopolymer Paste

Based on a set of preliminary trials, a constant molarity of 10 was adopted for the present study. Both the activators were together used for the preparation of the paste, wherein, the ratio of Na_2SiO_3 to NaOH was varied from 1 to 3 (in steps of 0.5). GGBFS was added as a partial replacement of FA at 10% and 20%, so as to facilitate curing under ambient (room) temperature prevailing in the laboratory. The binary blend FA + GGBFS is indicated by the notation $FA^{+,}$ here after.

In order to determine the desired content of Alkali Activator (AA) so as to ensure the desired consistency of the geopolymer paste and geo polymerisation, the concept of 'minimum voids approach' adopted in mix proportion of polymer concrete and as proposed by Kantha Rao and others [6] was adopted. For the FA and AAs used in the study, FA/AA was determined as 1.4 and the corresponding water/solid (w/s) ratio is 0.33 (Table 5). No external water was added to the binder/(s) and that the water available in the AAs were used / considered sufficient for the preparation of the geopolymer paste.

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Table 5 Mix Proportion of Paste

Material	By Volume	By Weight	FA/AA (by wt.)
FA	45.14	58.47	1.40
AA	54.86	41.77	

Note: Void content of FA =54.86 and void ratio=1.23 obtained using standard method was to determine FA/AA.

In order to study the influence of water content on the geopolymer paste, for a constant FA^+/AA of 1.40, w/s ratios were obtained for various ($Na_2SiO_3/NaOH$) Alkaline Activator ratios (AARs). Here, FA^+ indicate the combination of ASMs.

Similarly, in order to study the influence of FA^+/AA ratio on the geopolymer paste, for a constant w/s ratio of 0.33, FA^+/AA ratios were obtained for various Alkaline Activator ratios (AARs)

The details of mix proportion for the paste for the above two cases are summarized in Tables 6 and 7. Further, the influence of SF on the paste was also investigated and for that the above two cases of mix proportion were considered as 'reference mixes' wherein, 5% and 10% of FA content were replaced by SF. The details of mix proportion thus arrived at are summarized in Tables 8 to 9 and Tables 10 to 11, respectively.

D Preparation, Casting and Curing

Paste specimens of size 50 × 50 × 50 mm were cast for all the mix proportions summarized in Tables 6 to 11. Altogether 60 combinations of mixes were studied. CS of geopolymer pastes were determined in a 100 kN compressive testing machine (available in the laboratory of the institute), adopting the relevant Indian Standard at the end of 7 days. All the specimens were cast at room temperature, demoulded the next day and cured under ambient temperature. It was observed that all above 60 mixes were workable and no flash set was observed. In fact, the initial setting time was about 30 minutes, and no adverse effects like difficulty in demoulding and cracks on specimens, were observed. This may be attributed to the use of combination of ASMs used in this study.

Table 6 Mix Proportion of Geo Polymer Paste for various AARs (FA^+/AA=Constant)

Specimen No	$Na_2SiO_3/NaOH$ (AARs)	FA^+	GGBS (%)	FA^+ Fly Ash	GGBS	AA	FA^+/AA	Total Water	Total Solids	Water /Solid	Density (gm/cc)	Compressive Strength (N/mm^2)
31	1	150.5	10	135.45	15.05	107.5	1.4	64.18	193.82	0.33	1.82	24.72
32	1	150.5	20	120.4	30.1	107.5	1.4	64.18	193.82	0.33	1.9	30.21
33	1.5	150.5	10	135.45	15.05	107.5	1.4	62.09	195.91	0.32	1.85	21.66
34	1.5	150.5	20	120.4	30.1	107.5	1.4	62.09	195.91	0.32	1.87	34.92
35	2	150.5	10	135.45	15.05	107.5	1.4	60.7	197.3	0.31	1.8	20.95
36	2	150.5	20	120.4	30.1	107.5	1.4	60.7	197.3	0.31	1.84	30.25
37	2.5	150.5	10	135.45	15.05	107.5	1.4	59.71	198.29	0.3	1.79	23.86
38	2.5	150.5	20	120.4	30.1	107.5	1.4	59.71	198.29	0.3	1.85	28.25
39	3	150.5	10	135.45	15.05	107.5	1.4	58.96	199.04	0.3	1.73	12.95
40	3	150.5	20	120.4	30.1	107.5	1.4	58.96	199.04	0.3	1.74	29.86

Note: (i) FA^+ = (FA + GGBFS)

(ii) Specimen no. refers to the serial no. allotted to the specimen at the time of casting, and the same is used in the tables for easily identifying the specimen and the corresponding result.

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Table 7 Mix Proportion of Geo Polymer Paste for various AARs (W/S = Constant)

Specimen no	$Na_2SiO_3/NaOH$ (AAR)	FA^+	GGBS (%)	FA^+		AA	FA^+/AA	Total Water	Total Solids	Water /Solid	Density (gm/cc)	Compressive Strength (N/mm^2)
				Fly Ash	GGBS							
1	1	150.5	10	135.45	15.05	107.5	1.4	64.18	193.82	0.33	1.81	17.89
2	1	150.5	20	119.5	31	107.5	1.4	64.18	193.82	0.33	1.88	24.64
3	1.5	150.5	10	135.45	15.05	114	1.32	65.85	198.65	0.33	1.79	29.04
4	1.5	150.5	20	119.5	31	114	1.32	65.85	198.65	0.33	1.89	29.5
5	2	150.5	10	135.45	15.05	118	1.275	66.63	201.87	0.33	1.84	27.08
6	2	150.5	20	119.5	31	118	1.275	66.63	201.87	0.33	1.88	27.47
7	2.5	150.5	10	135.45	15.05	122	1.234	67.76	204.74	0.33	1.88	24.72
8	2.5	150.5	20	119.5	31	122	1.234	67.76	204.74	0.33	1.9	27.86
9	3	150.5	10	135.45	15.05	125	1.204	68.56	206.94	0.33	1.73	18.05
10	3	150.5	20	119.5	31	125	1.204	68.56	206.94	0.33	1.77	18.64

Table 8 Mix Proportion of Geo Polymer Paste for various AARs and 5% SF (FA/AA=Constant)

Specimen no	$Na_2SiO_3/NaOH$ (AAR)	FA+	GGBS (%)	FA+			AA	FA^+/AA	Total Water	Total Solids	Water /Solid	Density (gm/cc)	Compressive Strength (N/mm^2)
				Fly Ash	Silica fume	GGBS							
41	1	150.5	10	128.68	6.77	15.05	107.5	1.4	64.18	193.82	0.33	1.82	21.27
42	1	150.5	20	114.38	6.02	30.1	107.5	1.4	64.18	193.82	0.33	1.81	35.47
43	1.5	150.5	10	128.68	6.77	15.05	107.5	1.4	62.09	195.91	0.32	1.83	20.8
44	1.5	150.5	20	114.38	6.02	30.1	107.5	1.4	62.09	195.91	0.32	1.84	35.32
45	2	150.5	10	128.68	6.77	15.05	107.5	1.4	60.7	197.3	0.31	1.76	25.9
46	2	150.5	20	114.38	6.02	30.1	107.5	1.4	60.7	197.3	0.31	1.76	19.62
47	2.5	150.5	10	128.68	6.77	15.05	107.5	1.4	59.71	198.29	0.3	1.82	25.11
48	2.5	150.5	20	114.38	6.02	30.1	107.5	1.4	59.71	198.29	0.3	1.85	21.19
49	3	150.5	10	128.68	6.77	15.05	107.5	1.4	58.96	199.04	0.3	1.79	27.86
50	3	150.5	20	114.38	6.02	30.1	107.5	1.4	58.96	199.04	0.3	1.74	23.23

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Table 9 Mix Proportion of Geo Polymer Paste for various AARs and 10% SF (FA/AA=Constant)

Specimen no	Na_2SiO_3/NaOH (AAR)	FA+	GGBS (%)	FA+			AA	FA^+/AA	Total Water	Total Solids	Water /Solid	Density (gm/cc)	Compressive Strength (N/mm^2)
				Fly Ash	Silica fume	GGBS							
51	1	150.5	10	121.91	13.55	15.05	107.5	1.4	64.18	193.82	0.33	1.83	20.64
52	1	150.5	20	108.36	12.04	30.1	107.5	1.4	64.18	193.82	0.33	1.9	18.84
53	1.5	150.5	10	121.91	13.55	15.05	107.5	1.4	62.09	195.91	0.32	1.82	20.4
54	1.5	150.5	20	108.36	12.04	30.1	107.5	1.4	62.09	195.91	0.32	1.83	24.09
55	2	150.5	10	121.91	13.55	15.05	107.5	1.4	60.7	197.3	0.31	1.76	18.91
56	2	150.5	20	108.36	12.04	30.1	107.5	1.4	60.7	197.3	0.31	1.78	28.25
57	2.5	150.5	10	121.91	13.55	15.05	107.5	1.4	59.71	198.29	0.3	1.79	23.15
58	2.5	150.5	20	108.36	12.04	30.1	107.5	1.4	59.71	198.29	0.3	1.77	38.22
59	3	150.5	10	121.91	13.55	15.05	107.5	1.4	58.96	199.04	0.3	1.76	27.11
60	3	150.5	20	108.36	12.04	30.1	107.5	1.4	58.96	199.04	0.3	1.76	36.73

Note: (i) FA^+ = (FA + SF + GGBFS)

Table 10 Mix Proportion of Geo Polymer Paste for various AARs and 5%SF (W/S = Constant)

Specimen no	Na_2SiO_3/NaOH (AAR)	FA+	GGBS (%)	FA+			AA	FA^+/AA	Total Water	Total Solids	Water /Solid	Density (gm/cc)	Compressive Strength (N/mm^2)
				Fly Ash	Silica fume	GGBS							
11	1	150.5	10	128.68	6.77	15.05	107.5	1.4	64.18	193.82	0.33	1.82	17.66
12	1	150.5	20	113.53	5.98	31	107.5	1.4	64.18	193.82	0.33	1.86	23.54
13	1.5	150.5	10	128.68	6.77	15.05	114	1.32	65.85	198.65	0.33	1.84	18.6
14	1.5	150.5	20	113.53	5.98	31	114	1.32	65.85	198.65	0.33	1.9	32.57
15	2	150.5	10	128.68	6.77	15.05	118	1.275	66.63	201.87	0.33	1.8	18.44
16	2	150.5	20	113.53	5.98	31	118	1.275	66.63	201.87	0.33	1.85	40.83
17	2.5	150.5	10	128.68	6.77	15.05	122	1.234	67.76	204.74	0.33	1.78	23.45
18	2.5	150.5	20	113.53	5.98	31	122	1.234	67.76	204.74	0.33	1.87	39.74
19	3	150.5	10	128.68	6.77	15.05	125	1.204	68.56	206.94	0.33	1.8	18.44
20	3	150.5	20	113.53	5.98	31	125	1.204	68.56	206.94	0.33	1.8	21.19

Table 11 Mix Proportion of Geo Polymer Paste for various AARs and 10% SF (W/S = Constant)

Specimen no	$Na_2SiO_3/NaOH$ (AAR)	FA+	GGBS (%)	FA+ Fly Ash	FA+ Silica fume	FA+ GGBS	AA	FA^+/AA	Total Water	Total Solids	Water /Solid	Density (gm/cc)	Compressive Strength (N/mm^2)
21	1	150.5	10	121.91	13.55	15.05	107.5	1.4	64.18	193.82	0.33	1.82	16.4
22	1	150.5	20	107.55	11.95	31	107.5	1.4	64.18	193.82	0.33	1.81	13.34
23	1.5	150.5	10	121.91	13.55	15.05	114	1.32	65.85	198.65	0.33	1.78	30.61
24	1.5	150.5	20	107.55	11.95	31	114	1.32	65.85	198.65	0.33	1.78	23.39
25	2	150.5	10	121.91	13.55	15.05	118	1.275	66.63	201.87	0.33	1.72	22.76
26	2	150.5	20	107.55	11.95	31	118	1.275	66.63	201.87	0.33	1.69	31.42
27	2.5	150.5	10	121.91	13.55	15.05	122	1.234	67.76	204.74	0.33	1.87	15.23
28	2.5	150.5	20	107.55	11.95	31	122	1.234	67.76	204.74	0.33	1.76	21.58
29	3	150.5	10	121.91	13.55	15.05	125	1.204	68.56	206.94	0.33	1.81	13.73
30	3	150.5	20	107.55	11.95	31	125	1.204	68.56	206.94	0.33	1.9	16.87

III.RESULTS AND DISCUSSION

Compressive strength of geopolymer paste for a constant FA/AA ratio (=1.40) and constant w/s ratio (=0.30) for various AARs and for GGBS content 10% and 20% are summarised in Table 6 and 7. The above results are critically analysed and following are the salient observations/inferences:

E *Effect of GGBFS in FA^+*

i. For a constant FA/AA ratio, when the GGBFS content is 10% in FA^+, the compressive strength (CS) of the paste is maximum, (24.72N/mm^2), at AAR equal to1.0.

ii. However, when the GGBFS content is increased to 20% the CS of the paste increases and reaches a maximum value of 34.92 N/mm^2, at AAR of 1.5, and w/s=0.32 which is the highest CS attained among all the mixes considered, for a constant FA/AA ratio.

iii. This shows the influence of GGBFS in the mix, especially at a constant FA/AA ratio. Further, relatively the much higher Al_2O_3 content in FA seems to have contributed to the early strength, whereas, relatively much higher CaO content in GGBFS, along with silica content in the ASMs seem to have contributed for setting of the paste at the ambient room temperature. Thus, the combined use of ASMs seems to be advantageous in geopolymer paste, unlike the use of Class F FA and GGBFS in geopolymer paste, where in, only a small interaction has been reported between the above two precursors, under ambient conditions (27^0 C) [Kumar et al. (2010)]. Further, the CS attained in this study, is very much higher, that is, more than two times. Thus, the role of class C FA is better and advantageous than class F FA, when used along with GGBFS in geopolymer paste.

iv. On the other hand, when w/s is constant (0.33) the influence of variation of a GGBFS on the CS, for the same set of AARs, is not significant. Further, the maximum CS attained is about 29.00 N/mm^2 (AAR=1.5), which is less than the maximum CS attained, when compared to the mixes with constant FA/AA ratio. However, the reduction in CS is not significant (≤ 5% only).

v. From the above two approaches of mix proportioning it can be stated confidently that the 'minimum voids' approach is not only a rational approach, but leads to attain the higher CS for the geopolymer paste, for the set of materials considered in this study. Consequently, keeping a constant FA/AA ratio is the best approach for the design of geopolymer paste mixes.

F *Effect of SF in FA^+*

i. For a constant FA/AA ratio, when the SF content is 5% in the FA^+, the CS is maximum (35.47 N/mm^2) even at the lowest AAR (1.0) and when GGBFS is 20%. The above CS is comparable to the maximum CS attained by the paste, without the use of SF in the mix. This shows that the minimum SF content used (5%) in the mix does not influence the CS of the paste. However, it has helped to reduce the AAR from 1.5 to 1.0, for achieving comparable CS of the paste, which is advantageous, and may be attributed to the 'particle packing effect' of the mix by SF.

ii. However, when the SF content is 10% in FA^+, the CS gently increases, as the AAR increases for the constant GGBFS content of 20%, and attains the maximum CS of about 38.2N/mm^2, at an AAR of 2.5.

The above value is marginally higher than the CS of the paste at SF content 5%, but not significant. Based on the role of SF in influencing the CS of paste, it can be safely stated that SF need not be added to the paste.

IV CONCLUSIONS

Following are the salient conclusions based on the study:

i. 'Minimum voids approach' can be used to proportion geopolymer paste mixes, so as to attain maximum compressive strength, for a given / chosen set of alumina silicate materials (ASM) and alkali activators (AAs). Further, it is suggested that a constant fly ash-to-alkali activator ratio (FA/AA) is the best approach for the design of geopolymer mixes, rather than a constant water-to-solid ratio (w/s).

ii. The maximum value of compressive strength attained by the paste, when GGBFS content is 20%, AAR=1.5, is 34.92N/mm^2, among all mixes considered for a constant FA/AA ratio of 1.40. The combined use of fly ash and GGBFS, seems to have contributed to the setting and strength of the paste at ambient temperature.

iii. There is no significant influence of silica fume on the compressive strength of the paste, especially, when the kind of fly ash and GGBFS which have been used in this study as ASMs in the paste.

REFERENCES

1. Sanjay Kumar Rakesh Kumar Mehrotra S P (2010), Influence of granulated blast furnace slag on the reaction, structure and properties of fly ash based geopolymer, *journal of Material Science* 45:607 – 615.
2. Arkamitra Kar Indrajit Ray Udaya B Halabe Avinash Unnikrishnan Ben Dawson- Andoh September (2014) characterizations and quantitative estimation of alkali – activated binder paste from microstructures, *international journal of concrete structures and materials*, Vol. 8, No. 3, pp.213-228.
3. Abdel-Gawwad H A Abd El-Aleem A (2015) Effect of reactive magnesium oxide on properties of alkali activated slag geopolymers cement pastes Ceramics – Silikaty 59 (1) 37-47.
4. H Q Ma H G Zhu H Y Chen Y D Ni T Wang and S Yang (2019) Effects and mechanisms of slag reinforced coal gangue geopolymers, *The 7th Global Conference on Materials Science and Engineering*, 474
5. Rajamane N P Jayalakshmi R (2015), Quantities of sodium hydroxide solids and water to prepare sodium hydroxide solution of a given geopolymer concrete mixes. *CI Journal*, 33-36
6. Krishnamoorthy, S., Kantha Rao, V.V.L., (1993), 'minimization of voids – content and optimization of Micro Filler Addition in a Polymer Concrete Mix Design', Proc. Of Innovation world of concrete', (ICI- IWC- 93), 3-253 to 3-262.

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