DEVELOPMENT OF HIGH PERFORMANCE POZZOLANA CEMENTS - TECHNOLOGICAL OPTIONS

by

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ABSTRACT

The production of fly ash based pozzolana cement requires matching its performance level with that of ordinary portland cement (OPC). This paper discusses various technological options which are instrumental in enhancing performance capabilities of fly ash based cement (FAC) . The synergic combination of strategies which could well begin with specific selection criteria while sourcing ash from power plant narrow down performance level differences between FAC and OPC. Fly ash classification / beneficiation not only improves efficiency of fly ash , it may also provide carbon rich secondary fuel. A case study is presented on two fly ash samples with different particle size fractions and carbon content. The integration of control strategies and introduction of beneficiation schemes obviate the common problems such as fineness and LOI of fly ash. The cumulative effect leads to multiple benefits in terms of ash quality , cost reduction and FAC with pozzolanic activity index (PZI) at par with OPC. The systematic adoption of these methods with techno-economic study will provide basis for sustainable technology with considerable value addition.

INTRODUCTION

Fly ash is probably the major secondary material used in cement production, most common use being production of Fly Ash based pozzolana cement (FAC). However, even after comprehensive research & development programmes by leading national laboratories, the quantum of Fly Ash utilised is discerning low. The typical generation and utilisation figures from a modern thermal plant in India are shown in **Table 1.**

Activity	Quantity, lac t	Utilisation (%)
Generation of ash	9.2	-
Ash consumed in local application	7.7	83.7
Ash sold	0.17	1.85
Ash in Temporary Stock	1.34	14.56

Table 1 : Typical Generation and Ash Utilisation for a thermal plant

The trend indicates hardly 2% consumption against outside agencies.

At the end of the present century, the quantum of Fly Ash generation from thermal plant is expected to be of 100 million tonnes, with the kind of ash disposal problems we are aware of,

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the magnitude of the problem would increase further if more avenues for mass utilisation of fly ash are not explored. There could be host of reasons which restrict potential utilisation of fly ash, to name few, quality and availability are two major stigmas.

On the brighter side of the scale, increased customer awareness has prompted many cement producers to promote ideas to grade PPC on the lines of OPC. Under the present scenario, product strategy is market driven which puts more demand on enhancing performance levels of PPC. In most of the cases, FAC is considered as secondary product, the biggest apprehension is the performance level of FAC. The strength developments, setting behaviour are the principal attributes which needs to be improved to enhance efficiency levels of FAC.

The paper deals with methodologies which offer

- Improved quality of Ash to the user
- Improved performance level of Blends
- Increase in quantum of ash utilisation
- Improved Economy and Value addition

FLY ASH CEMENTS : PRESENT STATUS

Prior to embarking on the technological domains, it is imperative to get hold of the current situation with respect to FAC production in India. The production of blended cements including FAC for the last one decade is graphically shown in **Fig.1** (1).

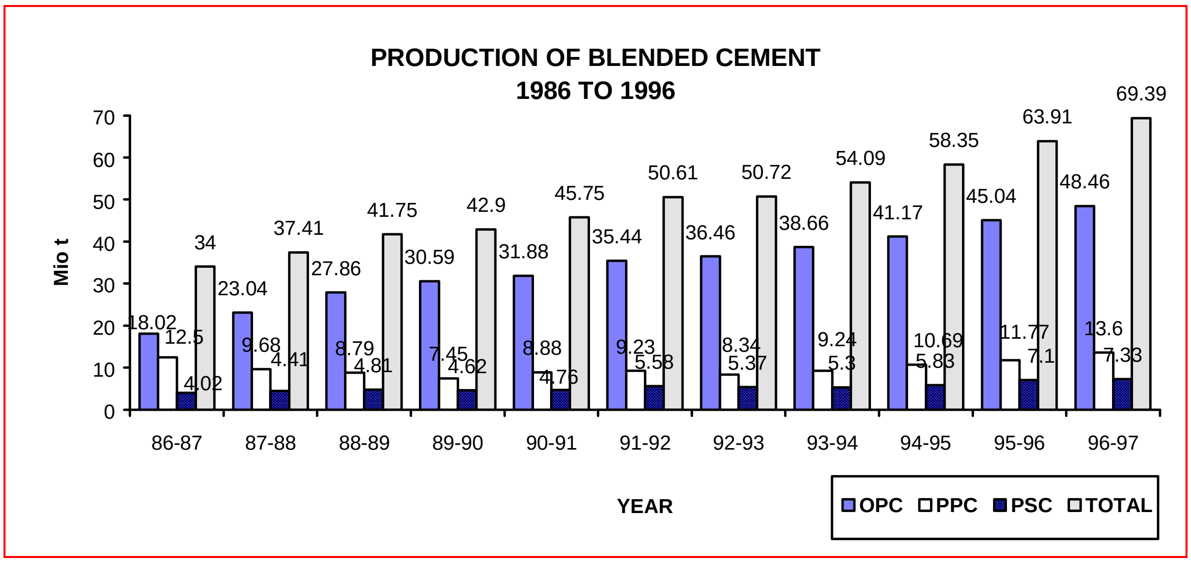


Fig.1 - Production of Blended Cements for the last one decade

The production of blended cements which is predominantly FAC shows upward trend for the last few years, present share being 13.6%, however, a monumental gap still persists between generation and utilisation of Fly Ash in India.

<u>PERFORMANCE LEVEL OF PRESENT INDUSTRIAL CEMENTS</u>

The performance level of commercial cements confirming to 33, 43 grade OPC in India and also similar data on pozzolana cements which include FAC and CCP(Calcined Clay Pozzolana) are provided in **Tables 2 and 2a**.

Plant / Parameters	A		B		C		D		E	
Grade	**33**	**43**	**33**	**43**	**33**	**43**	**33**	**43**	**33**	**43**
CaO	61.6	62.8	63.5	63.4	61.0	61.7	62.5	62.0	62.4	62.8
Blaine cm^2/gm	2751	2977	3067	2996	2977	2941	2828	2790	2526	2904
Setting Time										
IST	180	130	160	135	170	140	150	180	155	140
FST	230	175	220	195	230	180	210	240	205	195
Comp. Strength Kg/cm^2										
1 Day	159	151	157	177	224	216	186	224	167	194
3 Days	282	314	259	328	339	351	400	367	221	259
7 Days	390	443	441	471	390	422	479	445	269	328
28 Days	510	606	551	622	486	500	612	588	359	443

Table 2 : Performance level of industrial cements

Plant / Parameters	A	B		C		D		E	
Grade	**CCP**	**FAC**		**FAC**		**FAC**		**FAC**	
CaO	55.9	56.7	53.8	55.7	50.4	53.3	54.6	55.1	53.6
Blaine cm^2/gm	3691	3692	3660	3385	3222	3867	3919	3482	3660
Setting Time									
IST	160	120	145	155	120	129	121	145	155
FST	235	175	220	245	190	198	189	210	215
Comp. Strength Kg/cm^2									
1 Day	163	169	204	143	133	177	180	179	200
3 Days	315	312	297	249	239	392	377	362	381
7 Days	367	398	373	337	322	519	481	494	500
28 Days	451	547	481	-	-	659	615	681	668

Table : 2a : Performance level of pozzolana cements (15 % substitution)

It is apparent from the performance data that properties vary over a wide range depending on individual components of blend and also manufacturing process.

<u>BENCH MARK FOR FAC</u>

With the upgradation in technology, stricter quality control measures and current market trends, the quality of OPC is upgraded by manifolds. The performance characteristics of some of the leading G-53 brands rated as best cement in India are as follows:

Parameter	1	2	3	4	5	Avg.
Blaine	3154	3343	3052	3271	3363	3237
Setting Time						
IST	110	116	167	131	123	129
FST	180	203	252	214	191	208
Comp Strength kg/cm^2						
1 Day	245	247	215	232	201	228
3 Days	404	459	380	426	442	422
7 Days	496	554	469	549	564	526
28 Days	594	680	598	706	671	650

Table 3: Performance characteristics of G-53 cements

For FAC, average properties of **G-53 becomes the bench mark.**

TECHNOLOGY OPTIONS FOR DEVELOPING HP FAC

◊ ***Sourcing of Fly Ash***

The amount of total ash generated by power plant is a combination of Fly Ash (80%) and Bottom Ash (20%). Fly ash is collected in ESP and normally disposed off using ‘Dry’ or ‘Wet’ modes of disposal. Wet ash or pond ash is not a favourite option as it is found to be technically inferior to dry ESP ash (2). Fly ash particles are segregated by size in various fields of ESP. Larger particles fall off early and are collected in first field, carbon also tends to be segregated with the larger particles. Finer particles are carried over and are collected in fields which are farthest from the boiler. The granulometric analysis of fly ash from a single source provides total reflection of its pozzolanic character. The orientation of ash particles in ESP and their respective granulometry of two thermal power plants is shown in **Fig 2**.

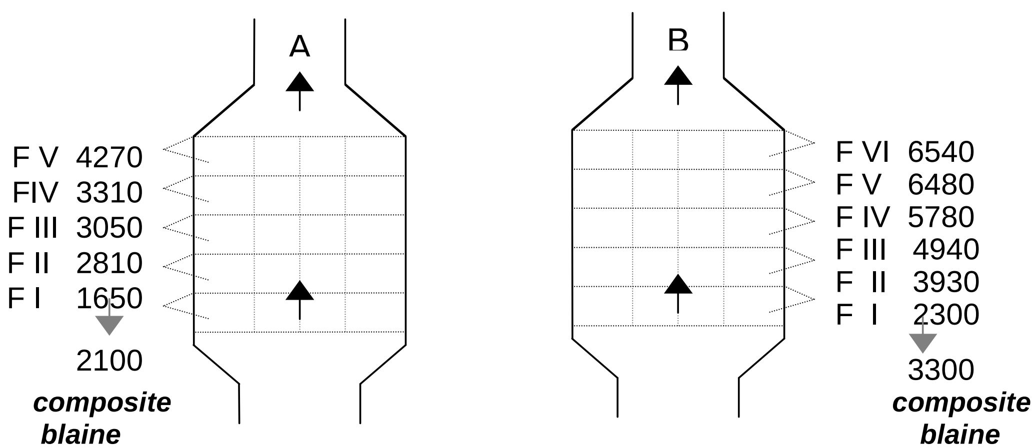


Fig.2 - Schematic representation of ash collection and orientation in ESP

➢ The quality of ash from respective plants reflects dependence of ash on source location, point of collection and ultimately power plant operation.

- ➢ It is evident that while ash from Plant A needs quality improvement, in case of plant B, composite ash can be suitably collected from storage silo.

- ➢ Collection of dry ash envisages use of closed vessels for an onward transport to user's site. Use of 'bulk' carriers is also suggested to avoid problems of pollution due to handling of fine dust.

- ➢ First field ash is coarser but at the same time 60-80% collection of ash particles takes place in first field hoppers, quantitative estimation is desired at the project pre-feasibility stage.

- ➢ For collection of ash particles from a particular ESP field, an intermediate storage needs to be erected adjacent to ESP. Alternatively, fly ash may be pneumatically conveyed through long pipe lines to user's site.

◊ ***CONVEYING OF ASH***

Depending on lead distances from power plant to FAC production sites, fly ash needs to be conveyed either through carriers or, in case production site is chosen in the vicinity of thermal plant it may be pneumatically transported using,

♦ **Lean Phase, Medium phase or Dense Phase Conveying**

Amongst the three conveying modes , Dense phase conveying (DPC) is the best option because of the following reasons:

- ∗ Low material to air ratio, 25 :1, much lower than other two modes
- ∗ Low transfer velocities, 3-5 m/sec
- ∗ Minimum wear rates
- ∗ Capacity to handle hot ashes
- ∗ Environmental friendly system

◊ ***QUALITY CONSIDERATIONS***

Each component of the blend has definite influence on the performance of FAC at all levels.(3) While high C_3S (50- 55 %) clinker is an essential requirement to have sufficient lime rich environment for pozzolana reactions, quality of fly ash also needs to be examined. The key quality issues are :

- **Granulometry, Carbon Content, Mineralogy, Chemical composition**

Fly ash with high reactivity and low carbon content is an ideal material to produce high performance pozzolana cements. Compliance with stipulated standards may not qualify fly ash as an ingredient of HP FAC , the quality index (QI) for fly ash is as follows:

PARAMETER	DESIRED

Fineness	**>3000 cm2/gm or min 50 % passing 45 micron**
LOI (carbon)	**< 3 %**
Lime Reactivity	**> 50 kg/cm2**

Accordingly, fly ash quality can be evaluated as per QI .

◊ ***PRODUCTION OF FAC***

FAC can be produced through intergrinding or separate grinding of fly ash and blending with portland cement. Fly ash is normally introduced through first chamber where it receives minimal grinding, in the finish compartment of the mill , it acts as grinding aid . Alternatively , in case fly ash is sufficiently fine, it can be fed through mill separator, coarse particles are returned to the mill and fines are secured as product. Co-grinding of fly ash has many advantages such as:

- **Improvement in grinding efficiency, Improved PSD, Higher Strengths**

Various system options for FAC production and insertion points for fly ash are shown in **Fig 3**.

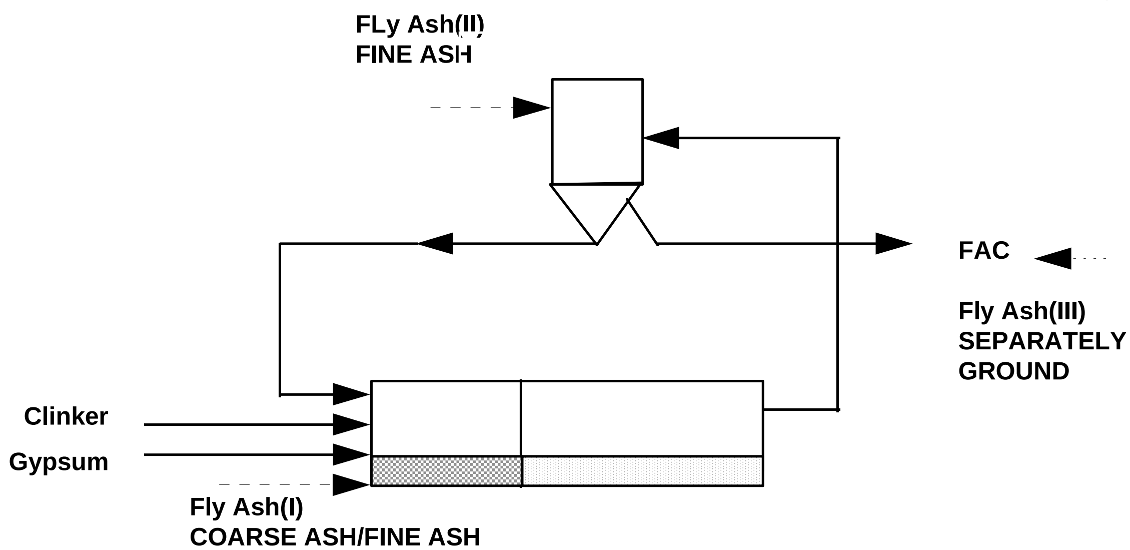


Fig. 3 : System Options for Production of FAC.

♦ ***QUALITY UPGRADATION***

Since power producers are in the business of electricity generation ,fly ash becomes a low priority area except for its disposal .The quality and consistency of ash is a common problem before the potential user. The adoption of the following methodologies can upgrade the quality as desired:

♦ **Mechanical Activation , Chemical Activation or Classification**

<u>Mechanical Activation</u>
Coarser fly ash can be subjected to light grinding to improve its efficiency(4).The influence of mechanical activation on fly ash is shown in **Table 4.** About 10 minutes grinding is sufficient to reuduce d50 significantly.

Grinding Time(min)	d50	Blaine (cm2/kg)
0	15.64	2810
10	7.86	3560
20	6.00	4320
30	5.21	4860

Table 4 : Influence of mechanical activation on fly ash

Chemical activation

Chemical activation of fly ash improves its efficiency ,Ghosh etal reported 60-100% efficiency improvement through chemical dosing and thermal treatment (5).

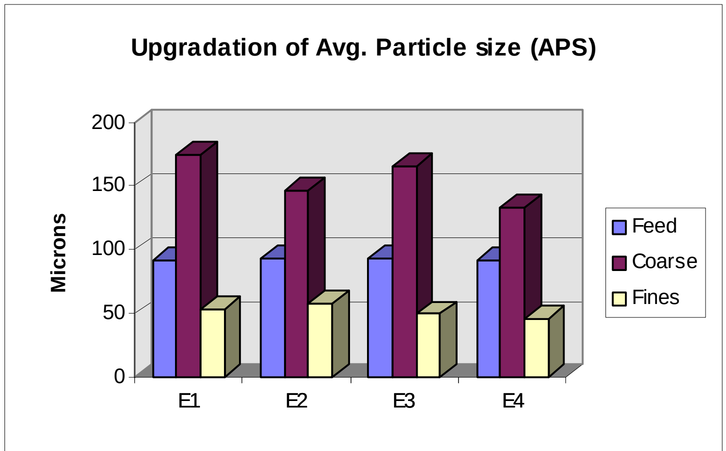
Air Classification of Fly Ash - A Case Study

Classification of Fly Ash through air separators is frequently used for removing coarse particles, the objective of this study was to understand aerodynamic behaviour of fly ash as well as carbon particles. A case study is presented on Air Classification of two specimens having different particle size range and carbon percentage (6), details are given in Table 5. Fly ash was classified through Sturtvent type pilot air classifier. Both tailings (coarse) and fine fractions were collected and investigated. The particle size analysis was supplemented by dry sieve analysis for carbon and fly ash separation studies. Grade efficiency i.e. tromp curves for fly ash as a whole and for carbon have been developed. The movement of the carbon particles during air classification process presented a disarrayed situation.

SIEVE SIZE(MIC)	SMPL-A %RET-VL	SMPL-A N%LOI	SMPL-A CUM%US	SMPL-B %RET-VL	SMPL-B % LOI	SMPL-B CUM%US
+212	20.02	4.82	99.98	19.27	1.83	100.07
-212+150	13.26	2.53	67.08	13.75	0.94	68.53
-150+125	6.42	1.02	49.79	6.54	0.41	52.39
-125+105	6.10	0.85	42.82	6.04	0.30	45.39
-105+90	5.96	1.07	37.01	5.71	0.47	40.29
-90+75	5.66	0.71	29.73	5.27	0.22	32.20
-75+63	5.04	0.59	24.86	4.63	0.16	28.41
-63+53	5.08	0.52	20.82	4.62	0.19	25.61
-53+45	4.96	0.58	17.30	4.50	0.21	22.36
-45	27.50	1.96	13.36	29.67	1.09	18.79
LOI		13.14			5.67	

Table 5 : PSD & LOI VALUES FOR SAMPLE A & B

The average particle size (APS) of feed, coarse and fines for different experimental conditions, E1-E4, are shown in **Figure- 4**. In general, APS is upgraded by a factor nearly 2.0. The size upgradation factor (SUF) is computed as the ratio of APS of feed to fines.



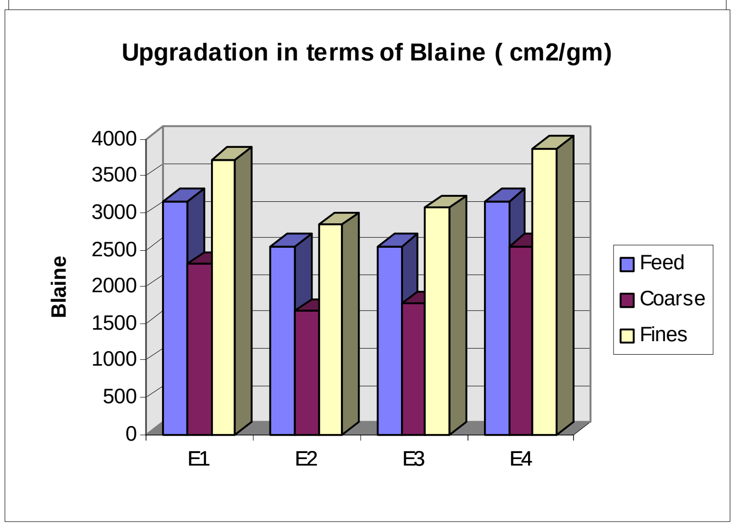


Fig 4 SIZE UPGRADATION IN TERMS OF APS AND BLAINE

Since blaine still remains a more conventional method for describing fineness, the change in blaine values from feed to fines along with coarse is also shown. The effectiveness of separation is reflected more in case of APS than in Blaine values.

DYNAMICS OF SEPARATION

The dynamics of separation of fly ash into two streams with respect to, Separation Index (SI) , Apparent By Pass (ABS) and other details on particle upgradation are provided in **Table 6**.

	E1	**E2**	**E3**	**E4**
CUT SIZE(mic)	110	105	99	70
ABP (%)	18	28	22	40
SI (P70/P30)	2.0	2.9	2.08	1.9*
UPGRADATION IN APS				

	E1	E2	E3	E4
FEED	92	93	93	92
COARSE	175	147	166	133
FINES	53	58	50	46
UPGRADATION IN BLAINE				
FEED	3162	2551	2551	3162
COARSE	2307	1667	1768	2551
FINES	3726	2846	3067	3877
SEPARATION OF CARBON PARTICLES				
FEED	13.14	5.67	5.67	13.14
COARSE	15.64	6.71	6.84	15.13
FINES	12.77	4.67	4.52	11.68
RR (%)	3	12.34	20.84	11.11

Table 6 : Dynamics of fly ash Separation

The above studies provide necessary evidence to resolve that ,

- Air classification is an effective means to improve quality of fly ash
- For a given cut point , consistent quality of fines can be obtained
- Carbon particles are ineffectively separated with very low reduction ratio (RR)

<u>High Performance Pozzolana - HPP</u>

The methodology which are discussed can be applied individually or integrated to develop and produce HPP. The data presented in **Table 7** shows cumulative impact of various approaches on developing HPP using ash available from Plant A and Plant B.

HPP	Blaine	Setting Time		Compressive Strength Kg/cm^2				PZI
		FST	IST	1	3	7	28	(Min. 80)
FAC FROM ASH B								
HPP B1	3375	120	175	210	398	570	705	97.2
HPP B2	3745	105	165	242	410	520	731	100.8
HPP B3	3950	95	170	245	435	568	756	104.2
G-53	3100	130	180	255	480	561	725	100.00
FAC FROM ASH A								
HPP-A1	3605	210	230	180	330	418	556	85.7
HPP-A2	3750	205	230	186	355	450	610	94.0
HPP-A3	4080	180	222	215	420	452	618	95.2
G-53	3273	125	170	245	441	546	649	100.0

Table 7 : Data on High Performance Pozzolana Cement.

- With increase in fineness of blend, efficiency of HPP improves for Ash A & B
- To achieve similar efficiency levels i.e. PZI >95%, blends based on Ash A needs more grinding. This clearly underlines the technological differences between Ash A and B.
- Data suggests that high quality base is essential to develop HPP.

- Data is suggestive of the fact that HPP based on Fly Ash B are easier to grind to develop strength levels similar to G53. It also indicates possibility of increase in quantum of ash addition.

- Setting behaviour of HPP B series is also compatible with G-53 grade.

- Fineness of the blend is a key vital factor which influences performance level of FAC.

- The increase in fineness completely negates the advantage of G-53 over FAC.

VALUE ADDITION

The presence of unburnt carbon is an inherent quality problem associated with Fly Ash. The amount varies from 3-10 % and may go higher during base load operations. High carbon ash is rendered unsuitable for use in FAC or even concrete.

Technologies have been developed and commercialised to separate carbon from fly ash (6 ,7). Dry as well as wet methods of fly ash beneficiation vis-a-vis carbon recovery are the recent advances in the field of fly ash utilisation.

Separation Technologies Incorporated (STI), USA, has already commissioned two units, 18 tph, at New England Power(NEP) plants at Salem Harbour and Brayton Point . These units are based on the principles of Electrostatic Separation (ESS). Fly ash with 6-25 % carbon is reported to be beneficiated to < 3 % carbon with 60-80 % product yield. Clean ash is sold in New England concrete market and recovered carbon has utility as fuel.

Mineral Resource Technology (MRT), Atlanta are collaborating with Michigen Technology University to market carbon separation technology based on forth floatation. Groppa et al(8) has reported detailed work on floatation techniques, carbon is reduced to 0.5 % carbon with clean ash yield of 95 %. In India Gujarat Ambuja Cements who has already taken lead role in mass utilisation of fly ash are in quest of these High Technology Solutions.

<u>Conclusions</u>

Technology options are available which can be effectively integrated to derive benefits of Fly Ash utilisation and production of Fly Ash cements which can emulate performance levels of OPC.

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