Discussion Forum

Concrete for hydro-electric projects: Combating alkali-aggregate reaction

The paper titled "Concrete for hydro-electric projects combating alkali-aggregate reactions" by S.C. Maiti, Raj K. Agarwal and Rajeeb Kumar published in January 2005 issue of the *Journal* (Vol. 79, No. 1, pp. 33-39) gives some useful information about the material constituents of concrete required for the different types of concrete for different structures in dam construction such as concrete gravity dam, intake structures and spillways, particularly with reference to long term alkali-aggregate reaction. Data furnished by them for alkali-content and heat of hydration in *Table* 1 of the paper indicates that for gravity dams, the good old ordinary portland cement (OPC) 33 grade scores over others on both these counts, excepting for some benefits in low heat of hydration level at the expense of high alkali content as in the case of portland pozzolana cement (PPC) *(ii)* and portland slag cement (PSC) *(ii)*, *(iii)*, *(iv)* and *(v)* ignorable as the benefit is marginal. Such being the case, why go for PPC and PSC particularly when consistent quality of low-lime fly ash and slag are not available everywhere for the production of factory blended PPC/PSC cement. Better impermeability of PPC or PSC – concrete is achievable only after prolonged curing and the thickness of members in gravity dam are so large that such improvement will have hardly any bearing on the design or hydraulic aspects. The authors' views in this regard will be highly appreciated.

Table 1: Typical data on alkali content and heat of hydration of cements*

Sl. No.	Cement		Alkali content, percent (as Na_2O equivalent)		Heat of hydration, kJ/kg at 7 days		Heat of hydration, kJ/kg at 28 days
1	OPC	33-grade	(i)	0.59		209	238
		43-grade	(ii)	0.59		320	341
		53-grade	(iii)	0.52		287	347
			(iv)	0.97			
			(v)	0.86			
			(vi)	1.29			
			(vii)	1.25			
			(viii)	0.96			
			(ix)	0.91			
2	PPC		(i)	0.58	(i)	251	295
			(ii)	0.77	(ii)	181	214
			(iii)	0.80	(iii)	199	230
			(iv)	1.02			
3	PSC (with more than 50 percent slag)		(i)	0.85	(i)	254	292
			(ii)	0.71	(ii)	188	226
			(iii)	0.67	(iii)	174	231
			(iv)	0.67	(iv)	213	252
			(v)	0.77	(v)	196	244
			(vi)	0.80			
			(vii)	0.78			
			(viii)	0.89			
(i)	Requirement of low heat Portland cement as per IS 12600, max.			—		272	314
(ii)	Requirement of ASTM Type IV cement and BS : 1370, max.			—		250	290

*Reproduced from author's paper published in January 2005 issue.

Further, alkali contents of all the blended cements tested by the authors excepting PPC *(i)*, are 20 to 80 percent more than these of OPC *(i)*, and *(ii)* mostly used in dam and hydraulic structures. Slight increase in heat of hydration can be taken care of by measures like replacing a part of the mix water by ice during construction but long term expansion in concrete due to alkali-aggregate reaction, where potentially reactive aggregate has to be used, even after 30 years, cannot be satisfactorily tackled by introducing more alkalis in the concrete through the use of blended cement. This is particularly true for cases of alkali-carbonate reactivity where PPC reacts too slowly to prevent dedolomitisation and PSC throws in more alkalies (0.65 to 0.89 percent) compared to OPC-33, 43 and 53 *(iii)*, OPC 53 is better avoided in high strength construction as well. Incidentally, the authors may kindly check some of the values reported in *Table* 1, as quoted below:

- 7-day heat of hydration for 43 grade OPC
- Actual percentage of pozzolana and their types reported in PPC *(i)* to *(iv)*
- Actual percentages of slag and its composition reported in PSC *(i)*, *(iv)* and *(v)*.

Further, is there any relationship between the alkali content and heat of hydration? Also is there any admixture – chemical or mineral which can control this AAR within manageable limit as silica fume is found to be ineffective in controlling this deleterious effect of the alkali-carbonate variety?

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The author's reply

I would like to thank Mr. Singha Roy for his keen interest in our paper.

Regarding consistency of fly ash and ground granulated blast furnace slag, we wish to inform that flyash is a variable material, whereas slags have a much more consistent chemical composition. Also grade I flyash (for mitigating alkali-silica reaction as stipulated in IS 456 – 2000) is not available in sufficient quantity in the country.

To combat ASR, it is advisable to use portland slag cement with slag content of 50-65 percent. The slag and OPC being consistent individually, the factory-made portland slag cement is a material having consistent properties. The alkali level of such slag cement is generally less than 0.90 percent (as Na_20 equivalent). But this alkali is not fully reactive[1], and therefore, such alkali content of PSC can be considered to be equivalent to less than 0.60 percent alkali (as Na_20 equivalent) of OPC.

Regarding data on heat of hydration of cement in Table 1 of our paper, we wish to inform that these data are typical and the three samples of OPC (33-grade, 43-grade and 53-grade) are not from the same source. The actual percentages of pozzolana or slag and their chemical compositions in these samples are also not known.

Hydration of portland cement is an exothermic reaction; it develops heat. The heat of hydration is liberated over time and the amount of heat at any given time is a function of content of potential clinker phases, cement fineness, ratio of water-cementitious material and temperature of curing.[2]

There is no relationship between the alkali content and the heat of hydration of cement. In fact, the heat of hydration of cement does not depend on its alkali content.

Regarding mitigation of alkali-carbonate reaction, it may be informed that there is no reliable chemical or mineral admixture known to reduce the expansion of concrete due to this reaction.

References

1. ______*Specification for the procedures to be used in sampling, testing and assessing compliance of concrete*, BS 5328 : part 4 : 1990, British Standards Institute.
2. Johansen, Vagn C, Taylor, Peter C and Tennis, Paul C. *Effect of Cement Characteristics on Concrete Properties*, Portland Cement Association, 5420 Old Orchard Road, Skokie, Illinois 60077-1083, USA, 2005, p. 40.

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Another reader comments

This has reference to the paper on "Concrete for hydro-electric projects combatting alkali-aggregate reactions", by S. C. Maiti *et. al.*, published in January 2005 issue of *ICJ*. The authors must be commended for highlighting the role of supplementary cementitious materials in mitigating alkali-aggregate reactions (AAR) in concrete used for hydel projects.

In this regard, it seems to me that the authors seem to be favourable to the use of PSC vis-à-vis PPC. I would beg to differ at this point. Since fly ash is now abundantly available in the country, its usage should be encouraged with a view to achieve sustainable development. Also, a plethora of literature supports the addition of fly ash in excess of 20 percent for mitigating effects of AAR. The latest revision of IS 456: 2000 also clearly states,

> "Further advantage can be obtained by use of flyash (Grade 1) conforming to IS 3812 or granulated blastfurnace slag conforming to IS 12089 as part replacement of ordinary Portland cement (having total alkali content as Na_2O equivalent not more than 0.6 percent or slag content is at least 20 percent or slag content is at least 50 percent".

Most of the PPC produced in the country incorporates flyash in excess of 20 percent and hence the use of PPC would be equally effective in mitigating the effects of AAR.

A well-known concrete technologist, Prof P K Mehta, in his book on 'Concrete - Microstructure, Properties and Materials' states, "usually the combination of high alkali portland cement with 40 to 65 percent GGBS or 30 to 40 percent low calcium flyash, or 20 to 30 percent natural pozzolans, have been found to be quite effective in limiting the alkali-aggregate expansion to acceptable levels".

Hence, I strongly feel that the present-day PPC containing flyash in excess of 25 percent is suitable in containing AAR.

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