A LITERATURE REVIEW ON ALKALI SILICA REACTIVITY OF CONCRETE IN PAKISTAN

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ABSTRACT: Pakistan has variety of topographic features including planes, sub-mountainous and mountainous ranges. These mountainous and sub-mountainous ranges possess a vast potential for concrete aggregates. However, alkali silica reactivity has largely been observed in the past, due to reactive nature of these aggregates. This study was planned to explore the possible causes of alkali silica reaction (ASR) and their consequences in the environment of Pakistan. Several materials can be used economically to mitigate alkali silica expansion. Among all possible remedies, use of granulated blast furnace slag is the most effective and economical option to control ASR. Use of other materials such as calcined or bentonite clay, rice husk ash, bagasse ash and silica fume may be effective against ASR.

Key words: Alkali Silica Reaction, Concrete, Aggregates and Dams.

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INTRODUCTION

The production of aggregates from rocks for construction purposes is one of the major industries of world. Pakistan has a vast potential of concrete aggregates due to numerous mountainous ranges like, Karakoram, Himalayas and Makran range (Ali *et al.*, 2014). Rivers running through these ranges and their tributaries possess abundant source of strong aggregates (Majid *et al.*, 2013). Transportation and labor costs can be reduced if the aggregates are available in close proximity of construction sites.

Utilization of aggregates in mega projects of Pakistan: The Indus River is one of the Himalayan River and is a major source of hydropower generation in Pakistan. Tarbela Dam is the first major dam constructed on this river in 1974 (Independent Consultants, 2011). Similarly, other major structures like Mangla Dam and Ghazi Barotha Hydropower Project have been constructed on the tributaries of Indus River. There are many other major structures, constructed on other rivers: Warsak Dam was constructed on Kabul River in 1960 (Izhar, 1990). For all of these mega structures, the economical source of concrete aggregates were the river bed. Besides, Margalla Hills near Taxila, Sakhi Sarwar in D. G. Khan and Kirana Hills in Sargodha are being widely used in Pakistan as concrete aggregates (Alam *et al.*, 1992 and Ahsan *et al.*, 2000). Recently, abundant data has been collected to evaluate the performance of aggregates used in different concrete structures (WAPDA, 2004). Research has been conducted to explore the mineralogical composition of various aggregates in Pakistan (Ali *et al.*, 2014; Khan *et al.*, 2009 and Gondal *et al.*, 2008).

Alkali silica reaction, a historic threat to concrete: Alkali Silica Reaction is a global problem as hydroxyl ions of concrete pore fluid react with silica of aggregates. Higher the alkali contents present in the concrete, more will be hydroxyl ions, which in turn will expedite the reaction with silica (Ghafoori and Islam, 2013). The consequence of this reaction will be alkali silica gel, which expands and produces stress in the concrete. The process starts from the contact surface of aggregate and cement paste (Hagelia *et al.*, 2004 and Idorn *et al.*, 1992). However, with the passage of time, gel formation increases, which in turn enhances cracking. Hydraulic structures were mostly affected by ASR as has been reported by Charlwood *et al.* (1994).

In Pakistan, evaluation of aggregates potential against ASR has been in practice since 1960 (Sandbergs, 1991; TAMS Consultants, 1965 and Stranger, 1961), however reported time span of ASR is small. This may be due to the reason that aggregate selection is generally based on physical properties. Such selection ignores the dangerous impact of ASR expansion. Himalayan rocks have slow reacting aggregates like gneisses, quartzite and other metamorphic rocks, which have potential of ASR expansion (Ahsan *et al.*, 2009 and WAPDA, 2004).

Evaluation of Structures: The first case of ASR was reported in Tarbela Dam, which was followed by similar case at Warsak Dam and Jinnah Barrage (Izhar, 1990 and Hassan, 1987). On the contrary, the evaluation of Mangla Dam for a period of 36 years provided no evidence of ASR (Bhatti *et al.*, 2005). Alternatively, different rock fragments are available at different locations in the beds depending upon their geology and transportation from catchments.

Warsak Dam: Warsak Dam is a concrete gravity dam, constructed on the Kabul River originating from Sanglakh Range of the Hindu Kush Mountains in 1960 (Aziz, 2014). The catchment of Warsak Dam is spread over an area 6734 square kilometers both in Pakistan and Afghanistan (Izhar, 1990).

Most severe case of ASR was reported in Warsak dam resulting in the partial shut off of the project for two years (Majid *et al.*, 2013 and WAPDA, 2004). On the basis of economy, bed material of Kabul River was used as aggregates in the construction. In 1962, cracks appeared in the powerhouse concrete and attributed to the differential settlement. In 1974, instrumentation of dam was carried out for monitoring and the evaluation of monitoring data was carried out from 1974 to 1982 (Izhar, 1990), which revealed that cause of the cracks was ASR. Repair works against ASR was started under the supervision of Canadian International Development Agency after the leakage of penstock (CIDA, 1992). ASR caused following problems in Warsak Dam (Izhar, 1990): (1) Cracks in generator floor were found along with the spalling of concrete and reinforcement was exposed on most of the locations, (2) Longitudinal cracks appeared on the turbine floor, which leaked under full reservoir condition, (3) Appearance of cracks and opening of construction joints were observed in valve gallery, superstructure and tailrace channel along with erosion of spillway chute.

In the petrographic analysis of concrete cores, it was found that almost 38% of total aggregates including greywacke, gneiss and quartzite were reactive and responsible for the ASR (Chaudhry and Zaka, 1998). The study showed that bed of Kabul River had siliceous aggregates, which were more reactive than Indus River bed material to cause ASR expansion (Ahmad and Shah, 2007).

Tarbela Dam: Tarbela Dam Project comprises of a main embankment dam and a pair of concrete auxiliary dam. The project was constructed on the Indus River in 1976. The Indus River originated from the Tibetan Plateau in the surrounding area of Lake Mansarova (Independent Consultants, 2011). Total catchment area of the river spreads over 168349 square kilometers including snow and glacier melt from the Himalayas southern slopes (WCD, 2000).

For construction of dam, processed river bed material was used as concrete aggregates to reduce the project cost. Few years after construction, cracks were observed in both spillways namely: service spillway and auxiliary spillway along with irrigation tunnel. After three years of evaluation, it was observed that cracks were caused by ASR (Majid *et al.*, 2013). It was found that the material was harmful and possessed ASR potential although it was slow (WAPDA, 2004 and Chaudhry and Zaka, 1994). Extensive research work has confirmed that the coarse aggregates from Indus River have ASR potential (Independent Consultants, 2011 and Ahmad and Shah, 2007).

Mangla Dam: Mangla Dam was constructed on the Jhelum River in 1967. The main embankment was earth fill with central clay as the core impervious barrier. Verinag Spring Kashmir in India was the point from where the Jhelum River originated. Catchment area of the Jhelum and its tributaries i.e., Neelum, Poonch and Kunhar rivers spread over 33411 square kilometers (Ali *et al.*, 2011).

Aggregates for construction of Mangla Dam were selected from the Jhelum River bed (Binnie and Partners, 1971) and were declared harmless after testing (Stranger, 1961). No signs of ASR were observed after the construction of dam. In 2004, before the raising of dam, feasibility study was conducted to evaluate the performance of in-service concrete (WAPDA, 2004). In this study petrographic examination was carried out in conjunction with destructive and nondestructive testings (Bhatti *et al.*, 2005). Test results showed that although cores had reactive aggregates, yet no major ASR problem was observed (WAPDA, 2004). Table-1 presents petrographic analysis results of concrete cores extracted from Tarbela, Mangla and Warsak Dam (Majid *et al.*, 2013). Results show the presence of considerable reactive minerals in the aggregates.

Table 1.-Petrographic Results of Dam Concrete Samples.

Reactive Minerals	Mangla Dam (%)	Tarbela Dam (%)	Warsak Dam (%)
Acid to Intermediate Volcanics	13.7	11.2	3.8
S-Type Granite	-	6.5	6.5
Slate / Phyllite	-	2.0	5.9
Greywacke	13.3	7.6	3.5
Strained Quartzite	61.8	5.8	8.7
Chert/Jasper	3.9	0.4	0.5
Schist / Gneiss	0.8	2.4	7.0
Granite Mylonite	-	2.7	1.3
Total	93.5	38.6	37.2

Possible Causes: The major causes of ASR were presence of reactive aggregates, alkali content, humidity and temperature (Charlwood and Solymar, 1994).

Reactive Aggregates: Investigations to explore causes of ASR for Tarbela, Mangla and Warsak Dam Projects revealed that the most prominent cause of ASR was reactive aggregates. It was found that the Indus bed material used in the construction of Tarbela Dam contained slow reactive aggregates like greywacke and cryptocrystalline silica, which caused ASR (Majid *et al.*, 2013). Similar aggregates were also observed in case of Warsak Dam (Chaudhry and Zaka, 1998). The minor cracks observed in case of Mangla dam could be attributed to alkali concentration (Majid *et al.*, 2013). Test results of Mangla Dam showed the phenomena of pessimum, because concrete cores extracted from spillway had more than 90% slow reactive aggregates that can cause ASR expansion (WAPDA, 2004). Because of these slow reacting aggregates and pessimum behavior, ASR could not be detected during investigations (Chaudhry and Zaka, 1994).

Strained quartz, present in many rocks of Pakistan was a reactive mineral and was responsible for ASR expansion (Charlwood and Solymar, 1994). At the time of construction of above discussed dams, there was a scanty knowledge of slow reacting aggregates and the tests available at that time were not sophisticated enough to detect their expansion (WAPDA, 2004). Various researchers like Magni *et al.* (1986) proposed different limiting values of slow reactive aggregates. They suggested that 15% is an acceptable limit. Whereas, in Norway it was reported that if quantity was greater than 20%, further testing was recommended. ASTM C 33, recommended to perform tests if reactive materials were present even less than 1%. In Tarbela and proposed Kalabagh Dam, testing on the Indus River bed aggregates was done according to ASTM C 289 and ASTM C 227. However, tests following these two standards could not detect ASR expansion (TAMS Consultants, 1965 and Kalabagh Consultants, 1987). Therefore, ASTM C 1260 was recommended to find out the expansion of slow reacting aggregates.

Alkali Content: Alkali Contents have a prominent role in alkali silica reaction. Increase in alkali contents may be due to cement and supplementary cementitious materials. In Pakistan different brands of cement are available for construction, which may have varying amount of alkalies. Commonly used brands of cement along with their alkali content have been presented in Table-2 (WAPDA, 2004).

From above statistics, it was observed that minimum alkali contents of cement brands in Pakistan were close to 0.6% (WAPDA, 2004). Tuthill (1980) observed that instead of 0.6%, alkali contents 0.4% were more appropriate to control ASR. Whereas, ASTM committee (Blanks, 1946) recommended 0.58% alkali contents for effective control of ASR. However low alkali cement i.e., 0.6 percent Na_2O does not necessarily mean that expansion will not occur (ASTM C 150). Even if more amount of low alkali cement was used with reactive aggregates, ASR expansion was still possible (Johnston, 1986). Besides, availability of low alkali cement is not very common as the nature of raw materials basically controls alkali content of cement. Another way to reduce alkali contents may be a modification of whole system of cement manufacturing, which will be highly uneconomical (Johansen, 1989). Some aggregates release alkalies in concrete mix, which influence and affect the ASR expansion (Berube *et al.*, 2002 and Stanton, 1942). Owing to the above discussed reasons, alkali content cannot be controlled at any stage. In all the structures affected by ASR, there is no report of using low alkali cement. Therefore, it may be inferred that alkali contents were not within the permissible limits to inhibit ASR.

Table 2. Alkalies in Different Cement Brands.

Cement Brand	Alkalies
Maple Leaf Cement	0.87
Fauji Cement	0.9
Askari Cement	0.58
Fecto Cement	0.59
Dandot Cement	0.71
Maple Leaf Low Alkali Cement	0.53

Humidity and Temperature: Generally ASR occurs at a faster rate at higher temperature and humidity. Relative humidity on site of Tarbela Dam remains greater than 70% for most time period of year and the average temperature ranges from 13^{o}C to 33^{o}C (Independent Consultants, 2011). This temperature and humidity is favorable for generating ASR conditions.

In some areas of Warsak Dam, silica gel was found along with crack that was the direct confirmation of ASR. ASR expansion was more in areas exposed to water or under submerged conditions. Saturation was an important factor in causing ASR expansion in most concrete parts of the Warsak Dam (Izhar, 1990).

In Indus plain, 2°C and 49°C was recorded as the mean minimum and maximum temperatures (WCD, 2000). The temperature ranged 6^{o}C to 48^{o}C in Mangla Dam area (Ali *et al.*, 2011). During the high temperature, the rate of ASR may increase.

Mitigations: As ASR in Warsak Dam was because of slow reacting aggregates so possible mitigations adapted were crack grouting, cutting slots for stress relieve and proper anchorage (Izhar, 1990). As it was post-construction so these were the best options to mitigate ASR expansion. However several options could be adopted during construction to overcome the potential of ASR expansion. Slag cement can be used to prevent the reactivity of aggregates (Independent Consultants, 2011). Use of pozzolans is effective against ASR expansion owing to pozzolanic reaction and reduction in alkali content (Tuthill, 1982). Following are different possible solutions that can be adopted during construction to avoid ASR expansion.

Non-Reactive aggregates: Non-reactive aggregates like limestone should be used to avoid ASR expansion. However, sometimes the use of non-reactive aggregates is not possible due to uneconomical reasons. So other options can be availed. Sometimes blending reactive aggregates with non-reactive ones can control ASR expansion (Hassan, 1987). However, grading and size of aggregates affect the ASR expansion (Multon *et al.*, 2009; Ramyar *et al.*, 2005 and Lu *et al.*, 2004). It was found that opal in range of 20-125μm expanded faster than coarser sizes, however overall expansion was the same (Diamond and Thaulow, 1974). Similarly, it was found that finer argillaceous dolomite limestone had faster and higher ASR expansion (Lu *et al.*, 2008). Greywacke aggregates could expand more even at low alkali contents, when used with other aggregates (BRE Digest 330, 2004). Therefore the size of aggregates and combination to be worked upon in field should be used in laboratory to evaluate the potential expansion due to ASR.

Blast Furnace Slag: According to ACI 116, Blast furnace slag has silicates and aluminosilicates of calcium, obtained in molten condition with iron from blast furnace. Pakistan Steel Mill Karachi is the only source of getting slag inside Pakistan. Slag weighing 270,000 tons is obtained annually from steel mill (Hassan, 1987). This has been used in the construction of Ghazi-Barotha Hydropower Project and Akra Kaur dam (Sandbergs, 1991 and GBHP Feasibility Report, 1996). From laboratory testing of Mangla dam, it was found that replacing 30-40% of cement with slag was effective against ASR expansion, even if testing conditions continued for a longer time (WAPDA, 2004). Blast furnace slag from Karachi steel mill fulfills the requirement of ASTM C 989 (Sandbergs, 1991). The chemical composition of slag along with limits has been shown in Table-3 (Hassan, 1987). About 65% heat of hydration was reduced by using 40% slag in replacement of cement, which was very helpful in mass concreting (Hassan, 1987). From Table-3, it could be seen that alkalies were present in slag. These alkalies should be taken in consideration, as ASR expansion may be increased by them. Although, slag was effective against ASR expansion, but using high amount of it reduced the pH of the concrete, resulting in corrosion.

Table 3. Chemical Composition of Slag.

Sr. No.	Chemical Constituents (%)	Pakistan Steel Mill Slag (%)	ASTM Limits for Slag (%)
1	SiO_2	35-37	30-40
2	Al_2O_3	15-17	8-18
3	Fe_2O_3	0.57-0.9	0-1
4	CaO	36-38	40-50
5	MgO	7.75-8.5	0-8
6	Mn_2O_3	0.9-2	0-2
7	S	0.5-1.5	0-2
8	Alkalies (Na_2O)	0.53-0.68	-

Low alkali Cement: ASTM C 150 recommended limit of alkalies less than 0.6% with reactive aggregates to prevent ASR expansion. Maple Leaf Factory in Pakistan is providing low alkali cement with 0.54% of alkalies (WAPDA, 2004). To produce low alkali cement, strict quality control and high fuel was required that made it an uneconomical option. That is why, it was not preferred generally. In the past it was being used in construction of Lahore Airport new passenger terminal (WAPDA, 2004). Generally low alkali cement was not preferred because even by its use, alkali silica reaction could occur (Tuthill, 1982 and Hadley, 1968).

Calcined Clay: Calcined Clay was produced by Maple Leaf Factory by using cement manufacturing facilities and was effective in controlling ASR (WAPDA, 2004). It has been investigated in Kalabagh Dam Project (Kalabagh Consultants, 1997). Metakaolin is a calcined clay and is available commercially in some countries. However in Pakistan no production of calcined clay is available commercially. Metakaolin is a nearly anhydrous solid obtained after calcination of kaolinite at a specific temperature (Sharif, 2011). Commercial name of kaolinite is China Clay. Metakaolin has pozzolanic properties and improves strength and durability (Sharif, 2011). Use of metakaolin is effective against ASR (Coleman and Page, 1997). Metakaolin in replacement of cement by 10-15% was effective to control ASR expansion (Ayub *et al.*, 2013). In Pakistan, deposits of kaolinite were located in Swat Khyber Pakhtoon Khwa and at Nagar Parkar Sindh. Kalabagh area has the clay stone, which after calcination could be used to control the ASR expansion (Kalabagh Consultants, 1997). Reduction in expansion by 78% was observed after testing calcined clay to control ASR (WAPDA, 2004).

Bentonite Clay: In 1898, Knight was the first one to propose the term "Bentonite" (Ahmad and Siddiqi, 1995). Bentonite is a natural occurring pozzolanic material. Bentonite deposits are present in different areas of Khyber Pakhtunkhwa province of Pakistan *i.e.*, Jehangira, Takht Bhai and Karak area (Afzal *et al.*, 2014; Memon *et al.*, 2012; Akram *et al.*, 2007-d; Badshah, 2003 and Ahmad and Siddiqi, 1995). Use of bentonite is not only cost effective but is also helpful in producing greenhouse effect. Using Bentonite Clay (BC) can increase the strength and improve the durability (Afzal *et al.*, 2014; Memon *et al.*, 2012 and Ahmad, 2011). BC in replacement of 25% can save 11% of the total cost (Zain *et al.*, 2011). Although no published research exists about the effectiveness of Pakistan bentonite against ASR expansion but as it has pozzolanic properties and can improve strength and durability (Mirza *et al.*, 2009), therefore it can be expected as a useful material in controlling ASR expansion.

Fly Ash: Fly ash (FA) is a fine residue material obtained after the combustion of powdered coal in power generation plants. It possesses cementitious properties and improves the concrete strength (Akram *et al.*, 2007-c; Oner *et al.*, 2005; Rizwan *et al.*, 2004 and Khan *et al.*, 2001). FA can only be obtained from Lakhra coal Power Plant in Pakistan. An area of 250 square kilometers is covered by Lakhra coal power plant. Power plant produces FA in powder form. Approximately 2 million tons of ash is produced annually from the plant (Memon *et al.*, 2010). However it is reported unsuitable for concrete because of its high quantity of gypsum (Aziz *et al.*, 2012; Aziz *et al.*, 2010 and WAPDA, 2004). Table-4 shows the comparison of Pakistan FA composition and ASTM C 618 limits for FA (Aziz *et al.*, 2012 and Aziz *et al.*, 2010). From Table-4, it is found that quantity of sulphate is higher in Pakistani FA. In different parts of the world, use of fly ash up to 30% in replacement of cement is found effective against ASR (Akram *et al.*, 2007-c and Detwiler, 1997). However the use of fly ash is not efficient in Pakistan because of the desulphurization process.

Table 4. Comparison between Pakistan Fly Ash and ASTM limits for Fly Ash.

Sr. No.	Chemical Constituents (%)	Pakistan Fly Ash (%)	ASTM Limits for Fly Ash (%)
1	SiO_2	20.3-25.2	($SiO_2 + Al_2O_3 + Fe_2O_3$) Min. 50.0
2	Al_2O_3	13.1-15.2	
3	Fe_2O_3	8.2-9.8	
4	CaO	21.2-24.0	No Limit
5	MgO	2.3-3.5	No Limit
6	SO_3	12.5-14.0	Max. 5
7	LOI	13.8-15.2	Max. 6

Blended Cement: Blended Slag Cement is produced in Karachi. During grinding of cement clinker, 30% slag was ground as replacement (WAPDA, 2004). Blended cement production is more sustainable as less fuel is consumed for clinker formation as well as CO_2 emissions and it improves the strength and durability properties of concrete (Khan, 2001 and Mehta, 1998). In many parts of the world, blended cements have been produced commercially and are effective in controlling ASR. Different researchers have tried to explore the production of blended cements in Pakistan through addition of natural occurring pozzolanic materials but commercially Pakistan has produced very small amount of blended cement. Natural pozzolans that are available in different areas of Pakistan and have been evaluated to be used in blended cement include Pozzolana deposits in different areas of Khyber Pakhtoon Khwa i.e., Karak, Mohmand Agency, Swabi and Swat and Laterite deposits in Ziarat area, Sibi, Loralai and Muzaffarabad (Imran *et al.*, 2015; Bukhari *et al.*, 2013; Khan *et al.*, 1984; Shah, 1976 and Usmani, 1969). Although there is no data available about its use however, use of blended cement is not cost effective against ASR expansion as it is not produced commercially in Pakistan.

Rice Husk Ash: Earth surface is covered by 1% rice crop and it is considered as the main food source of people (Akram *et al.*, 2007-a). In 2002, Pakistan had 5.77 million tons of production of paddy rice (Memon *et al.*, 2011). Husk is the rice kernel outer cover having two interlocking halves. It is not eatable and is removed. Approximately 20% of rice paddy is husk and accordingly Pakistan can produce 1.15 million tons of husk (Memon *et al.*, 2011). Ash is produced after combustion of rice husk. Different researchers have reported different percentage of ash obtained after combustion. Normally it ranges from 15-25% of rice husk (Mahmud *et al.*, 1997 and Cook *et al.*, 1976). By using Rice Husk Ash (RHA), almost 40% cost is reduced (Memon *et al.*, 2011). RHA is a pozzolanic material and improves strength (Jamil *et al.*, 2013 and Zain *et al.*, 2011). In many parts of world, ASR expansion is found controlled by using up to 15% RHA (Hasparky *et al.*, 2000 and Zhang *et al.*, 1996). Although no published research exists about the effectiveness of Pakistan RHA against ASR expansion but as it has pozzolanic properties and could improve strength and durability. Therefore it can be expected as a useful material in controlling ASR expansion.

Bagasse Ash: Pakistan is world's fifth largest sugarcane producing country (Akram *et al.*, 2007-b). Pakistan produces 50 million tons of sugar cane annually which is used mostly in sugar production (Akram *et al.*, 2007-e). As a result, 24-30% of bagasse obtained that is a waste product and used in sugar industry as a source of fuel (Ali *et al.*, 1989). Sugarcane Bagasse Ash (BA) is obtained after the combustion having main components silicon and aluminium oxides. Approximately, sugar industry uses 81% of the sugarcane (Akbar and Khawaja, 2006). Pakistan is capable of producing approximately 11 million tons of bagasse and after combustion 0.26 million tons of BA (Akram *et al.*, 2009). Using BA can increase the concrete strength and is also cost effective (Room *et al.*, 2014). Although little or no published research exists about the effectiveness of Sugarcane BA against ASR expansion but as it has pozzolanic properties and can improve strength and durability, therefore it can be expected as a useful material in controlling ASR expansion.

Silica Fume: Silica fume (SF) is polymorph of silicondioxide found in amorphous form. It is obtained as a byproduct during the production of silicon and ferrosilicon alloy. It is known as micro silica. SF is a pozzolanic material and improves properties of concrete (Pradhan *et al.*, 2014; Akbar *et al.*, 2013 and Toutanji and El-Korchi, 1996). Among all cement replacement materials, SF is the most effective one because of its fineness and high silica content (Sharif *et al.*, 2013). SF is available commercially in Pakistan (Amin *et al.*, 2014; Akbar *et al.*, 2013 and Sharif *et al.*, 2013). In some parts of the world, 12% SF is found effective in controlling ASR expansion (Boddy *et al.*, 2004). Although no published research exists about the effectiveness of commercially available SF against ASR expansion but as it has pozzolanic properties and can improve strength and durability, therefore it can be expected as a useful material in controlling ASR expansion.

On the basis of study, following materials (Table-5) with different pozollonic properties can be effective in controlling ASR.

Table 5.Quantity of pozollonic materials against ASR

Sr. No.	Pozzolanic Materials	Percentage in replacement of cement effective against ASR (%)
1	Blast Furnace Slag	30-40
2	Metakaolin	10-15
3	Fly Ash	30
4	Rice Husk Ash	15
5	Silica Fume	12

Conclusions: Based on the literature review, it is evident that the problem of ASR exists in major structures of Pakistan, necessitating proper testing before using aggregates. Different factors affect the ASR potential like reactive aggregates, alkali content, temperature and humidity. All these factors and their co-relation with ASR should be properly understood before using the potentially-reactive aggregates. Use of granulated furnace slag in the range 30-40% by mass of cement seems an appropriate solution to mitigate the problem of ASR. Use of some materials like, calcined or bentonite clay, rice husk ash, bagasse ash and silica fume may also prove effective against ASR. Further studies are suggested to be carried out for making their best use as a replacement of costly materials.

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