Pakistan Journal of Science (Vol. 65 No. 2 June, 2013)

Alkali Silica Reaction (ASR) Potential of Sand and Gravels from NW-Himalayan Rivers and their Performance as Concrete Aggregate at Three Dams in Pakistan

C. M. Majid[*], T. J. Bhatti[**], M. N. Chaudhry [*]
[*]College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan.
[**]National Engineering Services Pakistan (Pvt.) Ltd., (NESPAK), Lahore, Pakistan.
Corresponding Author: muzaffar.majid@yahoo.com

ABSTRACT: Concrete aggregates derived from river bed materials of many of the streams originating from the NW-Himalayan region and draining into Pakistan are found reactive in terms of Alkali-Silica Reaction (ASR). This paper describes the long term ASR related performance of concrete at three dams, i.e. Warsak, Tarbela and Mangla, where material from such streams has been used as concrete aggregates. On Warsak an aggressive and at Tarbela a mild ASR has been detected while at Mangla dam ASR free concrete is reported. The anomaly of occurrence and non-occurrence of ASR in concrete manufactured using aggregate derived from the same provenance is described.

Key words: Aggregates, Concrete, Alkali – Silica Reaction, Dams

INTRODUCTION

The Himalayan region forms a border between the Indian sub-continent and the rest of Asia. The region comprises rugged mountain chains, V-shaped very deep valleys and many of gigantic streams draining the plains of Indian sub-continent. The prominent streams include Indus, Ganges and Brahamputra. Geologically the area is complex and comprises a wide variety of igneous, metamorphic and sedimentary rocks. The streams originating from the region and draining Nepal, Pakistan, Bhutan and India have a huge potential for hydropower generation.

NW-Himalayan rivers in Pakistan, on which some hydropower projects were completed in the past while many more future hydropower development schemes have been proposed, have their catchments belonging to NW Himalayas. Many factors, in particular the young and immature geology and landform of Himalayas aggravated by the action of glaciers and tropical climate (hot summer followed by heavy monsoon), are responsible for massive land degradation. These factors have resulted in rivers of the region carrying a lot of load belonging to the rock types exposed in their respective catchment areas.

Owing to less efforts required for manufacturing the aggregates, these streams are always attractive sources of concrete aggregates for investors in mega projects, more particularly hydropower projects. It is anticipated that they will remain potential sources for future projects as well.

The Indus River is the most important and major source of hydropower development in Pakistan. Soon after the signing of Indus Water Treaty between Pakistan and India in 1960, the construction of Tarbela dam as integral part of Indus Basin Project was initiated and completed in 1974. Mangla dam under the same treaty on the Jhelum River (also a Himalayan river) was completed in 1968. Recently under its "Vision 2025 Program" the Water and Power Development Authority (WAPDA) in Pakistan has initiated many small and medium sized hydropower projects in the region and many large projects are anticipated. The Warsak dam was completed in year 1955 on Kabul River. For these dams the concrete aggregates were derived from the river beds on which they are constructed. After decades of construction, the service performance of these aggregates is available and discussed.

This paper highlights the findings of the in-service performance of aggregates derived from the NW Himalayan rivers at these three dams and provides general guidance to geologists, engineers and investors for selection of materials involved in future development projects.

Background of alkali-silica reaction: There has been an enormous amount of literature about the background theory and cases of Alkali-Silica Reaction in concrete structures after its discovery by Stanton in California, USA in 1940.

Alkali-Silica Reaction is a reaction in which certain aggregates react with the alkaline pore solution of concrete and manifests itself in extreme cases in the form of deterioration and distress in concrete. As the reaction's name implies, the reactive aggregate contains silica. However not all siliceous aggregates are reactive in terms of ASR. Only the amorphous non-crystalline/glassy form of silica, unstable crystalline polymorph of silica, poorly crystalline form of silica and microcrystalline quartz bearing rocks are reactive in concrete alkaline environment. The list of reactive minerals/rocks is long and available in literature.

The ASR in concrete structures is a global problem irrespective of geographic location and climatic conditions. A worldwide listing of 76 known cases of alkali aggregate reaction in hydraulic structures is available (Charlwood and Solymar 1994).

The history of reported ASR cases in Pakistan is not as old as in other countries; however, the studies in relation to finding the potential alkali susceptibility of concrete aggregates before using them in concrete at major dam projects are in practice since 1960 such as by (Bertacchi, 1991: Fookes,1980: Smith and Collis, 1993).

The first case of ASR in Pakistani hydraulic structures was reported by Mielenz (Petrographic examination of samples of concrete, Tarbela Dam, Pakistan, unpublished report for WAPDA). Another case was confirmed by Zaka et. al.1997 at Warsak dam. Recently, a free ASR behavior was reported for the 35 years old Mangla dam (Bhatti et. al. 2005) .

The common feature of all the three mentioned dams is that the used concrete aggregates belong to the same provenance i.e., gravels of NW Himalayan streams. The reserve of aggregates from this provenance is colossal and has huge economic viability for the hydropower development projects. It is envisaged that the millions of tons of concrete aggregates from these sources would be exploited in years to come for production of concrete.

At any location on the stream, the upstream geology and transport distance are the factors responsible for type and quantity of rock types available in stream bed load. Geology is the most important factor that needs to be considered in relation to ASR if the material is to be used in concrete.

Geological setup of Himalayas: The Himalayan Range is a singular unit of immense physical dimension flanking northern side of many countries of south Asia. The range pertains to the north-south traverse section and east-west longitudinal section. Geographically the Himalayan Range is divided into three parts i.e, Eastern, Central and Western units. On the basis of geological setting the whole of the range has been divided into three units which are equally applicable to each of the geographic sub-divisions.

The well-recognized geological units rising from south to north are the Siwalik (Sub-Himalaya), Lesser Himalaya, and Higher or Greater Himalayas. The Siwalik Range is the youngest and abuts the plains as foothills dipping to the north. It extends from Indus almost to the Brahamputra with one gap of over 3000 km where the fierce monsoon erosion has almost worn it away completely. The Lesser Himalaya is older and higher than Sub Himalaya, but with the same regional trend. The structure is more complex, being contorted by recumbent folds with older sedimentary rocks overthrusting younger ones. The Higher Himalaya, the axis and crystalline core of the whole range, is composed mainly of granites and gneisses with some meta-sedimentary rocks.

The northwest himalaya and Kohistan island ARC: The northwest Himalayas include suture zones representing large scale thrust faults (i.e, Main Mantle Thrust and Main Karakorum Thrust) due to India - Eurasia collision. Geographically, the mountain ranges occupy a large part of the State of Jammu and Kashmir, Northern Pakistan and some part of Afghanistan (Fig. 1 and 2).

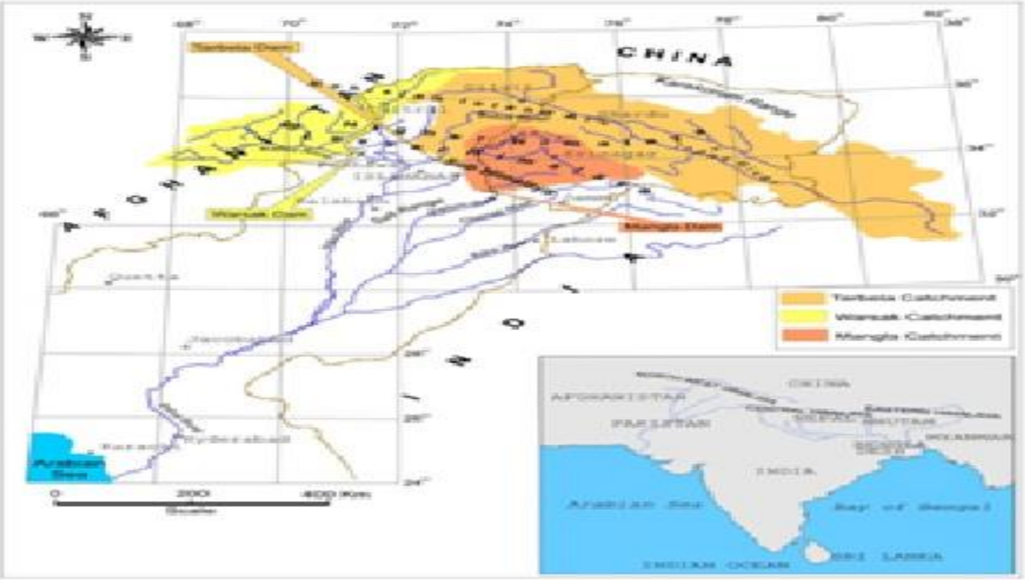
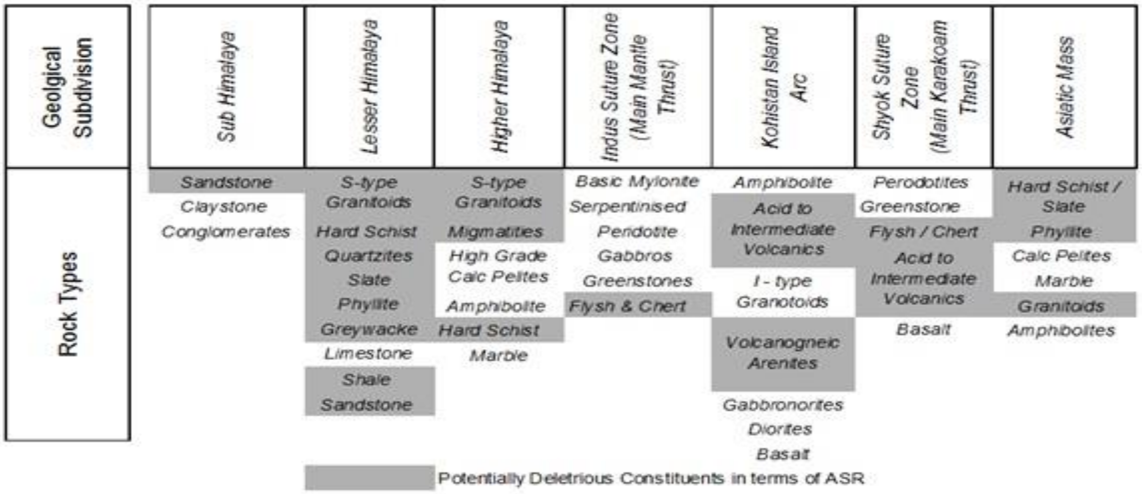


Fig. 1: Location of Tarbela, Warsak and Mangla dam with their respective catchments in NW Himalaya

Fig. 2: Geological Subdivisions of NW Himalayas

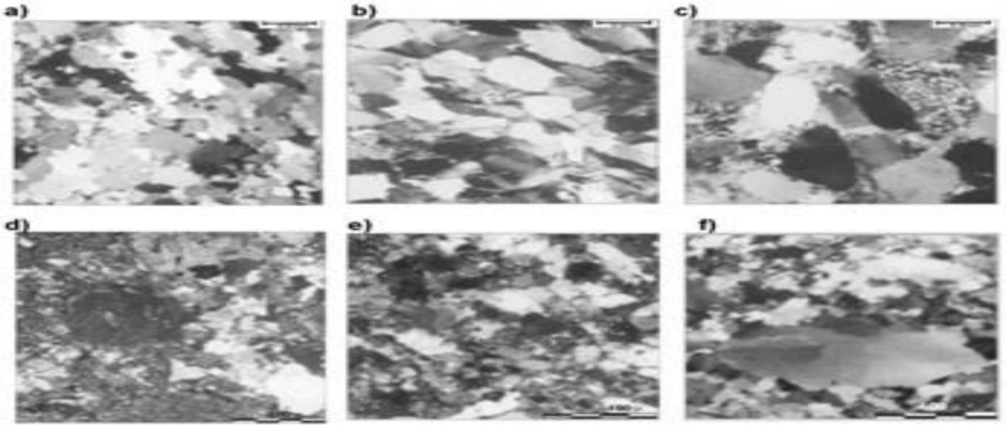
The rock types exposed in various geological subdivisions of Northwest Himalayas are shown in Fig. 3. Photomicrographs of some of the rock types are shown in Fig. 4.



Geolgical Subdivision	Sub Himalaya	Lesser Himalaya	Higher Himalaya	Indus Suture Zone (Main Mantle Thrust)	Kohistan Island Arc	Shyok Suture Zone (Main Karakoam Thrust)	Asiatic Mass
Rock Types	▨ Sandstone	▨ S-type Granitoids	▨ S-type Granitoids	Basic Mylonite	Amphibolite	Perodotites	▨ Hard Schist / Slate
	Claystone	▨ Hard Schist	▨ Migmatities	Serpentinised Peridotite	▨ Acid to Intermediate Volcanics	Greenstone	▨ Phyllite
	Conglomerates	▨ Quartzites	High Grade Calc Pelites	Gabbros	I - type Granotoids	▨ Flysh / Chert	Calc Pelites
		▨ Slate	Amphibolite	Greenstones	▨ Volcanogneic Arenites	▨ Acid to Intermediate Volcanics	Marble
		▨ Phyllite	▨ Hard Schist	▨ Flysh & Chert	Gabbronorites	Basalt	▨ Granitoids
		▨ Greywacke	Marble		Diorites		Amphibolites
		Limestone			Basalt		
		▨ Shale					
		▨ Sandstone					

▨ Potentially Deletrious Constituents in terms of ASR

Figure 3: A matrix of geological subdivisions of NW Himalayas and rock types of respective sub-division



Major nw himalayan rivers: The Indus River rises into the Tibetan Plateau north of Lake Manasarowar, at 5500 m elevation, in the Kailas Glacial Range. The catchment of Indus at Tarbela dam covers nearly all the geological sub-divisions of NW Himalayas except Outer or Sub Himalaya. The catchment of Kabul river is not as large as the Indus catchment but it consists in areas draining Kohistan Island Arc, Higher Himalaya, Lesser Himalaya Indus Suture Zone and Asiatic Plate.

The catchment of Mangla dam occupies the Jhelum, Neelum, Kunhar and Poonch rivers. The Kunhar and Neelum rivers flow through Higher Himalaya, Lesser Himalaya and Sub Himalaya where they join with the Jhelum river. The Poonch river drains Lesser and Sub Himalayan terrains. The Jhelum River originates from Lesser Himalaya. However upstream of Mangla dam 120 km stretch of the river flows in sub Himalayan terrain. The geological domains through which these three rivers flow are displayed in Fig. 1and 2.

Petrographic modals of aggregates at three selected dam sites: Petrographic studies of samples from the river bed of the three cited dam sites were carried out as per ASTM C 295. Concrete were studied petrographically. The results of these studies have been given in Table 1 and 2.

Table 1: Petrographic Modal Composition of Three Rivers Bed Gravels and Coarse Aggregates in Concrete

Mineral / Rock Constituents	*Indus River at Tarbela (n=12)*	*Kabul River at Warsak (n=10)*	*Jhelum River at Mangla (n=6)*	*Tarbela Dam (n=8)*	*Warsak Dam (n=10)*	*Mangla Dam (n=10)*
	Gravels			**Concrete Coarse Aggregate**		
Micro Fractured and Strained Quartzite*	5.3	9.6	62.2	5.8	8.7	61.8
Quartzite	19.9	19.5	-	21.5	18.2	-
S-Type Granite*	7.0	6.3	4.0	6.5	6.5	-
I- Type Granite	8.5	5.0	-	8.1	6.1	-
Diorite / Microdiorite	19.4	12.1	0.8	18.8	14.0	-
Slate / Phyllite*	1.7	6.9	0.4	2.0	5.9	-
Quartzwacke *	-	-	2.2	-	-	-
Lithic Arenite*	-	-	2.0	-	-	-
Greywacke Group*	8.1	3.3	1.3	7.6	3.5	13.3
Limestone + Marble	5.4	5.3	0.4	3.0	5.1	2.1
Acid to Intermediate Volcanics*	10.6	3.4	22.5	11.2	3.8	13.7
Basic Volcanics	3.0	1.5	-	2.7	2.0	-
Vein Quartz	0.1	0.2	0.2	0.1	0.1	-
Chert/Jasper *	0.3	0.8	0.5	0.4	0.5	3.9
Dolerite	0.2	0.1	-	0.3	0.2	-
Schist / Gneiss*	2.0	8.8	-	2.4	7.0	0.8
Microgabbro	-	-	0.6	-	-	-
Basalt	-	-	0.5	-	-	1.6
Microgranite	0.5	0.2		0.6	0.3	-
Metadolerite	-	-	1.8	-	-	2.8
Amphibolite + Garnet Amphibole	3.5	15.2	-	5.2	16.8	-
Granite Mylonite*	3.3	1.7	0.24	2.7	1.3	-
Sandstone	1.0	-		0.8	-	-
Epidosite	0.2	0.1	0.2	0.2	Traces	-
Total Deleterious Constituents	**38.1**	**40.8**	**96.0**	**38.6**	**37.2**	**92.7**

Minerals / rocks marked with asterisk sign are potentially reactive.

Case studies: The following paragraphs provides the history of using these aggregates together with observations and conclusions drawn from the in-service behavior of concrete of the three dams and puts forward guidelines for future usage of the same sources for concrete aggregates.

Warsak Dam (1960)

Project History: Warsak dam is a multipurpose project commissioned in 1960 for irrigation and power generation on Kabul River, in North West Frontier Province (NWFP) of Pakistan. The dam is a 180m long concrete gravity structure rising 76m above the foundation level. It has a generating capacity of 40MW.

Concrete and ASR Studies: The concrete for dam and powerhouse structure was manufactured using the coarse and fine aggregates taken from the bed of Kabul River.

Cracks in the concrete of powerhouse started appearing in 1962 only two years after completion and remained under observation by WAPDA. Extensive monitoring started in 1975 and in 1982 M/s Golder Associates confirmed the presence of ASR in concrete. An emergency repair of ASR-affected concrete was undertaken when a large number of rivets sheared in upstream connection of the valve of Unit No. 1 to the 18 feet diameter penstock, with the consequent major leakage of penstock water into powerhouse (CIDA, 1992).

Water and Power Development Authority (WAPDA) appointed the Canadian International Development Agency (CIDA) to rehabilitate the affected units 1 to 4 of the powerhouse. The agency retained the services of Bureau d'Etudes de Lignes de Transport inc. (BELT) to carry out the engineering, procurement and supervision of site work needed to modify and to repair the powerhouse concrete structure to counter the affects of AAR present at that time and anticipated in future. A joint venture of BELT and National Engineering Services Pakistan (NESPAK) completed the repair task in year 1992.

Petrographic modal analysis of concrete cores taken from the powerhouse area revealed that about 38% of the coarse and approximately the same proportion of fine aggregate were reactive in term of ASR. The major reactive species are slate/phyllite, greywacke, schist/gneiss and quartzite having microcrystalline and strained quartz. The studies conducted by Chaudhry and Zaka (1994) concluded that the slate / phyllite, greywacke, chert, and quartzite are the major contributor to ASR malady. The former two rocks were not metamorphosed to a degree where the rock recrystallizes into a stable metamorph in terms of ASR

Tarbela Dam (1971)

Project History: The dam is a multipurpose as for irrigation and hydropower generation. Investigations were started by the Government of Pakistan with the help of Messrs. Tiptoon and Hill Consulting Engineers (USA). In February 1960, TAMS of USA was appointed as project consultant to the TDO (Tarbela Dam Organization) for site investigation, project planning, preparation of detailed design and supervision of project construction.

Table 2: Petrographic Modal Composition of Three Rivers Bed Sands and Fine Aggregates in Concrete

Mineral / Rock Constituents	***(Indus River) Tarbela Dam (n=12)***	***(Kabul River) Warsak Dam (n=10)***	***(Jhelum River) Mangla Dam (n=2)***	***Tarbela Dam (n=8)***	***Warsak Dam (n=10)***	***Mangla Dam (n=6)***
	Sand			**Concrete Fine Aggregate**		
Quartz	30.4	31.2	36.5	28.2	30.0	38.3
Amphibole	6.8	8.2	1.2	6.0	7.2	0.4
Plagioclase/Albite	6.0	7.0	3.6	6.2	6.5	1.5
Orthoclase/Microcline	2.3	4.8	-	3.0	4.7	1.6
Magnetite	1.3	1.1	1.1	1.5	1.4	1.5
Biotite + Muscovite	6.2	4.2	1.9	6.8	5.2	3.0
Strained Quartz	7.1	4.0	-	6.5	6.0	-
Chlorite	0.3	0.6	0.3	0.2	0.3	-
Greenstone	0.5	0.8	-	0.6	0.5	-
Garnet	0.3	0.5	0.8	0.2	0.3	-
Sphene	0.2	0.2	-	0.1	0.2	-
Tourmaline	0.2	Traces	0.1	0.2	0.1	0.2
Lithic Arenite	-	-	0.4	-	-	-
Strained Quartzite	2.5	2.7	18.7	2.0	3.0	23.2
Quartzite	5.2	5.8	-	6.3	6.2	-
S-Type Granite	2.1	1.1	-	2.3	1.0	-
Diorite +Microdiorite	5.2	4.3	-	4.8	5.0	-
Phyllite/Slate	3.5	1.8	5.8	2.8	2.0	4.6
Greywacke Group	5.0	0.5	0.5	6.0	0.7	5.2
Limestone + Marble	1.2	2.7	20.8	1.5	3.0	6.2
Acid to Intermediate Volcanics	0.6	1.1	3.5	1.3	0.8	6.9
Chert / Jasper	0.2	0.5	0.2	0.5	0.7	4.1
Dolerite	0.1	0.2	-	0.2	0.3	-
Schist/ Gneiss	2.1	3.2	1.3	1.7	2.8	1.9
Basic Volcanics	0.7	1.6	-	1.0	1.3	-
Sandstone	Traces	-	-	Traces	-	-
Amphibolite + Garnet Amphibolite	3.5	6.2	-	3.5	7.1	-
Granite Mylonite	2.4	0.8	-	2.0	0.5	-
I-Type Granite	3.6	3.0	1.4	3.3	3.0	-
Microgranite	0.8	1.9	-	1.2	0.4	-
Epidosite	0.2	Traces	1.7	0.1	0.2	1.3

Minerals / rocks marked with asterisk sign are potentially reactive: In 1965 tender was announced and contract for main engineering works was awarded to Tarbela Joint Venture (TJV), a consortium of thirteen European firms led by Impregilo. Construction started in October, 1968 and principal structures were completed by July 1974.

The Concrete and ASR Studies:Coarse as well as fine aggregates were derived from the River Indus and used for the production of concrete. The material was declared harmless at the time of construction. The first appearance of ASR was in service spillway chute and in the auxiliary spillway. The irrigation tunnel structure showed extensive cracking (Swamy, 1992).

The ASR in Tarbela dam was first reported by Melienz (1982) three years after completion. ASR was reported 11 years after construction in some structures and thoroughly investigated by Chaudhry and Zaka (1994).

Mangla Dam (1967)

Project History: Studies for constructing a dam on Jhelum River were initiated in 1951 by the Punjab Irrigation Department. In 1952 Tippon & Hill of USA as consulting engineers investigated the feasibility of dam at Mangla.

After its establishment by Government of Pakistan, the Mangla Dam Organization (MDO) appointed Binnie and Partners of UK as consultants to carry out detailed investigations. Harza Engineering Company International of USA and Preece Cardew and Rider of UK were associated with Binnie and Partner and designed the main spillway and engineering of electrical and mechanical equipment. In 1960, the construction of Mangla dam was awarded to a consortium of 7 firms lead by Guy of Atkinson. The construction work was completed in 1967 one year ahead of schedule Hobbs (1998).

The main feature of the project included an embankment with a maximum height of 138 m and a total length of 13 km, two spillways and a powerhouse. The raising of Mangla dam is now in its implementation stage. The feasibility and detail design for raising has been completed by Mangla Joint Venture (MJV), a consortium of seven local and two foreign consultants (MWH) and Black and Veatch (BV) lead by NESPAK.

The Concrete and ASR Studies: Approximately 1.6 million m^3 of concrete were placed in the concrete structures of Mangla dam. The aggregates were obtained from the Jhelum River deposits downstream the main dam. Both fine and coarse aggregates were declared harmless on the basis of mortar bar NBRI test (Fookes,1980) and no maximum limit of alkalies in cement was specified.

The visual surveys during many periodic inspections revealed an ASR free concrete having no appreciable distress, cracking and other ASR related symptoms. Due to the positive indications of ASR free behaviour of Mangla concrete no attempt was made and nor was it found necessary to study the in-service performance before year 2004.

However for raising of existing spillway it was found necessary to ascertain the durability of 35 years old concrete. An investigatory programme comprising many destructive and non-destructive tests including petrographic evaluation of concrete was executed (Bhatti et. al. 2005).

DISCUSSION AND CONCLUSIONS

Major rock types contributing to the potential for Alkali-silica reaction in concrete are identified and their behavior has been evaluated through petrographic analysis and condition survey. It is generally seen that:

1. All reactive constituents in river bed material originating from the three sampled river bedss are categorized as slow/late expanding.
2. The aggregates are the same in terms of litholgical characteristics but vary in percentage. The fluctuation in percentage is due to the influence of local geology.

Comparing the three cases, it is evident that most severe reaction took place at Warsak powerhouse area. The petrographic modals derived from concrete cores and borrow areas show that higher percentage of slate/phyllite and schist/gneiss differentiates this modal from the Tarbela and Mangla.

At Warsak Dam the slate/phyllite and greywacke in the gravel source are very low grade metamorphic rocks. The metamorphism occurred to a degree where no reconstitution of minerals took place and therefore remained harmful (Chaudhry and Zaka, 1994). This together with the other rock types containing slowly reactive phases such as strained quartz was responsible for ASR. The XRD humps of greywacke show the absence of montmorillonite clay, so that the micro-crystalline matter had been the causative factor of ASR (Qureshi et. al. 2012: Shafique et. al. 2012).

Alkali-Silica Reactions at Tarbela Dam result from greywacke and rocks containing micro and cryptocrystalline silica. At the detailed design stage both rock types were declared innocuous on the basis that the rock types have been metamorphosed to a degree where reconstitution of minerals took place. However the detailed petrographic analysis by Chaudhry and Zaka (1998) demonstrated that no reconstitution took place and the rocks were potentially deleterious.

At Mangla dam, reaction has been detected only along some cracks but most of the concrete is ASR free. The possible reason of ASR along cracks is due to localized concentration of alkalies. From the analysis of concrete cores, it is evident that more than 90% of aggregates used for production of concrete were reactive in terms of ASR, with the results that the reaction took place outside the passimum curve, which is a possible reason of ASR non-occurrence. We conclude that the reaction at Tarbela and Warsak took place due to a balancing amount of available alkalies and reactive aggregate in source.

In severity of ASR occurrence, Tarbela stands between Warsak and Mangla. The percentage of reactive material in case of Warsak and Tarbela is the same but with different individual constituents. It is now believed that if we assume the other conditions conducive for initiation of ASR are alike for both dams, then the only difference is the higher amount of slate/phyllite in Kabul River aggregate compared to Indus at Tarbela.

The source of aggregate consisting variety of rock types possesses special problem i.e., no single passimum curve may derive which may be applicable to the source aggregates. The fluctuation in the percentage and size of reactive materials in the source results in hindering the establishment of a single passimum curve and so a safe limit of reactive aggregates in source. In the absence of such a curve measuring the reactivity potential of the aggregate through some quantitative tests is required. But evaluating the reactivity of aggregates remains a problem since its discovery. Some tests conducted in the past have now lost their significance. The ASTM C-1260 which is nowadays in practice is somewhat conservative in predicting the ASR potential of aggregates.

In such cases it is prudent to take help from the existing structures where the same source has been used. The performance record provides best judgment of aggregate's potential reaction by alkali silica reaction. The survey of exiting concrete structures in the close vicinity of any proposed project with similar source provides valuable information. Experience with the ASR related study of gravels of NW Himalayas shows that this statement is not always correct. Declaring the river bed material reactive in one certain stream might not be applicable to tributaries of the same stream.

It is recommended that if no precise service record is available, a comprehensive petrographic analysis supplemented by other techniques should be conducted for ASR susceptible material.

The potential risks involved in using these aggregates for new construction can be minimized by taking preventive measures. One measure is using the pozzolanic materials. The mixing of inert material is not advised, since this may aggravate the potential and shifting of expansion on the passimum peak. On small jobs or situations in which the pozzolanic materials are economically not efficient but made part of specifications only to curb the potential risk of ASR it is recommended to develop a quarry in innocuous rocks.

Acknowledgment: The authors acknowledge the support and help provided by the Higher Education Commission (HEC), Pakistan for carrying out the subject studies.

REFERENCES

Bhatti, T.J., M.N.Chaudhry, and G.Hassan. Alkali-Silica Reaction Potential of Jhelum River Aggregates and their Performance at Pakistan's Mangla Dam, International Waterpower and Dam Construction, Willmington Publishing UK, 57 (1):26-29 (2005).

Bertacchi, P. Alkali-Aggregate Reaction in Concrete Dams, 79(8): 141-158 (1991).

Charlwood, R.G. and Z. V. Solymar. A Review of Alkali-Aggregate Reactions in Dams" Dam Engineering, 5 (2):31-62 (1994).

Chaudhry, M.N. and K.J. Zaka. Tarbela Dam: A discussion on the Discrepancy between the Laboratory Testing and In-service Behavior of Indus Aggregate in Cement Concrete Dam Engineering, Willmington Publishing, UK, 5(1): 63-80 (1994).

Chaudhry, M.N. and K.J., Zaka. Petrographic Evaluation of Alkali Aggregate Reaction in Concrete Structures of Warsak Dam, N.W.F.P. Pakistan – A Case Study" in Proceedings Eighth International Congress, Assoc. Engin. Geol. and Environment : 41-46 (1998).

CIDA, Warsak Hydroelectric Powerplant Emergency Repairs to Units 1 to 4" Completion Report, Canadian International Development Agency, (1992).

Fookes,P.G. An Introduction to the Influence of Natural Aggregates on the Performance and Durability of Concrete, Quarterly J. Engg. Geol., 13(2): 207-229 (1980).

Hobbs, D.W. Alkali-Silica Reaction in Concrete, Thomas Telford, London: 62-77(1998).

Mielenz, R.C. Petrography Applied to Portland Cement Concrete, Reviews in Engineering Geology, Geological Society of America, GAEGA, 1(2): 1-38 (1982).

Qureshi, J., S. A. Mahmood, A. S. Almas, H. M. Rafique, S.R. Ahmad and A. Masood. Dem based geomorphic analysis along Kalabagh fault and Potwar plateau to constrain surface deformation: Inferences from Remote Sensing and GIS. Pakistan J. Sci., 64(2):7-12 (2012).

Smith, M.R., and L. Collis. Aggregates-Sand, Gravel and Crushed Rock Aggregates for Construction Purposes, 2nd Edition, The Geological Society, London: 223-331 (1993).

Swamy, R.N. The Alkali-Silica Reaction in Concrete, The Blackie Publishing Group, Bishopbriggs, Scotland, Cements and Concrete Composition, 14(1):72-74 (1992).

Shafique, U., M. S. Khan, A. Mustafa, S. Arif. Engineering Geological Characterization of Lahore Soil, based on Geotechnical Testing and Mineralogical Composition Using X-Ray Diffraction, Pakistan J.Sci., 64(3):192-195 (2012).

Zaka K. J., I. H. Baluch and M.N. Chaudhry. Provenance, Alkali Aggregate Reaction (AAR) and In-service Behaviour of N.W. Himalayan Sands and Gravels in Cement Concrete at Tarbela and Warsak Dams N.W.F.P – Pakistan" Geol. Bul. Pu. Uni., 31(32): 53-67 (1997).