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# Evaluation of Nepali Aggregates for Alkali-silica Reactivity Using Accelerated Mortar Bar Test Method

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## Abstract

In many countries, large concrete structures needed to be replaced by new structures because treatment of Alkali Silica Reaction (ASR) was not feasible. Availability of amorphous or poorly crystalline silica is a necessary condition for ASR and it has been a common problem in several countries located in cold geographical regions. Some Nepali rocks also comprise amorphous silica as detected in Sanjen Hydropower Project (SHP) and Tanahu Hydropower Project (THP) during the examination of aggregate through various tests. ASR kinetics and the resulting expansion are observed to be enhanced with an increase in temperature and humidity. Accordingly, the risk of ASR is expected to be prominent in Nepal where temperature and humidity are relatively high. However, systematic research on ASR in Nepal is scarce and the possibility of ASR is little known. This paper determines the reactivity of potential aggregate sources considered for some large infrastructures in Nepal. Accelerated mortar bar test based on the guidelines of ASTM C1260 was performed on aggregate specimens collected from the Pokhara Regional International Airport Project (PRIAP), THP, and SHP. 14-day longitudinal expansion of the mortar bar prepared from the aggregated collected from PRIAP, THP, and SHP was 0.1%, 0.17%, and 0.06% respectively. The aggregate collected from THP is deleterious, whereas aggregate collected from PRIAP and SHP is non-reactive. This study demonstrates that Nepal may have many sources of aggregates that are reactive.

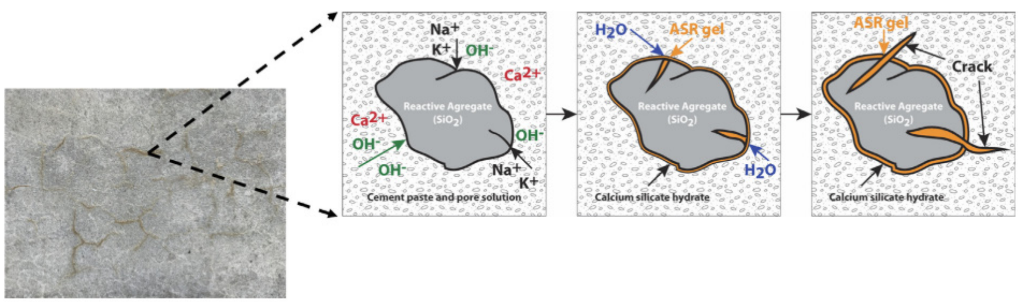
***Keywords:*** Alkali-silica reaction, Nepal, ASTM C1260, concrete infrastructures

## Introduction

Concrete has been proven to be a durable material, but it is susceptible to a variety of physical, chemical, electrochemical, or biological deteriorations (Ferche, 2020). Alkali-silica reaction (ASR) is one of the chemical deterioration. The ASR is the chemical reaction between the alkali hydroxide $(Na^+, K^+)$ from the concrete pore solution and the amorphous or poorly crystalline silica available in certain types of aggregates. After the chemical reaction (demonstrated in Figure 1), a hydrophilic gel is produced, which expands in the presence of water leading to pressure build-up that causes macroscopic expansion and cracking. This results in serious structural problems and can eventually lead to the demolition of the structures. Therefore, ASR is sometimes colloquially called concrete cancer.

**Figure 1**

*ASR Development*




Source: Figueira et al. (2019)

### Factors Affecting ASR

There are various factors affecting the ASR, among which temperature, humidity, and alkali content are comparatively more significant than others. These factors are explained in detail in the following sections.

#### *Alkali*

Alkali hydroxide from the concrete pore solution plays a crucial role in developing the ASR. The most significant source of alkali in concrete comes from Portland cement. However, other components may also affect the amount of alkali, including de-icing salts, supplementary cementitious material, specific admixtures, and aggregates (Sakaguchi et al., 1989). According to Fournier and Berube (Fournier & Bérubé, 2000), increasing the alkali component of the mixture causes an increase in the ultimate ASR expansion.

***Humidity***

Humidity plays a vital role in the development of alkali-silica reactions. Humidity is highlighted as a reagent and a reaction media in ASR (Larive, 1997). The same thing is highlighted more thoroughly by Bazant and Steffens (Bazant & Steffens, 2000), which is mentioned in the points below.

(a) Water acts as an essential medium to transport the alkali ions and hydroxyl ions needed for the reaction.

(b) Formation of gel by the dissolution of siloxane bond can only be achieved in the presence of water.

(c) Gel is hydrophilic in nature, which expands by absorbing the water.

***Temperature***

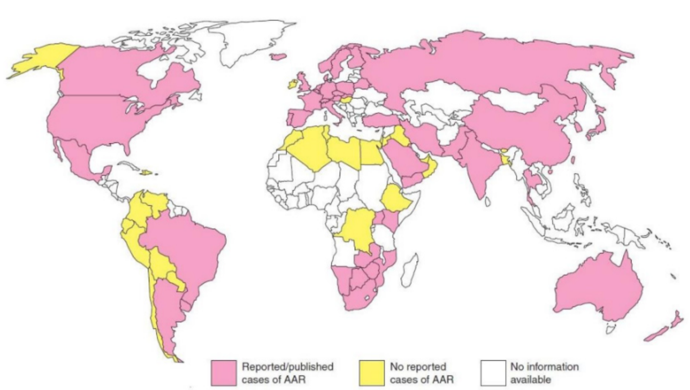
ASR is thermo-activated, and reaction rates are accelerated at higher temperatures (Franz-Josef Ulm, Olivier Coussy, Li Kefei, 2000). The research performed by Larive shows that the final expansion is also increased to some extent by the effect of temperature (Larive, 1997).

**Global Status of ASR in Nepal**

Alkali-Silica Reaction (ASR) is a harmful distress mechanism affecting the durability and serviceability of concrete infrastructure all over the world. Globally, many large structures including dams, bridges, and airport rigid pavement are affected by ASR. ASR has been reported in numerous concrete structures across countries such as Canada, the United Kingdom, the United States, the Netherlands, France, Denmark, Japan, and South Africa (Sims & Poole, 2017).

**Figure 2**

*Alkali-aggregate reaction in the world*




Source: Sims & Poole (2017)

**Status of ASR in Nepal**

Nepal falls into the category of countries with no available information on ASR occurrences, as illustrated in Figure 2 (Sims & Poole, 2017). It is worth noting that Nepal experiences relatively higher temperatures and humidity levels compared to the regions in Europe, Canada, and the USA where ASR cases are prevalent. Accordingly, the risk of ASR is expected to be prominent in Nepal where temperature and humidity are relatively high.

***Possible Reactive Rock and Mineral Type in Nepal***

Table 1 provides a list of rock types containing reactive silica ($SiO_2$) as a major component, which can potentially lead to ASR. Some of the rocks mentioned in Table 1 such as meta-sandstone, quartzite, genesis, and grey shale that are responsible for ASR Studies have been found in Nepal (Dhital, 2015; Joshi & Koirala, 2018). This suggests that the conditions necessary for ASR that is the availability of amorphous or poorly crystalline silica could exist in the aggregates found in Nepal.

**Table 1**

*Possible reactive rock and mineral type*

| Rock type | | Reactive Mineral and Glass |
|---|---|---|
| Andesite | Hornfels | Cristobalite |
| Arenite | Quartz-arenite | Cryptocrystalline (or microcrystalline) quartz |
| Argillite | Quartzite | Opal |
| Arkose | Rhyolite | Strained quartz |
| Basalt | Sandstone | Tridymite |
| Chert | Shale | Volcanic glass |
| Flint | Silicified Carbonate | |
| Gneiss | Siltstone | |
| Granite | Tuff | |
| Greywake | | |

Source: Thomas et al. (2007)

***Specifications Related to ASR in Nepal***

Table 2 outlines the inclusion of ASR-related provisions in the specifications established by various government bodies in Nepal. These specifications are found within the section on aggregate testing, a prerequisite before commencing any construction project. Notably, the standard material specifications for road and bridge work and Nepal Building Code (NBC) 101:1994 exclusively reference the Indian Standard (IS) 2386-1963 part 7 as the method for assessing aggregate reactivity. The scope of this test is a chemical test and mortar bar test.

A chemical test is perform to assess the potential reactivity of an aggregate with alkalis present in Portland cement . This is determined by measuring the amount of reaction that occurs within 24 hours at 80°C between the aggregate, which has been crushed and sieved to pass a 300-micron IS Sieve and be retained on a 150-micron IS Sieve, and a 1 N sodium hydroxide solution. This chemical test outlined in Indian Standard completely resembles the ASTM C289 (ASTM, 2003): Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates.

Physical test (mortar bar test) determines the nature of aggregate by measuring the change in length of the mortar bar. The mortar bar is prepared with crushed aggregate and cement. Aggregate should be crushed according to the specified gradation mention in the code itself. Thus prepared mortar bar is immersed into the sodium hydroxide at 38°C for 1-2 years and expansion is measured intermittently This mortar bar test outlined in Indian Standard completely resembles ASTM C1293 (ASTM, 2008): Standard Test Method for Determination of Length Change of Concrete. ASTM C289 is considered unreliable for identifying potential alkali-aggregate reactivity (Lindgård et al., 2012). ASTM C1293, though another option, is not practical due to the long time duration required to get reliable data.

The Civil Aviation Authority of Nepal (CAAN) has specified that aggregate testing should adhere to Indian Standard (IS) 383/3.2 notes under IS 2386 Part 7. When IS 383/3.2 notes are followed under IS 2386, the physical test is referred to as the accelerated mortar bar test. In this physical test, mortar bar prepared of cement and crushed aggregate is kept under 80°C for 14 days and the expansion is measured intermittently. Aggregate should be crushed according to the specified gradation mention in the code itself. This accelerated mortar bar test outlined in Indian standard completely resembles ASTM C1260 (ASTM, 2014): Standard Test Method for Potential Alkali Reactivity of Aggregates. Though ASTM C1293 and ASTM C1260 both are physical tests, considering the short time duration to get reliable results, ASTM C1260 is extensively used to find the reactivity of aggregate used in the construction of concrete structures. Nevertheless, the Federal Aviation Administration (FAA) states that the 14-day test defined by ASTM C1260 is not enough to find the reactivity of aggregate used in the construction of airfield rigid pavement (Federal Aviation Administration, 2014). Further, FAA modified the ASTM C-1260 test and extend it from 14 days to 28 days ((FAA), 2021). Modified ASTM C1260 classifies the nature of aggregate based on 28-day expansion value((FAA), 2021). Thus, the current specifications of Nepal look incompetent to find the reactivity of aggregates used in the construction of concrete structures.

**Table 2**

*Specification details provided by concerned government bodies of Nepal for ASR*

| S.N. | Specification | Client | Test Standard |
|---|---|---|---|
| 1 | Standard Specification for Road and Bridge Works | Ministry of Physical Infrastructure and Transport | Indian Standard (IS) 2386-1963 Part 7 (IS, 1963) |
| 2 | Division 20 400- Structural Concrete | Civil Aviation Administration of Nepal (CAAN) | IS 383/3.2 notes (IS, 1970) when tested under IS 2386 Part 7 |
| 3 | Nepal Building Code (NBC) 101: 1994 | Department of Urban Development and Building Construction (DUDBC) | • 2386- 1963 Part 7 (IS, 1963) |
| 4 | Design Guidelines for Headwork of Hydropower Project | Ministry of Energy, Water Resources and Irrigation | Specific standards are not mentioned. However, performing an alkali reaction test is mentioned under the heading of the chemical test. |
| 5 | Water Conveyance System Design Guidelines | Ministry of Energy, Water Resources and Irrigation | Specific standards are not mentioned.<br>However, the aggregate source should not be deleteriously reactive with alkalis in cement. |

Nepal appears to have a high potential for ASR, but the reactivity of the aggregate and the forms of alkali-silica reaction are mostly unknown. Indeed, there are preventive measures like using supplementary cementitious materials and limiting the alkali content in the aggregate (Duchesne & Bérubé, 2001; Saha et al., 2018). In the implementation of preventative measures, the reactivity of aggregate must be measured before the construction of structures. However, during the literature review, it was found that the current specifications of Nepal look incompetent to find the reactivity of aggregates. That being the case, awareness about ASR is little in Nepal and the test of aggregates for ASR has not been a mainstream test in the infrastructure projects. Therefore, this study aims to determine the reactivity of aggregate sources considered for some large infrastructures in Nepal.

## Methodology

Information was gathered from the large infrastructure projects of Nepal, and it was found that some Nepali rocks comprise amorphous silica in the Sanjen Hydropower Project and Tanahu Hydropower Project. Accordingly, the Sanjen Hydropower project and Tanahu Hydropower project were selected. In addition, aggregate was also collected from the Pokhara Regional International Project. All three places from where the sample was collected are listed below in Table 3.

**Table 3**

*Nomenclature of the sample collected from different projects in Nepal*

| | |
|---|---|
| Aggregate from Pokhara Regional International Airport Project (PRIAP) | ASR-P |
| Aggregate from Tanahu Hydropower Project (THP) | ASR-T |
| Aggregate from Sanjen Hydropower Project (SHP) | ASR -S |

### *ASR-P*

Seti River starts from the Annapurna range and Machhapuchhere Himal, composed of the Tibetan Tethys and Himalayan Genesis. Paleozoic and Mesozoic sedimentary rocks with fossiliferous limestone make up the Tibetan Tethys. At the Kotre quarry site, the transported fossiliferous limestone is gathered (Joshi & Koirala, 2018). This site is considered one of the best-identified aggregate sources in Nepal in terms of physical strength.

### *ASR-T*

This aggregate is the riverbed material from the Seti River around the location of THP, near to Damauli area. According to the geologist involved in THP, ASR-T is quartzite.

***ASR-S***

SHP is in Rasuwa, Nepal. Aggregate was collected from the borrow site of SHP by blasting the rocks. The rock type of aggregate is quartzite, which is green in color. Quartzite is a metamorphic rock that is composed of mostly quartz, where the sand grains and the silica cement that holds them together are recrystallized during metamorphism.

**Material**

The ASR-P and ASR-T is the riverbed material. Unlike ASR-P and ASR-T, ASR-S is not riverbed material. It is a rock obtained by blasting rocks near the SHP. The chemical and Physical properties of the cement used in ASTM C-1260 are presented in Table 4. The cement is ordinary Portland cement of 43-grade cement available in Nepal and has passed all the requirements of Nepal Standard (NS) 572:2076 (NS, 2076).

**Table 4**

*Test Certificate of Cement*

| OPC 43 Grade Cement | | | | | |
|---|---|---|---|---|---|
| Laboratory Temperature: | 27±2 ˚C | Sand: Water: | Standard Sand Distilled Water | Type of Kiln: Process: | Rotary Kiln (New Dry process) |

| Chemical Requirement | | |
|---|---|---|
| Particulars for testing | Requirement as per NS 572 2076 (43 GRADE) | Testing Result |
| Lime Saturation factor (LSF) (CaO-0.7SO3)/ (2.8SiO2+1.2Al2O3+0.65Fe2O3) | 0.66-1.02 | 0.857 |
| The ratio of Alumina to Iron Oxide (Al2O3/Fe2O3) | ≥0.66 | 1.19 |
| Insoluble Residue (%) | ≤2.0 | 0.85 |
| Loss on ignition (L.O.I.) (%) | ≤4.0 | 1.41 |
| Magnesia (MgO) (%) | ≤5.0 | 4.28 |
| Sulphuric Anhydride (SO3) (%) | ≤3.0 | 1.91 |
| Chloride (Cl-) (%) | - | 0.017 |
| $R_2$0 (%) (total alkali content) | - | 0.57 |

| Physical Requirement | | | |
|---|---|---|---|
| Particulars for testing | | Requirement as per NS 572 2076 (43 GRADE) | Testing Result |
| Blaine Specific surface area (m2/kg) | | ≥225 | 318.0 |
| Normal Consistency (%) | | - | 28.0 |
| Setting Time (Minutes) | Initial | ≥45 | 200.0 |
| | Final | ≤600 | 265.0 |
| Soundness | Le-Chatelier (mm) | ≤10 | 0.5 |
| | Autoclave (%) | <0.80 | 0.11 |
| Compressive Strength (MPa) | 3-days | ≥23.0 | 30.5 |
| | 7-days | ≥33.0 | 41 |
| | 28-days | 43-58 | 60 |

**Method**

ASTM C1260 is the accelerated mortar bar test performed to find the reactivity of aggregate (ASTM, 2014). In this test, the mortar bar was prepared from a combination of sand, cement, and crushed aggregate. A total of nine specimens for the lab works, where three specimens for each aggregate-cement combination. A water-to-cement ratio equal to 0.47 by mass was used in the experimental work. The mold size to cast the mortar bar was 25 x 25 x 285 mm.  The prepared mortar bar was cured for 24 hrs. After curing for 24 hours, the specimens were immersed in the hot water at 80°C. Two days after the casting, zero reading was taken from the specimen. Take each bar out of the water one at a time, and dry it with a towel. Take each bar's zero reading as soon as it has dried, and then read once it is in place. For the conditioning, the bar specimen was submerged fully in a container containing 1N sodium hydroxide for 14 days at 80°C temperature. The reading was taken intermittently for up to 14 days. During measurement, specimens were removed from the container, and measurements were taken before the significant cooling. Maintain a temperature of 80 ± 2 °C or higher in the oven where the specimens are kept in the containers. To ensure the least amount of heat loss due to an unintentional power outage, a water bath was produced inside the oven.

**Criteria to Classify the Aggregate as per ASTM C1260**

The longitudinal expansion of the mortar bar is tracked over 14 days. When exposed to NaOH for 14 days, longitudinal expansions of less than 0.10% indicate the non-reactive nature of aggregate. Expansions of more than 0.20% in 14 days indicate that the aggregate is potentially reactive. Mortar bar expansions between 0.10% and 0.20% exhibit marginal behavior that encompasses neither the reactive nor non-reactive nature of aggregate. In such a case, ASTM C1260 has defined other alternatives to classify the nature of aggregates.

## Results and Discussion

### ASR-P

After the accelerated mortar bar test, the expansion of the mortar bar in 14 days is observed to be 0.1%. As per ASTM C-1260, mortar bar expansion of less than 0.1% is considered to be non-reactive. Hence, ASR-P is non-reactive.

### ASR-T

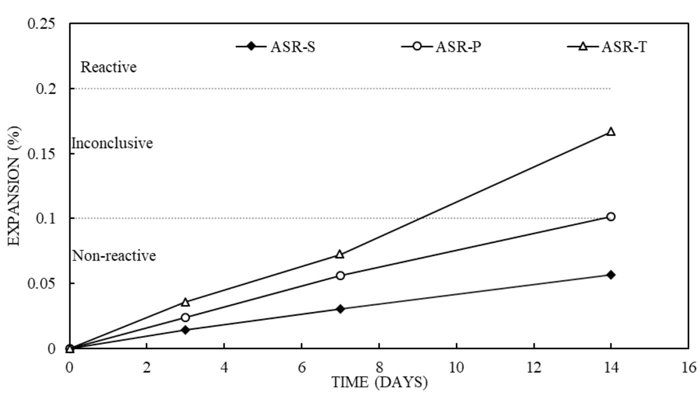
The expansion percentage of the aggregate of THP at 14 days is 0.17%. The expansion lies between 0.10 and 0.20 % at 14 days. As per ASTM C1260, the reactivity of ASR-T is non-conclusive. However, considering the field performance in the past research (Stark et al., 1993), ASR-T is reactive.

### ASR-S

14-day mortar-bar expansion of SHP is 0.06%. As the 14-day expansion is less than 0.1%, the ASR-S is not reactive, as per ASTM C-1260. However, based on the personal correspondence with the SHP personnel, it was found that an ASTM C289 was used to classify the nature of the aggregate and the results show that the aggregate was reactive. Results from the ASTM C289 and ASTM C1260 were found to be opposing each other. Considering the reliability of the ASTM C1260 (Lindgård et al., 2012), this study accepts the result of the ASTM C1260 over the ASTM C289 test. Accordingly, the ASR-S is non-reactive.

**Figure 4**

*Evolution of Longitudinal expansion as per ASTM C-1260*



## Conclusion

Aggregate samples were collected from the three parts of Nepal: THP, PRIAP, and SHP. ASTM C120 test was used to find the reactivity of the aggregate. Aggregate collected from THP is reactive , whereas aggregate collected from PRIAP and SHP is non-reactive. This study demonstrates that Nepal may have many sources of aggregates that are reactive.

Considering the nature and scale of ASR consequences abroad, infrastructure construction in Nepal should pay the utmost attention to preventing or mitigating ASR in Nepali infrastructure. To achieve this, a site-specific screening process for aggregates before the construction of concrete structures should become a standard practice in Nepal. Currently, the construction industry in Nepal mostly refers to the mortar bar test (similar to ASTM C1293) and chemical tests (such as ASTM C289) in their specifications. Specifically, ASTM C289 test is mainly used to assess aggregate reactivity. However, if we take into account the time required for testing, ASTM C1293 is impractical, and considering the reliability of results, ASTM C289 is not dependable (Lindgård et al., 2012). Therefore, it is recommended to incorporate the accelerated mortar bar test (similar to ASTM C1260) into Nepal's specifications instead of the test like ASTM C289 and ASTM C1293.

ASTM C1260 is widely used to find the reactivity of aggregate used in the construction of all the concrete infrastructure except airfield rigid pavement. FAA has recommended the use of modified ASTM C1260 to classify the nature of aggregate use in airfield rigid pavement ((FAA), 2021). Modified ASTM C1260 was not found in the specifications of CAAN of Nepal to find the reactivity of aggregate. Therefore, CAAN must include modified ASTM C1260 in their specification. Further, absence of modified ASTM C1260 in specifications indicates a need for future research to find the reactivity of aggregate based on modified ASTM C1260.

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