Materials Explore 1 (2023) 83-99

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# Conditions for the Formation of Alkali-Silica Reaction in Hot Mix Asphalt

**Duygu Demirtürk**

Civil Engineering Department, Ankara Yıldırım Beyazıt University, Ankara, Turkey

*Email: ddemirturk@aybu.edu.tr, duygudmrtrk@gmail.com

## Abstract

Alkali-Silica Reaction (ASR) is the well-known durability problem of concrete during its service life. There are many studies on the formation, significance, diagnosis, and prevention of ASR in concrete. Although ASR in concrete is the subject of many studies, there are very few studies on ASR formation in Hot Mix Asphalt (HMA). This is because the high alkali content in the pore solution of concrete, which is one of the main components of ASR, cannot exist in HMA. The conditions required for ASR formation in HMA are also unknown. Recently, a limited number of studies have focused on the use of de-icers and recycled concrete aggregates to investigate the formation of ASR in HMA. The formation of ASR in HMA should be considered as an attractive research topic and raise the


Materials Engineering Research| ISBN: 978-81-956233-1-0 | In Series: Materials Explore
DOI: https://doi.org/10.59196/tric.mex/978-81-956233-1-0_5

question of which conditions lead or will lead to the formation of ASR. Indeed, the main purpose of this study is to investigate the conditions that may cause ASR in HMA, as opposed to the assumption that ASR in HMA cannot be fully observed. The study favours the method of reviewing existing studies and creating a combination of possible conditions for the formation of ASR in HMA.

## Keywords

Alkali-Silica Reaction, de-icer, hot mix asphalt, recycled concrete aggregates

# 1. Introduction

Alkali-silica reaction (ASR) causes significant and detrimental problems influencing the durability of cement-based materials. ASR generally occurs when alkali cations (Na+ and K+) in the pore solution discharge hydroxyl ions (OH-) [1]. They interact with the silanol groups present in the silicate phases of the aggregates [1,2]. At the end of this reaction, an alkali-silica gel product is obtained, which transforms from crypto-crystalline to amorphous structure [3]. When the alkali-silica gel absorbs water, the volume of this gel increases. This builds up internal pressure, causing cracks in the concrete and weakening the structure. It is stated that three conditions are necessary for ASR to occur. These are the presence of reactive silica, which comes from aggregates; the presence of water or moisture, mainly from the pore solution of the concrete but also from the external water supply during the service life; and alkali ions, which come mostly from the cement. While the reactivity of an aggregate depends on various factors such as geological origin, mineral structure and texture, the alkali contents also vary depending on the preferred cement. In this regard, the mechanisms, causes, symptoms, and outcomes of ASR in concrete have been extensively studied by researchers recently [4-8]. Until recently, there has been little research on the probability of ASR occurring in Hot Mix Asphalt (HMA) [9,10]. The conditions or environment that trigger ASR in concrete have been blamed for speculating whether ASR happens in HMA.

In particular, the question is whether ASR can occur in HMA consisting of reactive aggregates when an external alkali source is present. As it is well known, HMA consists of aggregates, bitumen and air components, and the role of bitumen is to bind the aggregates together like cement. Unlike cement, bitumen is a multicomponent system consisting of hydrocarbons and heteroatoms. After the fractionation of bitumen by specific solvents, four leading chemical families (saturates, aromatics, resins, and asphaltenes) can be distinguished [11]. Then, the effect of bitumen on ASR behaviour when reactive aggregates are used is still a research topic. Because the triggering of ASR depends on the combination of alkali, silica, and moisture content simultaneously. Therefore, the conditions under which these three parameters are present in HMA are crucial for developing ASR. Moreover, bitumen acts as a barrier between reactive aggregates and alkalis. Thus, the interaction between bitumen and reactive aggregates should be questioned when creating an alkaline environment.

ASR in HMA is strongly dependent on the behaviour of the bitumen. Winter is ideal for this behaviour because asphalt pavements commonly use de-icing agents [12]. The damaging mechanism of de-icing agents combines chemical reactions, emulsions and distillations, and additional stress generation in HMA [13]. Of the two main pavement types – Portland Cement Concrete (PCC) pavement and asphalt pavement - the latter is generally considered less susceptible to de-icing agents [13]. Before the recent development of acetate and formate-based de-icing agents, the effects of de-icing on asphalt pavements were relatively minor. However, it is stated that de-icing agents can have adverse effects on HMA by promoting the penetration of moisture, oxygen, and other aggressive substances into the interior of the HMA [13]. Thus, de-icing agents weaken the binding ability of the bitumen to the aggregates and allow the external alkali source to access the reactive aggregates.

Another possibility for forming ASR in HMA is using recycled concrete aggregates (RCAs). The use of RCAs in asphalt pavements is becoming more attractive day by day in the name of sustainability due to its positive impact on the economy and environment [14]. It is well known that many natural resources are consumed during construction. This makes the construction industry a good candidate for reusing demolition waste as raw materials. However, when recycled aggregates subjected to ASR are reused, it is also essential to consider whether this reaction can be triggered in HMA. The quality of recycled aggregate varies greatly and depends on the destroyed structure and, thus, on the manufacturing process. Therefore, it is found that RCA is of inferior quality to natural aggregate [15]. This directly causes the RCA to be susceptible to chemical reactions such as ASR. In this context, this study aims to investigate possible conditions leading to the formation of ASR in HMA. Identifying these conditions will provide potential study paths on a disregarded topic.

## 2. ASR Formation in HMA Using De-icing Agents

In winter, the presence of snow or ice on the pavement surface is not desirable for driving performance. In general, road administrations strive to use resources for snow and ice removal as efficiently as possible. Plowing and de-icing agents are both costly and time-consuming alternatives that require quick responses to sudden changes in road safety due to snow and ice accumulation [16]. In this regard, it is stated that de-icing agents can be roughly divided into inorganic salts, such as sodium chloride (NaCl), organic salts, such as magnesium calcium acetate ($CaMg(CH_3COO)_4$) and organic compounds such as urea ($CO(NH_2)_2$) [17]. On the one hand, acetates and formates are currently used as primary de-icing agents on airfield pavements. On the other hand, chloride-based de-icing agents, which are normally used on road pavements, are not used on airfields to avoid possible metal corrosion on aircraft and negative environmental impacts [18]. According to previous studies, acetates, and formates on PCC pavements of airfields accelerate ASR significantly [19]. Since these agents are a potential source of alkali, which is an essential parameter for ASR formation [20].

In contrast to studies on the relationship between deicers and ASR in concrete, little attention has been paid to the potential adverse effects of deicers on asphalt pavements because the assumption that asphalt is sufficiently resistant to chemical deicers has not been proven. Moreover, there are currently no specifications in the United States that investigate and address the adverse effects of de-icing agents on asphalt pavements. In addition, there is little research on the interactions between asphalt and de-icing agents [21]. However, while asphalt is physiochemically stable to chlorides, this may not be the case for acetates and formates [18]. According to Pan et. al. (2008), both the aqueous solution test and Fourier Transform Infrared (FTIR) analysis indicate that the acetate anion ($CH_3COO^-$) promotes emulsification of the asphalt binder. Thus, a possible mechanism is proposed to explain the emulsification of asphalt when exposed to acetate-based de-icing agents [22]. Overall, it can be concluded that the use of de-icing agents, especially acetate-based, has a detrimental effect on HMA and leads to susceptibility to moisture. Therefore, the behavior of bitumen with de-icing agents provides an overview that is critical to understanding ASR in HMA. Firstly, de-icing agents can affect the binding properties of bitumen due to the emulsification mechanism. Since bitumen is mainly bound to the surface of the aggregate by the polar constituents at the bitumen-aggregate interface, the loss of these polar constituents in the bitumen leads to a reduction in binding strength, which may ultimately aggravate the failure of adhesion in HMA [22]. After the adhesion fails in HMA, the deicers and water can penetrate into the pavement layers. That is, when de-icing agents damage bitumen, the bitumen can no longer act as a layer between aggregates and de-icing solutions. This results in moisture and alkali components coming together with silicious component.

In other words, de-icing agents are material to consider in terms of triggering ASR because they allow the combination of alkali content and siliceous aggregates in solutions. **Figure 1** below also expresses this situation visually. According to this figure and the study from which this figure was taken, the role of de-icing agents in HMA with recycled aggregates exposed to

ASR was investigated. Additionally, this study shows that the bitumen provides some protection against ASR. [23]. This is because the presence of mortar residues on the recycled aggregate used in this study once again demonstrated the importance of the role of bitumen as a protective layer. De-icing agents can trigger existing ASR in mortar residues. Thus, it is a situation that should be avoided in HMA. The bond between the aggregate and the bitumen is weakened by de-icing agents, making the aggregate more unstable.

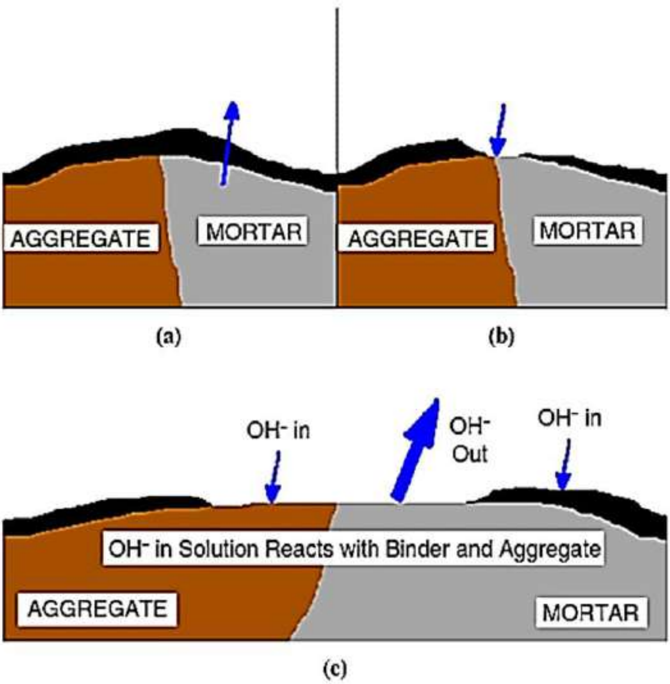


**Figure 1.** Interaction between de-icing solution and compacted HMA: (a) $OH^-$ diffuses into solution, (b) alkaline solution reacts with binder, and (c) exposed mortar releases $OH^-$ to a greater extent [23].

Apart from this study, there are very few sources in the literature on the effects of bitumen on ASR and whether ASR is triggered when de-icing agents are used. While some studies mainly focus on the impact of de-icing salts on HMA performance, others focus on the different de-icing solutions and their effects. Some of them are listed in **Table 1**. The most critical work in this area is by Apeagyei et al. (2009). When exposed to a potassium acetate de-icing solution, they investigated whether an alkali-silica reaction occurs in asphalt concrete containing reactive aggregates and calcium hydroxide. Considering all these studies, it is evident that there is a lack of comprehensive studies on the ASR effect of de-icing agents in HMA. In particular, the behaviour of bitumen in ASR cannot be fully explained, and the methods for measuring and detecting ASR in HMA are also inadequate.

**Table 1.** Previous studies with de-icing agents used in HMA for various purposes

| Year | Authors | Purpose | De-icer Types |
|---|---|---|---|
| 2002 | Hassan et al. | To examine the harmful effects of newly released de-icing agents and conventional road salts on the durability of aggregates for pavement construction and asphalt concrete when immersed in solutions of varying concentrations and subjected to freeze-thaw cycles. | Potassium acetate, sodium formate, urea, and road salt. |
| 2008 | Pan et al. | Evaluation of the influence of de-icing/anti-icing agents on the deterioration of acetate-based airfield asphalt concrete. | Sodium acetate |

| | | | |
|---|---|---|---|
| 2009 | Apeagyei et al. | Evaluate whether potassium acetate de-icing solution causes an alkali-silica reaction in asphalt with reactive aggregate and calcium hydroxide. | Potassium acetate de-icing solution |
| 2009 | Shi et al. | Review of the use of de-icing agents in winter maintenance of Portland cement concrete, asphalt concrete and airport pavements | Sodium chloride, magnesium chloride, calcium chloride, calcium magnesium acetate, potassium acetate, potassium formate, sodium acetate, and sodium formate. |
| 2011 | Goh et al. | Modification of asphalt with nano-clay and carbon microfibers and evaluation of its tensile strength after exposure to water or de-icing solutions. | Sodium chloride, magnesium chloride, calcium chloride. |
| 2013 | Anastasio et al. | Evaluation of the effects of different de-icing solutions on asphalt mixtures. Different concentrations of each de-icing chemical were selected and tested on asphalt material subjected to a predefined number of freeze-thaw cycles. | Sodium chloride, potassium formate |
| 2021 | Najafi Moghaddam Gilani et al. | To explore how de-icing agents like sodium chloride, potassium acetate, and calcium magnesium acetate impact the fatigue and moisture characteristics of asphalt when combined with nano-hydrated lime. | Sodium chloride, potassium acetate, and calcium magnesium acetate |

# 3. ASR Formation in HMA Produced with Recycled Concrete Aggregates

Concrete is widely recognized as the building material of choice. On the other hand, it's recommended that the debris generated during demolition be converted into recycled concrete aggregate (RCA) when a building reaches the end of its useful life [15]. A viable link between RCA and pavement sustainability needs to be established. Given the high percentage of aggregates used in the production of HMA, it's clear that the inclusion of RCA can improve pavement sustainability. The global environmental, social, and economic impacts of the transportation sector make it imperative to study its sustainability [24]. Therefore, the use of RCA in the production of HMA is an interesting and important topic to investigate.

It is well known that the aggregates used in the production of HMA must meet certain boundary conditions to achieve the expected performance. While many physical properties, such as density, shape, surface texture, and aggregate porosity, affect the optimum binder content, the aggregates' durability affects the pavement's bearing capacity [25,26]. On the other hand, some researchers have stated that the RCA requires some preprocessing [15,30]. The reason for this was mortar residues adhering to the RCA surface, which would lead to differences in the performance of the aggregates [27-34]. In addition, the researchers pointed out the quality of the RCA reuse, explaining that it is as different as the composition that makes up the RCA. This is because the quality of RCA is highly variable, as it depends on the destroyed structure and the production process. It is well known that many physical and mechanical properties of aggregates, such as density, surface texture, shape, water absorption capacity, and mechanical resistance, change during the RCA manufacturing process [15]. Some test results from previous studies for RCA and natural aggregate are shown in **Table 2**. According to **Table 2**, RCA is weaker than natural aggregate in terms of mechanical and physical properties. This situation makes the performance of HMA with RCA questionable.

**Table 2.** Some previous results on mechanical and physical properties of RCA [15]

| Authors | LA Abrasion (%) | | Density (g/cm3) | | Water Absorption (%) | |
|---|---|---|---|---|---|---|
| | RCA | Natural | RCA | Natural | RCA | Natural |
| Cupo-Pagano et al. (1994) | 28.5-31.0 | - | 2.640 | - | - | - |
| Shen and Du (2004, 2005) | - | - | 1.870-2.202 | 2.516-2.655 | 8.8 | 0.6 |
| Paranavithana and Mohajerani (2006) | - | - | 2.708 | 2.863 | 2.9 | 0.3 |
| Jiménez et al. (2011) | 33-34 | 20 | - | - | 3.7-9.6 | 1.6-4.7 |
| Rafi et al. (2011) | 36.88 | 27.11 | 2.187 | 2.452 | 4.57 | 1.09 |
| Pasandín and Pérez (2013, 2014) | 32 | - | 2.63-2.65 | - | 5.08-8.74 | - |

There is also the question of whether the aggregates affected by ASR can be used in HMA if they are recycled. Mills-Beale & You (2010) mentioned that Federation Aviation Administration (FAA) funded project investigated whether ASR in aggregates is a problem because it is not well known whether the use of ASR-contaminated RCA affects the performance of HMA [35]. Since ASR expansion is due to the water-absorbing gel, it is desirable to use

ASR-affected RCA (ASR-RCA) in a way that minimizes exposure to moisture [23]. Moreover, studies of RCA have indicated that RCA is rougher, more angular, and more absorptive than conventional aggregates. When these aggregate properties change, the performance of the HMA produced with RCA inevitably changes.

Mukhopadhyay et al (2010) presented a study that will shed light on the studies on the use of RCA with ASR in HMA [23]. As a result of the study, it was found that although some level of ASR occurs in HMA made with ASR-RCA and exposed to de-icing solutions, the degradation caused by it was not significant. The study also recommended a guide to identify potential mechanisms of deterioration with ASR-RCA in HMA. On the other hand, recent studies have investigated the behaviour of RCA exposed to ASR using standard physical and mechanical tests to control the quality of natural aggregates [36-38]. However, knowledge of the chemical and mineralogical properties of RCA also allows better interpretation of the results that occur with mixtures of RCA and other materials [39]. Few studies on HMA associated with ASR-RCA can be found in the literature. While mainly mechanical tests have been performed on HMA produced with recycled aggregates, ASR behaviour has not been extensively studied [30-35].

# 4. Conclusion

The possibility of an alkali-silica reaction in HMA was investigated in this study. The study attempts to explain whether the three essential parameters of alkali, silica, and moisture content required for the development of ASR can exist in HMA. However, few studies have indicated that the behaviour of bitumen controls the development of ASR in HMA. This is because bitumen adheres to the surface of the aggregate and holds it together. It also serves as a protective layer between the external environment and the aggregate. This protective layer makes the aggregate vulnerable when exposed to corrosive chemical solutions such as de-icing agents. In this case, the alkaline component of the de-icing agents can react with reactive aggregates, leading to the formation of ASR. RCA is another possible situation that provides the environment for ASR in HMA. If these RCAs already contain an ASR product, this is considered a triggering parameter for ASR in HMA. However, despite studying all these situations, there is no standard method for measuring ASR behaviour in HMA. Although this study has highlighted several conditions that reveal ASR behaviour in HMA, it is important to note that there are still gaps in the literature in this field. Therefore, this study highlights the need for innovative and comprehensive approaches to measure ASR in HMA.

## Abbreviations

| | | |
|---|---|---|
| *ASR* | : | *Alkali-Silica Reaction* |
| *ASR-RCA* | : | *ASR-affected RCA* |
| *FTIR* | : | *Fourier Transform Infrared* |
| *HMA* | : | *Hot Mix Asphalt* |
| *RCAs* | : | *Recycled Concrete Aggregates* |

## Acknowledgement

Throughout the research, this study was not financially supported by any institution.

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