# EFFECT OF DIFFERENT TYPES OF AGGREGATES ON AUTOGENOUS AND DRYING SHRINKAGE OF CONCRETE

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## ABSTRACT

This paper summarizes recent research completed by the UWM Center for By-Products Utilization on the effects of different types of coarse aggregate in concrete on the shrinkage properties of concrete. Three types of coarse aggregate were used in the concrete mixtures: crushed quartzite stone, semi-crushed river gravel, and crushed dolomitic limestone. Concrete mixtures were made with and without a shrinkage-reducing admixture. Both autogenous shrinkage and drying shrinkage were evaluated for each concrete mixture.

Concrete mixtures made with semi-crushed river gravel and crushed dolomite showed a significantly lower autogenous shrinkage than the concrete made with crushed quartzite. Use of dolomitic limestone appears to be useful in reducing early-age autogenous shrinkage and drying shrinkage of concrete compared with using river gravel or quartzite as coarse aggregate. Use of crushed dolomitic limestone in concrete led to the lowest early-age drying shrinkage, followed by semi-crushed river gravel, and crushed quartzite stone. However, at later ages, the drying shrinkage became similar for most aggregates. River gravel often had the highest drying shrinkage at later ages. As a whole, the effect of the source of coarse aggregate on drying shrinkage appears to be noticeable but small.

Keywords: aggregates, air entrainment, autogenous shrinkage, concretes, chloride-ion penetration, drying shrinkage, shrinkage reducing admixture.

# EL EFECTO DE DIFERENTES TIPOS DE AGREGADOS SOBRE LA CONTRACCIÓN AUTOGENA Y SECADO DEL CONCRETO

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## RESUMEN

Este artículo resume la reciente investigación terminada por el Centro para la utilización de By-Productos de la Universidad de Wisconsin-Milwaukee sobre los efectos de los diferentes tipos de agregado grueso en concreto en las propiedades de contracción del concreto. Se utilizaron tres tipos de agregado grueso en las mezclas de concreto: piedra cuarcita triturada, grava de río semi triturada, y caliza dolomítica triturada. Las mezclas de concreto se hicieron con y sin aditivo reductor de contracción. Ambos la contracción autógena y la contracción de secado se evaluaron por cada mezcla de concreto.

Las mezclas de concreto que se hicieron con grava de río semi triturada y dolomíta triturada mostraron una contracción autógena significativamente más baja que el concreto hecho con cuarcita triturada. El uso de caliza dolomítica parece ser útil en la reducción a temprana edad de la contracción autógena y la contracción de secado de concreto comparado con el uso de grava de río o cuarcita como agregado grueso. El uso de caliza dolomítica triturada en concreto lo llevo a la contracción de secado más baja a temprana edad, seguido por grava de río semi triturada, y piedra cuarcita triturada. Sin embargo, a edades más tardías, la contracción de secado se volvió similar para la mayoría de los agregados. La grava de río a menudo tuvo la contracción de secado más alta a edades más tardías. En conjunto, el efecto de la fuente del agregado grueso en la contracción de secado parece ser notable pero pequeño.

Palabras Clave: agregado, concreto, autógeno, contracción, cuarcita, grava de río, caliza dolomítica, secado.

## 1. INTRODUCTION

Shrinkage cracking is a major cause of concern for concrete structures. In addition to weakening the structure, these shrinkage cracks have the potential to allow infiltration of moisture and chloride ions that accelerate the corrosion of steel reinforcement and reduce the durability of concrete [1, 2]. The four main types of shrinkage associated with concrete are plastic shrinkage, autogenous shrinkage, carbonation shrinkage, and drying shrinkage.

Plastic shrinkage is associated with moisture loss from freshly placed concrete into the surrounding environment. Autogenous shrinkage is the early shrinkage of concrete caused by chemical consumption of water from capillary pores due to the hydration of cementitious materials, without loss of water into the surrounding environment. This type of shrinkage tends to increase for lower water to cementitious materials ratio (W/Cm) and higher cement content of concrete mixtures. Carbonation shrinkage is caused by the chemical reactions of various cement hydration products with carbon dioxide present in the air. This type of shrinkage is usually limited to the surface of the concrete. Drying shrinkage can be defined as the volumetric change due to the drying of the hardening concrete. This type of shrinkage is caused by the diffusion of water from hardened concrete into the surrounding environment [3].

Modulus of elasticity is the most important property of aggregate that directly influences drying shrinkage of concrete. Troxell et al. [4] reported that the drying shrinkage cracking of concrete increased 2.5 times when an aggregate with high elastic modulus was substituted by an aggregate with low elastic modulus. Also, larger size of coarse aggregates permit the use of a leaner concrete mixture, resulting in lower shrinkage. Increase in the aggregates content also reduces the shrinkage of concrete [5]. The pore structure of aggregate particles may have a strong effect on autogenous shrinkage. Aggregate particles may contain water in pores, which provides the “internal curing” for hydrating cement paste hence reducing autogenous shrinkage. Lura et al. [6] reported that the addition of light-weight aggregates (LWA) in the concrete mixture reduces the self-desiccation of cement paste. In their study LWA concrete with aggregate having a degree of saturation 50 % and 100 % exhibited autogenous swelling, up to an age of three months. On the other hand, normal weight aggregate concrete mixture exhibited shrinkage of up to 470 micronstrain at the same age. LWA concrete showed lower drying shrinkage at the initial age, but at later ages the rate of shrinkage was higher compared with normal-weight aggregate concrete due to lower modulus of elasticity of LWA offering less resistance to the shrinkage of the cement paste. Matsushita and Tsuruta [7] reported effects of the type of coarse aggregate on autogenous shrinkage of concrete. The coarse aggregate studied included Andesite, Crystalline Schist, and Amphibolite. They concluded that if the volume of coarse aggregate was maintained constant, the type of coarse aggregate negligibly affected the autogenous shrinkage of high-strength concrete.

## 2. RESEARCH SIGNIFICANCE

This research was conducted to evaluate and compare the effectiveness of three different sources of shrinkage-reducing admixtures (SRA-1, SRA-2, and SRA-3) for reducing autogenous shrinkage and drying shrinkage of concrete made with and without fly ash. In addition, the effects of the SRAs on concrete air content, slump, initial setting time, chloride-ion penetrability, and changes in air content and slump during the first hour after concrete production were investigated.

## 3. EXPERIMENTAL PROGRAM

### 3.1. MATERIALS

Type I portland cement (ASTM C 150) was used in this work. ASTM Class C fly ash was obtained from the We Energies' Pleasant Prairie Power Plant (P4), which met the requirements of ASTM Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete (C 618). Natural sand was used as fine aggregate. The sand met the requirements of ASTM C 33. Three types of coarse aggregate were used in this research: A1, crushed quartzite stone; A2, semi-crushed river gravel; and A3, crushed dolomitic limestone. The coarse aggregates met the requirements of ASTM C 33. All of the three types of coarse aggregate had a maximum size of 3/4 inches and met the grading requirements for WisDOT Size No. 1 (AASHTO No. 67). All admixtures were supplied by the Euclid Chemical Company. Detailed test data for properties of materials used and data related to two other sources of SRAs are provided elsewhere [1].

### 3.2. CONCRETE MIXTURES

Table 1 shows the mixture proportions and fresh properties of Grade A-FA concrete mixtures made with chemical admixture from Source 1 (Euclid) and coarse aggregate A1 (crushed quartizite stone). The table also includes other Grade A-FA concrete mixtures made with coarse aggregates A2 (semi-crushed river gravel) and A3 (crushed dolomitic limestone).

### 3.3. SPECIMEN PREPARATION AND TESTING

Test specimens of concrete were made and cured according to the ASTM Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory (C 192). The concrete mixer used was an electrical power-driven, revolving drum, tilting mixer. Test specimens were prepared for time of initial setting (ASTM C 403), Autogenous shrinkage (a detailed and working improvement built upon a test procedure originally drafted by the Japan Concrete Institute (JCI) [7]), drying shrinkage (ASTM C 157), and electrical indication of chloride-ion penetrability (ASTM C 1202).

Table 1. Mixture Proportions and Fresh Properties of Concrete

| Mixture designation* | S1-00-FA-A1 | S1-24-FA-A1 | S1-00-FA-A2 | S1-24-FA-A2 | S1-00-FA-A3 | S1-24-FA-A3 |
|---|---|---|---|---|---|---|
| Cement (lb/yd$^3$) | 394 | 392 | 386 | 394 | 393 | 394 |
| Class C Fly Ash (lb/yd$^3$) | 170 | 169 | 166 | 170 | 169 | 170 |
| Water (lb/yd$^3$) | 226 | 210 | 221 | 203 | 226 | 221 |
| W/Cm | 0.40 | 0.37 | 0.40 | 0.36 | 0.40 | 0.39 |
| Fine aggregate, SSD (lb/yd$^3$) | 1400 | 1400 | 1220 | 1250 | 1400 | 1400 |
| Coarse aggregate, ≤ 3/4 in., SSD (lb/yd$^3$) | 1700 | 1690 | 1830 | 1870 | 1710 | 1710 |
| MRWRA-1 (fl. oz./yd$^3$) | 22.0 | 21.8 | 12.7 | 5.2 | 23.6 | 6.0 |
| AEA-1 (fl. oz./yd$^3$) | 4.0 | 0.5 | 4.1 | 0.5 | 8.0 | 0.5 |
| SRA-1 (fl. oz./yd$^3$) | 0 | 136 | 0 | 137 | 0 | 136 |
| Slump (in.) | 2 | 2 | 3 | 3.5 | 2.4 | 2.5 |
| Air content (%) | 6.0 | 6.4 | 6.0 | 6.4 | 7.5 | 6.8 |
| Air temperature (°F) | 69 | 69 | 70 | 69 | 68 | 68 |
| Concrete temperature (°F) | 70 | 70 | 69 | 71 | 66 | 68 |
| Density (lb/ft$^3$) | 144 | 143 | 142 | 144 | 144 | 145 |

* The number following S1- indicates the approximate dosage rate of SRA-1 in fl. oz./100 lb of cementitious materials

The properties of freshly mixed concrete were determined, and test specimens were cast for the evaluation of time of initial setting, autogenous shrinkage, drying shrinkage, and chloride-ion penetrability of concrete. The specimens for time of setting and autogenous shrinkage were kept in sealed condition. To minimize evaporation of water from the concrete test specimens, they were covered with either lids or plastic sheets. The specimens were removed from the molds 24 ± 8 hours after casting. The demolded specimens were moist cured at 73 ± 3°F, in a moist room at a relative humidity of not less than 95% or in lime-saturated water.

## 4. RESULTS AND DISCUSSION

### 4.1. MIXTURE PROPORTIONS AND INITIAL SETTING

In this research project, three sources (manufacturers) of chemical admixtures were selected; however, only one source (SRA-1) is reported in this paper. Additional detailed information is available elsewhere [1]. Concrete mixtures were made using mid-range water-reducing admixture (MRWRA), air-entraining admixture (AEA), and shrinkage-reducing admixture (SRA). For each source, three dosage rates of SRA were used: (1) zero (reference); (2) the average recommended dosage rate (average of the minimum and maximum dosage rates); and (3) the maximum recommended dosage rate. The reference (base) concrete mixtures were: WisDOT Grade A-FA (fly ash); and CBU High-Cm A-FA-A (30% higher cementitious materials than WisDOT Grade A-FA).

SRA-1 had a water-reducing effect and an air-entraining effect. Concrete mixtures containing SRA-1 required only minimal amounts of MRWRA-1 and AEA-1. When SRA-1 was used in Grade A-FA mixtures, either the W/Cm (Mixture S1-24-FA-A1), the required amount of MRWRA-1 (S1-24-FA-A3), or both (Mixture S1-24-FA-A2) decreased considerably. Use of SRA-1 in any grade of concrete mixtures also led to a sharp reduction in the required dosages of AEA-1 (Table 1) for all three types of coarse aggregates, A1, A2, and A3.

Time of initial setting of concrete was determined. It was used for starting the measurements for autogenous shrinkage. The time of initial setting of concrete did not change considerably (Fig. 1) with change in

SRA-1 dosage or the use of different types of aggregates (A1, A2, or A3). The time of setting was either reduced by up to 1.25 hours or increased by up to 1.75 hours (Fig. 1).

Time of initial setting of concrete increased for Grade A-FA fly ash concrete mixtures by 3 to 5 hours compared to corresponding Grade A no-ash concrete mixtures. Use of high amounts of cementitious materials decreased the setting time by about an hour compared to corresponding Grade A-FA fly ash concrete mixtures. In general, the influence of coarse aggregate type on the initial setting time was not noticeably different.

## 4.2. AUTOGENOUS SHRINKAGE

The test results for autogenous shrinkage of concrete mixtures containing chemical admixtures from Source 1 are presented in Fig. 2 and Fig 3.

The Grade A-FA concrete, Mixture S1-00-FA-A1, showed increase in autogenous shrinkage after 14 days. The addition of SRA-1 to Grade A-FA concrete, Mixture S1-24-FA-A1, considerably reduced the autogenous shrinkage of concrete, especially at relatively early ages of up to 14 days, after which the autogenous shrinkage increased noticeably (Fig. 3).

As for the influence of the type of coarse aggregate, the concrete mixtures made with Aggregates A2 and A3 showed a significantly lower autogenous shrinkage than the mixtures made with Aggregate A1 (Figs. 2 and 3).

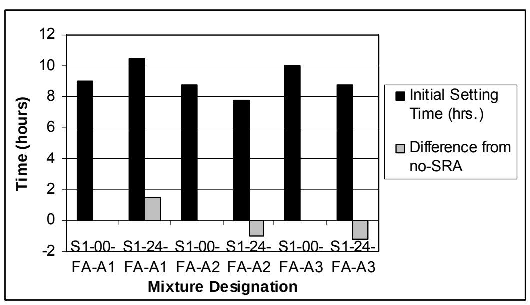


Fig. 1. Time of initial setting of concrete

SRA-1 was not effective in reducing the autogenous shrinkage of the Grade A-FA fly ash concrete made with Aggregate A2 (Mixture S1-24-FA-A2). But still, the autogenous shrinkage of concrete mixtures containing Aggregate A2 was either similar or lower than that of the SRA-1 treated concrete mixtures containing Aggregate A1. SRA-1 was highly effective when used with Aggregate A3, resulting in the lowest autogenous shrinkage of the concrete Mixture S1-24-FA-A3 among all of the Grade A-FA concrete mixtures made with chemical admixtures from Source 1.

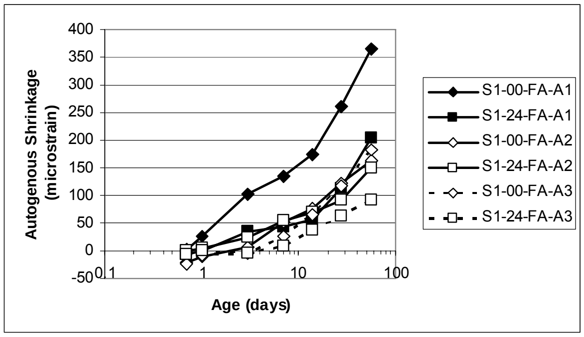


Fig. 2. Autogenous shrinkage of Grade A-FA fly ash concrete made with three sources of aggregates vs. age (Aggregates A1, A2, A3)

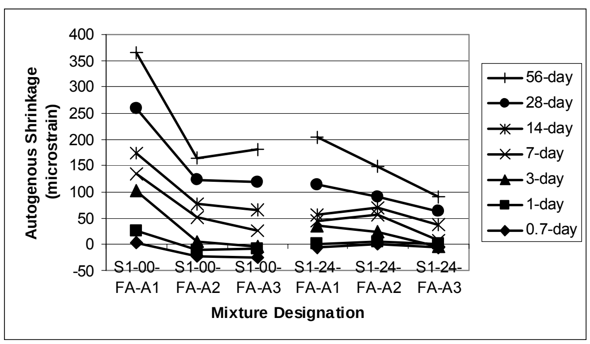


Fig. 3. Autogenous shrinkage of Grade A-FA fly ash concrete vs. aggregate type (Aggregates A1, A2, A3)

## 4.3. DRYING SHRINKAGE

The test results for drying shrinkage of concrete (subsequent to 28 days of moist curing) are shown in Fig. 4 and Fig. 5.

SRA-1 was quite effective in reducing the drying shrinkage of Grade A-FA fly ash concrete mixtures. The relative reduction in drying shrinkage was greater at early ages (Fig. 4). Figs. 4 and 5 show the influence of the type of coarse aggregate on drying shrinkage. At the air-storage period of 4 days, the concrete mixtures made with Aggregate A3 showed a lower drying shrinkage than the ones made with Aggregates A1 and A2. At air-storage period of 14 days and later, the drying shrinkage of concrete mixtures became similar regardless of the type of coarse aggregate, although Mixture S1-24-FA-A2 containing Aggregate A2 showed somewhat higher drying shrinkage at late air-storage periods than Mixtures S1-24-FA-A1 and S1-24-FA-A3. As a whole, the effect of the type of coarse aggregate on drying shrinkage appears to be relatively small.

## 4.4. CHLORIDE-ION PENETRABILITY

The test results for electrical indication of chloride-ion penetrability into concrete are shown in Fig. 6 and Fig 7. As for the effect of the type of aggregate, Aggregate A1 was the best at all test ages, leading to the lowest penetrability (the highest resistance to penetration) (Figs. 6 - 7).

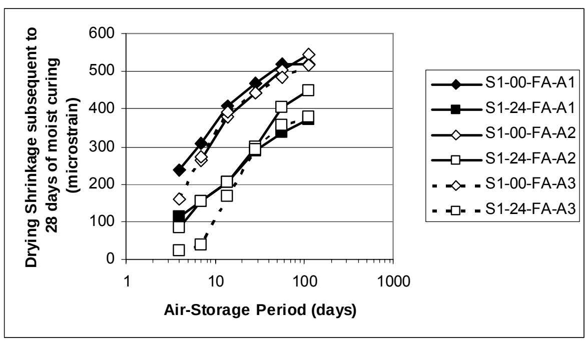


Fig. 4. Drying shrinkage of Grade A-FA fly ash concrete made with three sources of aggregates vs. age (Aggregates A1, A2, A3)

Aggregate A2 was the second best, and the concrete mixtures made with Aggregate A3 resulted in the highest penetrability of chloride ions into concrete (the lowest resistance to penetration). Use of SRA-1 itself did not significantly increase or decrease the chloride-ion penetrability into Grade A-FA fly ash concrete (Figs. 6 and 7).

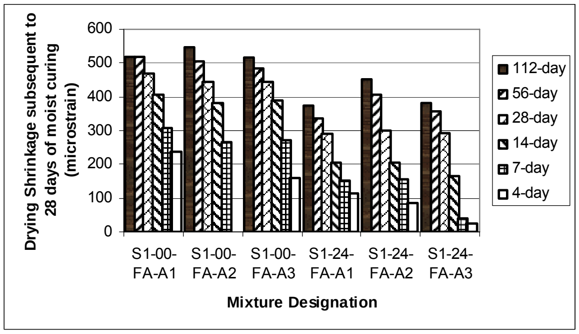


Fig. 5. Drying shrinkage of Grade A-FA fly ash concrete vs. aggregate type (Aggregates A1, A2, A3)

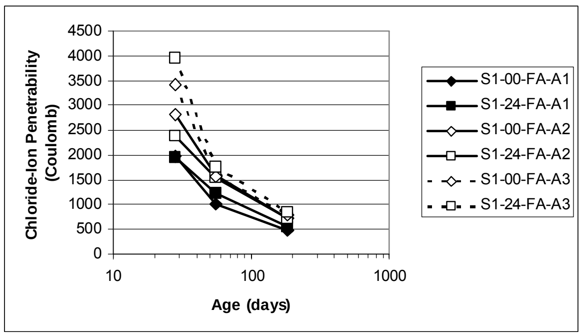


Fig. 6. Chloride-ion penetrability into Grade A-FA fly ash concrete made with three sources of aggregates vs. age (Aggregates A1, A2, A3)

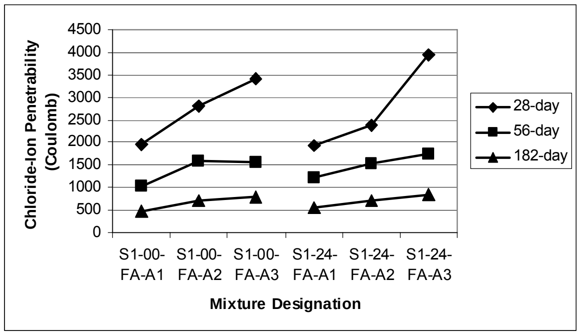


Fig. 7. Chloride-ion penetrability into Grade A-FA fly ash concrete vs. aggregate type (Aggregates A1, A2, A3)

## 5. CONCLUSIONS

Using Grade A-FA mixture proportions (30% replacement of cement with Class C fly ash), effects of three types of coarse aggregate were evaluated: Aggregate A1, crushed quartzite stone; Aggregate A2, semi-crushed river gravel; and Aggregate A3, crushed dolomitic limestone. SRA-1 was used with a mid-range water-reducing admixture (MRWRA) and air-entraining admixture (AEA) supplied by the same manufacturer. SRA was added last into a concrete mixer after all the other ingredients were intermixed.

Based on the experimental program conducted and the test results obtained, the following summary results and recommendations are given:

- To minimize the drying shrinkage of concrete, the following amount of SRA-1 is recommended for Grade A-FA fly ash concrete: 40 fl. oz./100 lb of cementitious materials (2.6 L/100 kg of cementitious materials).
- The drying shrinkage reduced in an approximate proportion to the amount of SRA used. When SRA is used in excess of the above recommended dosage rate, drying shrinkage may not reduce any further.
- SRA was most effective in reducing the drying shrinkage of concrete during early periods (up to about four days) of exposure

to drying when the rate of drying shrinkage would otherwise be the highest. At later periods of drying, when the rate of drying shrinkage would usually be lower, the rate of drying shrinkage of the SRA concrete was similar to the rate of drying shrinkage of the no-SRA concrete. Thus in effect, SRAs eliminated much of the initial high drying shrinkage only.

- By using SRA in Grade A-FA concrete mixtures, the drying shrinkage at the age of four days reduced by up to about 67 to 83%, and the drying shrinkage at the age of 28 days reduced by up to about 48 to 66%.
- In general, SRA-1 did not affect or decreased the chloride-ion penetrability into concrete (higher resistance to penetration). As a whole, the concrete mixtures containing chemical admixtures from Source 1 showed the lowest 182-day chloride-ion penetrability (the highest resistance to penetration).

Effect of the type of coarse aggregate:

<u>Drying shrinkage:</u> Use of Aggregate A3 often led to the lowest early-period (up to 7-day) drying shrinkage, followed by Aggregate A2, and Aggregate A1 (the highest early-period shrinkage). However, the late-period (56-day) drying shrinkage of the concrete made with Aggregate A2 or A3 became either about the same as or higher than that of the concrete made with Aggregate A1. Often, use of Aggregate A2 resulted in the highest late-period drying shrinkage.

<u>Autogenous shrinkage:</u> In general, use of Aggregate A3 resulted in the lowest autogenous shrinkage, followed by Aggregate A2, and Aggregate A1 (the highest autogenous shrinkage), especially at early ages.

<u>Chloride-ion penetrability:</u> The type of coarse aggregate did not noticeably affect the 182-day chloride-ion penetrability into concrete; however, at the early age, concrete made with Aggregate A1 had the lowest chloride-ion penetrability (the highest resistance to chloride-ion penetration), followed by concrete with Aggregate A2, and concrete with Aggregate A3 (the lowest resistance to chloride-ion penetration).

Thus, use of A3 (dolomitic limestone) seems to be helpful in reducing early autogenous shrinkage and drying shrinkage compared with using A2 (river gravel) or A1 (quartzite stone).

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