



# An investigation into the influence of superabsorbent polymers on the properties of glass powder modified cement pastes



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## HIGHLIGHTS

- Glass powders were shown to affect the absorption of SAP in pore solutions and in the cement pastes.
- Addition of SAP decreased the electrical resistivity of the glass powder modified cement pastes.
- The improvement in hydration with SAP was similar in the cement pastes with and without glass powders.

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## ABSTRACT

This study examines superabsorbent polymer (SAP) absorption, mechanical strength, hydration, and electrical resistivity of glass powder modified cement pastes. The absorption of SAP was monitored using optical microscopy and shown to be higher when glass powders were used. Addition of SAP was found to improve hydration due to internal curing. The cement pastes with SAP exhibited a decreased compressive strength due to macrovoid formation. The glass powder modified cement pastes experienced a large reduction in electrical resistivity as a result of SAP addition; increased pore connectivity in these cement pastes is suggested as a possible cause of the reduction in electrical resistivity.

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## 1. Introduction

Autogenous shrinkage induced cracking is a critical issue in high performance cementitious materials [1–7]. In low water/binder ratio cementitious materials, the water in the mixture is gradually depleted during the hydration reaction and as a result, the relative humidity of microstructure is decreased [8,9]. When relative humidity in the pore structure of cementitious materials is decreased, the capillary pore pressure is increased, resulting in autogenous shrinkage in the solid skeleton of the microstructure. Due to mechanical constraint, the autogenous shrinkage generates tensile stress, which can cause crack formation in the cementitious materials at early age when the materials have a low tensile strength [10,11].

Internal curing to maintain high relative humidity inside the material with the use of an internal water reservoir has been shown to be a viable method to reduce autogenous shrinkage in cementitious materials [1,2,10,12–21]. Superabsorbent polymers

(SAP) have received increasing attention as an internal curing agent in recent years [2,10,17–21]. A key advantage of SAP is its versatility in size distribution and absorption/desorption characteristics, which allow it to be adapted to specific mix designs.

Prior studies have shown improvements in the hydration of cementitious materials when SAP was used due to internal curing [19,22,23]. The potential of SAP to increase microstructure densification has been discussed in previous work [21,23–26]. The effect of SAP on the transport behavior was studied [18,19,27] and enhancement in the resistance to chloride permeability was indicated [18,19]. However, cementitious materials containing SAP have been found to exhibit a general reduction in compressive strength as a result of the formation of macrovoids due to SAP absorption in the fresh mixture [4,21,28–30]. It is important to note that the cement mix design and the physical and chemical characteristics of SAP strongly affect their influence on cementitious materials [4,7,18,20,29].

Supplementary cementitious materials (SCM) are commonly utilized in cementitious materials to improve their durability characteristics and extend their service life [31]. Utilization of waste glass powder as a viable supplementary cementitious material

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has received increased attention due to the rising cost of local virgin materials and the environmental impact of replacing cement in civil engineering applications [32–44]. Prior investigations have indicated that microscale size glass powders improve the durability characteristics of the materials [33,34,37,38,40,45–49]. The pozzolanic properties of glass powder with a microscale size distribution is responsible for the observed enhancement in the performance of cementitious materials [32,34,37,50,51]. A few studies examined the drying shrinkage of cementitious materials modified with glass powder [35–37,52]. Shayan and Xu [35,37] showed that the drying shrinkage of concrete modified with glass powder was acceptable. Sharifi et al. [52] indicated a decrease in drying shrinkage as a result of using glass powder, while Kara et al. [36] concluded an opposite trend.

A few prior efforts studied the effect of SAP on the properties of cementitious materials blended with supplementary cementitious materials such as fly ash [25,53], silica fume [18,20] and ground granulated blast furnace slag [18,53]. However, studies on the influence of SAP on the behavior of glass powder modified mixtures do not exist in the literature. Knowledge of the effect of SAP on the performance of the glass modified mixtures is necessary for the design of such materials in internal curing applications. The aim of this study is to focus on this knowledge gap by studying how the addition of SAP influences the hydration, strength and transport properties of glass powder modified mixtures. The detailed interaction between SAP and the cement pastes modified with glass powder was studied. Hydration at early age was evaluated using semi-adiabatic calorimetry and at late ages using non-evaporable water content measurement. Electrical resistivity as a measure of the transport property of cementitious materials was assessed with electrochemical impedance spectroscopy (EIS). The change in the microstructural features arising from the addition of SAP was examined using scanning electron microscopy (SEM), X-ray diffraction (XRD), and thermogravimetric analysis (TGA).

## 2. Experimental methods

### 2.1. Materials and sample preparation

In this study a sodium polyacrylate SAP was used. The size distribution of SAP is depicted in Fig. 1a, indicating a median size of 200  $\mu\text{m}$ . An SEM micrograph of SAP is shown in Fig. 1b. The size distribution was obtained by evaluating the SEM micrographs of about 100 particles using the ImageJ software. A type I/II Portland cement was used in the preparation of samples. In this study, two glass powders with different chemical compositions were used. GP-I is made of amorphous calcium aluminosilicate processed from waste glass fibers and GP-II is obtained from post-consumer recycled glass. The chemical compositions of the cement and glass powders are listed in Table 1. GP-I and GP-II had a similar median particle size of about 8.4  $\mu\text{m}$  per manufacturer's specifications.

The absorption behavior of SAP is governed by the chemical characteristics of solutions such as ionic strength and pH [54–56]. Ions, including  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{OH}^-$ , are present in the pore solution as a result of cement clinker dissolution during hydration. The addition of supplementary cementitious materials, such as glass powder, affects the pore solution chemistry, which influences the SAP absorption behavior in the cementitious mixtures. Such an effect has not been examined in the past; therefore, the interaction between SAP and the extracted pore solutions of glass powder modified cement pastes was evaluated in this paper.

Fresh mixtures with a 0.36 water/binder ratio were prepared and used to extract pore solutions. Control cement paste without glass powder and cement pastes with 20%, by binder mass, replacement of cement with GP-I and GP-II were prepared. A

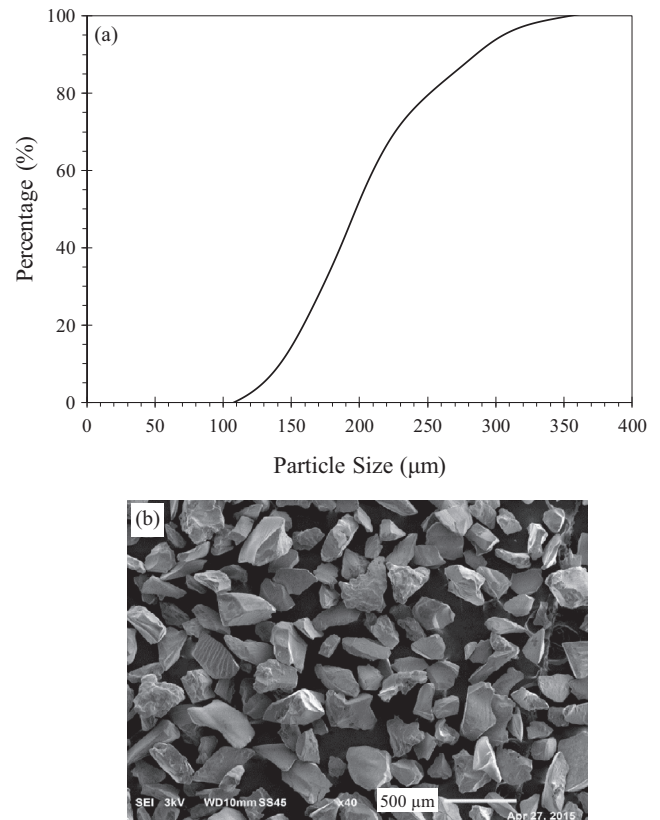


Fig. 1. (a) Cumulative size distribution of SAP particles. (b) Scanning electron micrograph image of SAP particles.

Table 1  
Chemical compositions of cement, GP-I and GP-II.

Composition (%)	Cement	GP-I	GP-II
$\text{SiO}_2$	20.8	57.5	63.3
$\text{Al}_2\text{O}_3$	5	12.7	6.4
$\text{Fe}_2\text{O}_3$	3.7	0.06	0.31
CaO	64.2	22.7	17.1
MgO	0.9	3.6	4.5
$\text{Na}_2\text{O}$	0.2	0.62	6.1
$\text{K}_2\text{O}$	0.4	0.06	0.07
$\text{SO}_3$	2.8	0.22	0.19
$\text{TiO}_2$	0.2	0.98	0.44
$\text{B}_2\text{O}_3$		0–6	0–5
Loss on ignition (%)	2.14	0.5	1
Median particle size ( $\mu\text{m}$ )		8.4	8.4

lignosulfonate-based superplasticizer (WRDA<sup>®</sup> 60, W. R. Grace & Co.-Conn.) at a concentration of 0.5%, by binder mass, was added to all cement pastes to improve workability. Water and binders were mixed at a slow speed for about 30 s followed by mixing at a medium speed for another 60 s. The pore solution was obtained by filtering cement pastes through a glass microfiber filter subject to a negative pressure in a filtration setup. To track the influence of changing pore solution chemistry on SAP absorption in each paste, the filtration process started at two different times corresponding to 0 and 50 min after the initial contact of water and binders. It should be noted that the filtration lasted for about 15–20 min and this can be accounted for in determining the actual time of the pore solution. The extracted pore solution was immediately stored in polypropylene bottles to avoid carbonation.

The mix designs of the cement pastes cast in the experiments are listed in Table 2. Cement pastes were prepared with an effec-

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