

ABSTRACT

There is currently a growing concern over the carbon footprint of the cement industry because it is responsible for no less than 5-8% of man-made CO₂ emissions. The production of Portland cement (PC), the most commonly used cement, is also associated with other environmental concerns, such as air pollution, land and resources depletion and energy intensiveness. The need for more sustainable binder alternatives to the PC has fuelled many research activities over the past few decades. Alkali activated materials (AAMs) have evolved as more environmentally friendly binders with promising mechanical and durability properties. More recently, MgO-based binders also have been proposed with technical advantages as well as environmental merits. Both types of binders can utilise a wide range of supplementary cementitious materials (SCMs) such as ground granulated blast-furnace slag (GGBS, S) and fly ash (FA, F).

Alkali-activated slag (AAS) and alkali-activated fly ash (AAF) binders have both shown excellent performance and technical advantages compared to PC such as high compressive strength and high resistance to sulphate attack. However, the activation process of each material has its own disadvantages such as high levels of drying shrinkage of AAS binders and the need for thermal treatment for AAF. The joint activation of S and F (AASF), therefore, has been proposed as an effective approach to counterbalance the disadvantages of each activation process and to provide a much larger resources for the precursors of AAMs. Furthermore, there is a growing interest in utilising near neutral salts, such as Na₂CO₃ (NC), as activators to produce AAMs. This offers several advantages including reduced alkalinity of the systems, lower cost and carbon footprint and better workability of the fresh paste compared with that of other conventional activators. Hence, the current research focuses on the activation of S and F blends using NC as an activator.

Moreover, the combination of reactive MgO and AAMs has the potential to overcome some drawbacks of AAMs such as shrinkage. Although rheology is one of the most important properties of fresh concrete, the number of systematic studies investigating the fundamental rheological parameters of AASF systems is limited. Therefore, the influence of the relevant factors as well as commercial superplasticisers (SPs) on the rheological properties of NC-activated binders is essential. The current study is dedicated to understanding the reaction mechanism of NC-activated S/F (NC-SF) binder as a more sustainable binder. The study involves the investigation of the key parameters affecting the reaction process, microstructure development and fresh and hardened properties of this binder.

The main findings of this study indicate that the reaction process of NC-SF takes place through three main steps. The first step involves the dissolution of the precursors (S and F); the second step relates to an induction period; and the last step involves a continuous process where the precipitation of the main binding gels and other products occurs. The main binding phase of these mixtures was C-A-S-H and/or C-(N)-A-S-H type gel with a low Ca/Si ratio. Secondary reaction products such as hydrotalcite-like phases (Ht), gaylussite and calcite are formed.

The primary factors affecting the properties of NC-SF binders are the S/F ratio, NC dosage, and curing conditions. The inclusion of F delays the reaction process and results in different gel chemistry of the binding phase. It is clear that F improves the rheological properties of the binder and shrinkage behaviour. It is also found that mixtures with up to 25% F have an insignificant change in the compressive strength. However, further increase in F content leads to a notable reduction in the compressive strength, particularly for samples cured underwater. The increase of the NC concentration from 5% to 10% is beneficial to the reaction kinetics, phase assemblage, microstructure development and mechanical properties of the binders. The increase in NC dosage, however, leads to rheological loss due to increase in the solution viscosity. Sealed curing improves the compressive strength development.

In addition, the incorporation of reactive MgO and the addition of SPs are critical to the properties of AASF. The incorporation of reactive MgO has a marked influence on the reaction of NC-SF mixes: It accelerates the reaction kinetics, enhances the formation of Ht, increases slightly the compressive strength and reduces the porosity and the drying shrinkage of the binder. However, it has negative effects on the rheological properties of the binder. The addition of the modified lignosulphonate-based superplasticiser (SP-C) improves the rheological properties of the binder while other commercial superplasticisers did not show much improvement. Although SP-C slows down the reaction, only slight reduction in the compressive strength of NC-SF cement pastes is observed.

NC-SF concrete mixes develop acceptable mechanical strengths and demonstrate high resistance to sulphate attack and carbonation ingress. They also showed higher resistance to acid attack than the sodium silicate-activated slag concrete. Here, emphasis is placed on the potential of developing NC-SF binders with excellent performance and less complicated production methods. Further investigations to increase the applicability of such binders are required.