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New approach for delaying the internal temperature rise of fire resistant mortar made with coated aggregate

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HIGHLIGHTS

- Fire retardant coated aggregate has been developed with paraffin and aluminium hydroxide.
- Coating thickness of the coated aggregate was measured from 0.165 to 0.32.
- 50% PACA specimen was delayed at 17 min in comparison with the plain specimen.
- The fire resistance of the mortar has been significantly improved by using coated aggregate.

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ABSTRACT

Scientifically, resistant properties of steel structures decrease rapidly with an increase of the temperature. Therefore, steel structure is protected with low thermal conductivity materials from high temperatures. Thus, in this study, for developing fire resistance mortars on the surface of steel structure, the coated aggregate was developed with the zeolite aggregate, paraffin, and aluminium hydroxide. In case of paraffin and aluminium hydroxide, they were used as the coating materials on the surface of zeolite aggregates. First, aluminium hydroxide was coated on the surface of the zeolite aggregate with polymer as the bonding material. After that, paraffin was coated on the surface of coated aggregate with aluminium hydroxide. After the coated aggregate were developed, physical and chemical experiments were conducted. The results of the mechanical experiments presented that compressive strength of specimens with coated aggregates was decreased in comparison with the general specimen. In addition, the bonding strength test indicated that every specimen with or without coated aggregates showed similar results. However, fire resistance properties of specimens with coated aggregates presented that it has a lower thermal conductivity and internal temperature than the plain specimen. Especially, the specimen with coated aggregates was delayed at 17 min compared with the plain specimen on the increase of the internal temperature around 200 °C in the mortar. Therefore, it was confirmed that coated aggregates developed have an effect to decrease the internal temperature and delay time of the increase of the heat by reacting coating materials with heat.

1. Introduction

In the world, steel and concrete have used the most raw materials in the construction field. Especially, steel has many valuable benefits, such as high strength, low weight, ductility, fast construction, and usability on the shapes etc. However, in case of steel structure, it has the disadvantage on the fire resistance capacity or durability. When steel structure exposed to fire, steel characteristics need to protect by it in order to ensure safety for human and reduce material loss [1]. Fire protection on the surface of the steel structure is an important topic because of the enforcement of the existing standards as well as society awareness of fire risks [2]. There are many protected materials and methods, such as rockwood, brick, gypsum, perlite-vermiculite, calcium silicate and intumescent paints, insulation paints and fire-protecting mortar etc. In case of paints, it provides smooth finish, while mortars cause to leave rough surfaces. However, intumescent and insulation paints could not reached at high resistance time [3]. Conventionally, fire-proof mortars contained with vermiculite and/or perlite as the lightweight aggregates can improve the thermal insulation and conductivity as well as their capacity of the weight on these minerals can retain water or obtain the porous insulating mortar.

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Zeolite is a crystalline alumina silicate with pores, channels and cavities. It possesses several special properties such as ion exchange, molecular sieves, catalytic activity etc. [4]. Zeolite aggregate has a high porosity. It can be activated with a high energy after calcination at temperatures more than 400 °C [5]. The surface of the zeolite can generate a large amount of the heat because of the adsorption. This heating increase could be observed on the surface of the zeolite. Phase change materials (PCM) are well known for the thermal storage materials which can possess a large amount of heat energy stored for its phase change stage [6]. It is called as the latent heat material. PCM generally used in the concrete can be divided with two principal types, such as inorganic and organic [7,8]. Paraffin is an organic material as a representative material used in the concrete or mortar. Paraffin is a hydrocarbon (CnH2n+2) [9]. It is generally melted within 20–70 °C. The use of paraffin with a phase change temperature of 26 °C in the concrete or mortar has been successfully demonstrated by previous researches that paraffin is inactive in an alkaline medium, chemically stable and inexpensive [10–14]. In addition, paraffin can reduce the temperature variation because of its ability of the absorption and ejection on the heat energy to the environment. The paraffin absorbed and stored energy suffered a change from a solid state to a liquid stage during temperature increase [15–18]. Aluminium hydroxide (AH – Al(OH)3), currently the most used metal hydroxide fire retardant material because of the low expense and the high loadings. AH has an ability of the decomposition, when exposing to heat at 180–200 °C and then releasing water. The water release can decrease the heat by a cooling effect and diluting the pyrolysis gases, while the AH remains in the condensed phase and can act as a barrier to heat and mass flux [19,20]. AH decomposes as the following reaction [20]:

$$2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O$$

The thermal decomposition of AH has been previously described [21–23] the endothermic loss of approximately 35% by mass of water between 1170 and 1300 Jg^{-1}. AH is very suited for polymers that are processed below its decomposition temperature and decompose close to AH's decomposition temperature so that water release coincides with fuel release from the decomposing polymer. It limits the range of suitable applications for AH [20]. Typically at least 60% by mass of AH is needed to achieve good fire retardant properties [24].

The main purpose of this study is to develop coating aggregate incorporated with paraffin, and aluminium hydroxide as the coating materials on the surface of the zeolite aggregate in order to apply to the fire spraying mortar for the protection of the steel structure. For developing coating aggregates, several type coated aggregates with variation amounts of paraffin and AH were developed after conducting various mixing. In addition, the physical and chemical evaluation of the coated aggregate were conducted by various experiments, such as compressive strength test, bonding test, thermal conductivity test, residual compressive strength test, internal thermal temperature measurement, and SEM analysis, after the coated aggregates were developed.

2. Experimental program

2.1. The decision of a light weight aggregate and fire resistance materials as a coating material

2.1.1. The determination of the fire resistance materials

For applying to a fire resistance mortar on a surface of the steel structure as a protection material with fire, mortar was developed with coated aggregate using zeolite, aluminium hydroxide and paraffin. Zeolite is a well-known lightweight aggregate. It is usually used in mortar as a fire resistance material because of a lower thermal conductivity than general aggregates. Therefore, in this study, zeolite was used by a mine produced in the national area. The chemical properties of zeolite aggregate are presented in Table 1. Thus, silica sand produced by the national factories was used for comparison with zeolite aggregate or coated aggregate. The chemical and physical properties are shown in Table 2.

Table 1
Chemical and physical properties of zeolite.

SiO2 (%)	Al2O3 (%)	Fe2O3 (%)	CaO (%)	MgO (%)	Na2O (%)	K2O (%)	Ig. loss (%)	Specific gravity (g/cm^3)
70.84	15.76	1.38	1.23	1.31	1.07	1.72	6.69	0.9 ~ 1.2

Table 2
Chemical and physical properties of silica sand.

SiO2 (%)	Al2O3 (%)	Fe2O3 (%)	CaO (%)	MgO (%)	Size (mm)	Ig. loss (%)	Specific gravity (g/cm^3)
98.31	0.79	0.11	0.05	0.02	0.35 ~ 0.7	0.51	2.65

For improving properties of the aggregate with fire, the coated aggregate was developed with aluminium hydroxide (A-H) and paraffin as a coating material. A-H is a typical incombustible material with low toxicity, low smoke-ability, and excellent insulation. The reaction mechanism of A-H generates water when exposing to heat at 180–200 °C. Therefore, AH has a good property that heating temperature can be decreased by evaporating with heat. The reaction mechanism of AH is shown in Fig. 1.

AH used in this study was purchased form Nippon Metal Company, Japan. The chemical and physical properties of AH are shown in Table 3. For improving bonding property on the surface of zeolite with AH, polymer based on PVAc (Polyvinyl Acetate) was used. In case of PVAc polymer, it has an outstanding performance of the bonding property in comparison with other polymers. AH has a high absorption rate. Thus, it has a disadvantage when making mortar. For protecting coated AH on the surface of zeolite, paraffin was used on the surface of AH as a coating material. Paraffin is a well-known material with property of heat energy storage. Paraffin can decrease temperature due to the ability of heat storage. The flash point of the paraffin is 200 °C. Paraffin has a similar property with AH. Therefore, paraffin produced by Nippon Seiro-Company in Japan was used as a second coating material. The properties of paraffin are shown in Table 4.

2.1.2. The procedures of the coating ratio on the surface of zeolite

In this paper, for developing a coating aggregate with zeolite, aluminium hydroxide, and paraffin, coating methods was conducted as follows;

(1) The surface of zeolite attached 10, 20, 30, and 40% of AH with polymer as the bonding material. The usage of AH is calculated in consideration on the mass ratio of zeolite. In addition, the usage of polymer as the bonding material is decided at 15% after many experiments conducted.
(2) After coating AH with polymer on the surface of zeolite, it put the drying oven, after that it dried for 1 h.
(3) After drying it, paraffin is coated on the surface of coated zeolite with AH. The paraffin is coated at 15% of all amounts of coated zeolite by considering mass ratio of coated zeolite. The procedure of coating method is shown in Fig. 2.

2.1.3. The determination of the usage of the coated zeolite

For evaluating properties and deciding the usage of the coated zeolite as a material to the fire resistance mortar, mortar speci-