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Effects of elevated temperatures on properties of self-compacting-concrete containing fly ash and spent foundry sand

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ABSTRACT

In this paper an attempt has been made to study the use of spent foundry sand and fly ash on the properties of Self-Compacting-Concrete (SCC) such as compressive strength, splitting tensile strength, modulus of elasticity, rapid chloride permeability, porosity and mass loss when exposed to elevated temperatures. The influence of fly ash as partial replacement of cement, and spent foundry sand as partial replacement of sand on the properties of SCC is investigated. In this research, mixes were prepared with three percentages of fly ash ranging from 30% to 50% and one controlled mixture without fly ash was also prepared for comparison. Fine aggregate was replaced with 10% of spent foundry sand. The specimens of each concrete mixture were heated up to different temperatures (27 °C, 100 °C, 200 °C, and 300 °C). In order to ensure a uniform temperature throughout the specimens, the temperature was held constant at the maximum value for 1 h before cooling. Using Ordinary Portland cement, an increase of about 24–25% in compressive strength, 18–22% in splitting tensile strength was observed at 28 days when fly ash content was decreased from 50% to 30%. Also test results clearly show that there is little improvement in compressive strength within the temperature range of 200–300 °C as compared to 27–200 °C. But the rate of splitting tensile strength and modulus of elasticity loss was higher than that of the compressive strength loss at elevated temperatures and with the increase in percentage of fly ash. In this paper X-ray diffraction and Scanning Electron Microscopic (SEM) observations were also made to explain the observed residual compressive strength increase between 200 and 300 °C.

1. Introduction

Self-Compacting-Concrete (SCC) was introduced in 1989 by Professor Ozowa of Japan [1] and then developed by Bartos and Grauers [2] and Okamura and Ouchi [3]. Recently, this concrete has gained wide use in many countries for different applications [4]. Use of SCC in the construction industry has been widely growing in the entire world and a good growth of use is predicted for it in the near future. Therefore it is necessary to determine its long-term properties and service performances, such as durability and fire resistance [5]. Although the use of SCC has many technical and economical advantages, its supply cost could be two to three times higher than that of normal concrete depending upon the composition of the mixture and quality control of concrete produced. Such a high premium has somehow limited SCC application to general construction. For SCC, it is generally necessary to use super-plasticizers in order to obtain high mobility. Adding a large volume of powdered material can eliminate segregation. The powdered materials are fly ash, silica fume, lime stone powder, glass filler, quartzite filler and ground granulated blast furnace slag that can be added to increase the slump of the concrete mix and also to reduce the cost of SCC. Out of these materials fly ash, which is a byproduct of thermal power plants or a fine inorganic material with pozzolanic properties has been reported to improve the mechanical properties and durability of concrete when used as a cement replacement material. The incorporation of fly ash also reduces the need for viscosity modifying chemical admixtures [6]. Not only does the use of fly ash protect the environment, it also improves a number of concrete properties, resulting in better workability, higher ultimate strengths and increased durability. Foundry sand which is a waste material, used in this research is high quality silica sand with uniform physical characteristics. It is a by product of ferrous and nonferrous metal casting industries, where sand has been used for centuries as a moulding material because of its thermal conductivity. Metal foundries use large amounts of sand as part of the metal casting process. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as "foundry sand." Like many waste products, foundry sand has beneficial applications to other industries. Industry estimates that approximately 100 million tons of sand is used in production annually, of that, 6–10

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million tons are discarded and are available to be recycled into other products and in industry.

In a recent study, Siddique and de Schutter [7] reported that in the United States alone up to 10 million tons of foundry sand are discarded annually and are available for recycling. Siddique et al. [8] replaced up to 30% of sand in concrete with spent foundry sand. The concrete mixtures prepared with spent foundry sand had higher compressive strength, split tensile strength, and modulus of elasticity than the control mixtures without spent foundry sand. Khatib and Ellis [9] replaced up to 100% of sand with spent foundry sand and observed a resulting strength loss with an increase in spent foundry sand content. Naik et al. [10] replaced 25–35% of paving stones with spent foundry sand and reported that almost all mixtures satisfied the minimum compressive strength requirements. Bakis et al. [11] prepared asphalt concrete in which 20% of sand was replaced with spent foundry sand. In their study, the indirect tensile strength decreased almost linearly with an increase in spent foundry sand. Kraus et al. [12] used foundry silica dust as a replacement material for fly ash in the manufacture of SCC. Foundry silica dust replaced with 30% of class C fly ash, reported some reduction in 3-day compressive strength and considerable reduction in 28-days compressive strength. In other study, Mustafa et al. [13] replaced 100% of sand with spent foundry sand and up to 70% of Portland cement with fly ash and produce SCC with compressive strength around 40 MPa at 28 days. Their results also showed that the rapid chloride permeability of most concrete containing fly ash and spent foundry sand was below 750 coulomb at 90 days, which indicate relatively high quality SCC mixtures.

As the use of SCC becomes common, the risk of exposing it to elevated temperatures increases. Influence of elevated temperatures on mechanical properties of concrete is of very much important for fire resistance studies and also for understanding the behaviour of containment vessels, chimneys, nuclear reactor, pressure vessels during service and ultimate conditions structures like storage tanks for crude oil, hot water, coal gasification, liquefaction vessels used in petrochemical industries, foundation for blast furnace, coal and coke industries, furnace walls, industrial chimney, air craft runways, etc. subjected to elevated temperatures. Concrete structures including walls and pipes may also be exposed to elevated temperatures which may result in significant damage. Hence to predict the response of structure after exposure to elevated temperature, it is essential that the strength properties of concrete subjected to elevated temperature be clearly understood. Variation of compressive strength, split tensile strength, modulus of elasticity, rapid chloride permeability, porosity and mass loss are some of the important properties to be investigated when concrete structures are subjected to elevated temperatures. Degradation of mechanical behaviour of concrete due to exposure to high temperature has been studied since 1950s in western countries [14,15]. The rise in temperature of the concrete over 1000 °C is enough to destroy the original material. At early stages of heating the evaporable water from concrete is lost over in the range of 20–110 °C. Above 110 °C the cement hydrates decompose, calcium hydroxide is broken down and the calcium carbonate suffers decarbonation. The aggregate also suffers changes, which contributes to the general loss of structure safety [16]. The decrease in compressive strength depends on the aggregate, cement paste and the initial moisture content of the specimen [17]. Some of the studies on SCC subjected to elevated temperature showed both decrease in strength and increase in the risk of spalling or a similar behaviour to that of vibrated concrete. Noumowe and Aggoun [18] presented the experimental work on the high temperature behaviour of conventional vibrated high strength concrete and self-compacting high-strength concrete by using polypropylene fibre, and concluded that residual mechanical properties in reference to the initial mechanical properties of self-compacting high-strength concretes were similar to that of conventional high strength concrete. Castillo [19] presented the experimental results of compressive strength in the temperature range of 100–300 °C and observed the decrease in compressive strength of high strength concrete by 15–20%. Jin et al. [20] presented the experimental results of compressive strength of SCC during high temperature exposure. They concluded that after heating to 100 °C and subsequent cooling, the compressive strength of all mixtures decreased as compared to the room-temperature strength. Hanaa et al. [21] studied the mechanical and microstructural properties of self-consolidating concrete at ambient temperature and after heating by using limestone filler and reported that after a moderate decrease (5%) in compressive strength between 20 and 150 °C, an important increase (25%) was observed between 150 and 300 °C. In other studies Khoury [22] and Phan and Carino [23] reported the decrease in strength between 20 and 150 °C on vibrated concretes. Ye et al. [24] evaluated the phase distribution and microstructural changes of self-compacting cement paste at elevated temperature. It was found that self-compacting cement paste showed a higher change of total porosity in comparison with high performance cement paste. Ghandehari et al. [25] evaluated the residual mechanical properties of high strength concretes after exposure to elevated temperatures by using silica fume, and reported that after heating to 200 °C the strength of all of the concretes slightly improved when compared to strength at 100 °C. Siddique [26] studied the properties of SCC mixes, incorporating fly ash content up to 35%. The author observed the decrease in chloride penetration with the increase in fly ash content above 30%. Patel et al. [27] reported that the use of fly ash decreased the rapid chloride penetration. Nehdi et al. [28] reported that the presence of fly ash reduced the penetrability from approximately 3000 Coulomb to less than 1000 Coulomb. Zhu and Bartos [29] reported the significant reduction of chloride diffusivity of SCC with fly ash. Shi [30] states the use of supplementary cementing material such as fly ash may have a significant effect on the chloride migration of concrete as measured by the rapid chloride permeability test. Bakhtiyari et al. [31] evaluated the mechanical properties and changes in the phase composition of the paste of SCC containing different powders at elevated temperatures. They found that, if fine quartzite powder is used as filler in the SCC, it will accelerate the strength development at high temperatures up to 500 °C, because of its partial pozzolanic activity, enhanced at such temperatures. They also concluded that it can be said as a general rule that 500 °C is a critical temperature for concretes exposed to fire.

As SCC was becoming a more widely used material and there was no published study on the use of spent foundry sand as replacement material of sand at elevated temperatures. The present research was done to evaluate the behaviour of SCC subjected to elevated temperature by using locally available materials. Total mass of cementitious materials was 500 kg/m^3 with 30–50% replacement of cement with fly ash. Fine aggregate was replaced with 10% of spent foundry sand. Water-to-cementitious material ratio for various fly ash SCC mixes was ranging from 0.38 to 0.42. The super plasticizer content was below 2% of the total powder content (cement + fly ash) for all the mixes. The effect of elevated temperature on compressive strength, splitting tensile strength, modulus of elasticity, rapid chloride permeability, mass loss and porosity was investigated. X-ray diffraction and Scanning Electron Microscopic (SEM) observations were also made in this research.

2. Experimental programme

2.1. Materials

2.1.1. Cement

Ordinary Portland cement (Grade 43) was used for preparing concrete mixes. Its physical properties are as given in Table 1.