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主　論　文　の　要　旨

論文題目　**STUDY ON APPLICABILITY OF SPHERICAL SHAPED EAF SLAG FINE AGGREGATE IN CONCRETE**
(コンクリートへの球形電気炉酸化スラグ細骨材の適用性に関する研究)

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論　文　内　容　の　要　旨

Electric Arc Furnace (EAF) oxidizing slag is a steel manufacturing by-product. Utilization of by-product material such as EAF slag in concrete as replacement of aggregates is attracting increased popularity due to several reasons such as safe and environment friendly disposal of industrial wastes that contain heavy metals, encounter the problem of depletion of natural aggregate stock for rapid infrastructural development etc. Several previous studies indicate that replacement of aggregates (either coarse and/or, fine) in concrete by EAF slag is advantageous as it enhances the mechanical properties of concrete. It can be noted that all the previous studies utilized the conventional angular shaped EAF slag in concrete by replacing coarse and/or, fine aggregates and reported poor workability of such concrete at higher slag replacement ratio due to the less ball bearing effect because of angular shape. For the improvement of workability increase in water content is an option although the risk of degradation of durability properties such as drying shrinkage as a result of increased water content is high.

Recently, a new production method has been developed where slag granules are formed by passing of high-pressure cold air through the molten slag and the slag particles thus obtained become spherical in shape. Due to spherical shape, it is expected that the former

problems of workability and durability can be solved. In addition, because of high particle density chances of obtaining concrete of improved mechanical properties by incorporating spherical shaped EAF slag are high. In contrary, due to spherical shape and high particle density, risk of higher bleeding and subsequent particle segregation of such concrete is more which eventually might reduce the strength of associated concrete. In this context, a thorough study on the applicability of the newly developed spherical shaped EAF slag fine aggregates in concrete is necessary. Therefore, this study aims to investigate the applicability of spherical shaped EAF slag fine aggregates in concrete at different slag replacement ratio and W/C ratio.

In order to facilitate the study, three different experimental programs were undertaken that systematically investigated the fundamental and durability properties, thermal properties and high temperature influence and water proofing characteristics of concrete produced by spherical shaped EAF slag fine aggregates at different slag replacement ratio and water to cement (W/C) ratio. The details of the study is described below.

Chapter 1

Chapter 1 starts with the research background and motivation of this study. In this chapter, a newly developed spherical shaped EAF slag fine aggregate is introduced along with its production method and expected performance in concrete. This chapter also includes the review of related key literatures, significance and objective of this study and the dissertation outline along with detail experimental program.

Chapter 2

In Chapter 2, all physical properties of the newly developed as well as conventional EAF slag fine aggregate, natural sand, and gravel are discussed with experimental results. Experimental results indicate that spherical shaped EAF slag possesses higher sphericity (0.92), lower void ratio, larger particle density (3.6g/cc) and lower water absorption than that of angular shaped EAF slag and natural sand.

Chapter 3

Chapter 3 introduces the fresh behavior of concrete produced by spherical shaped EAF slag fine aggregates along with the justification of choosing different experimental parameters such as water to cement ratio (W/C), slump, air content etc. Based on the material properties as discussed in chapter 2, mix proportions were designed for two different W/C, slump and air content of 0.4, 5cm, 5% and 0.6, 12cm, 5% respectively with

an aim to investigate the utilization possibility of such material in concrete pavement and normal concrete respectively. From the mix proportions it was confirmed that spherical shaped EAF slag concrete requires 16% lesser mix water and cement than normal concrete when all sand is replaced by spherical slag. Study on the fresh concrete behaviors revealed that spherical shaped EAF slag concrete at higher slag replacement ratio and W/C imparts higher bleeding although corresponding particle settlement due to segregation even at longer sized specimen (500mm) is very low to negligible.

Chapter 4

In chapter 4, applicability of spherical shaped EAF slag in concrete is investigated for different W/C ratio, slump and air content. Both mechanical and durability properties of concrete are examined and discussed. In so far as the mechanical properties of slag concrete are concerned, spherical shaped EAF slag fine aggregates were found to be advantageous in concrete at lower W/C, slump and air content of 0.4, 5cm and 5% as they impart higher strength and elastic modulus than normal concrete. In contrary, at higher W/C, slump and air content of 0.6, 12cm and 5% normal concrete showed improved behavior than slag concrete. The mechanism of improved strength and elastic modulus of spherical shaped EAF slag concrete were identified by digital image correlation method (DICM) as improved particle adhesion of such concrete that prolongs the origination and resists the propagation of cracks due to loading. Regarding durability properties, due to stronger particle resistance, spherical shaped EAF slag concrete showed approximately half of drying shrinkage in comparison to normal concrete when all sand is replaced by spherical slag. In addition, water absorption and air permeability of such concrete were found be lower than normal concrete.

Chapter 5

Chapter 5 investigates the stability of spherical shaped EAF slag fine aggregate in concrete during thermal change. Spherical shaped EAF slag fine aggregate concrete demonstrated improved material stability by showing superior behavior such as lower thermal expansion, thermal conductivity, thermal diffusivity and specific heat than normal concrete during thermal change. The mechanisms behind such behaviors were clarified due to lower porosity, higher particle density and lower moisture content and mineralogical compositions. Improved freezing and thawing resistance of spherical shaped EAF slag concrete was observed up to 200 freezing-thawing cycles, beyond which resistance deteriorates due to lower air retention capacity of such concrete.

Chapter 6

In chapter 6, a thorough study on the high temperature influence of concrete produced by spherical shaped EAF slag is presented with all experimental results. Under high temperature exposure, spherical shaped EAF slag concrete showed lower mass reduction than normal concrete due to lower volume of cement pastes. Up to a heating exposure of 500°C, spherical shaped EAF slag concrete manifested improved residual elastic modulus and similar to slightly improved residual compressive strength than normal concrete. Image analysis results by DICM confirmed the damage of concrete due to heating in the form of compression closing cracks and it was proved that the degradation of elastic modulus and compressive strength of concrete due to high temperature heating is dictated by the extent of compression closing cracks. On the other hand, residual flexural strength and tensile fracture energy of spherical shaped EAF slag concrete was found to be lower than normal concrete due to higher particle fragility of slag during heating.

Chapter 7

Chapter 7 investigates the water proofing capacity of spherical shaped EAF slag concrete. Regarding water proofing, spherical shaped EAF slag concrete showed improved behavior than normal concrete as the reduction of compressive strength of such concrete under water during static compression test was much lower in comparison to normal concrete. Similarly, concrete produced by spherical shaped EAF slag fine aggregates experienced higher fatigue life due to slower damage accumulation than normal concrete under water at lower stress level.

Chapter 8

Finally, chapter 8 concludes with major findings and includes the recommendations for future study.

In a nutshell, this study revealed some important findings through the confirmation of the applicability of spherical shaped EAF slag fine aggregates in concrete especially at lower W/C and slump of 0.4 and 5cm. Utilization of this newly developed by-product material in concrete should contribute to solve many structural problems and durability concerns and to ensure environmentally safe, sustainable and economic construction.