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Beneficial Role of the Industrial Wastes to Combat Adiabatic Temperature Rise in Massive Concrete

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Abstract: An evaluation was made on the mutual beneficial role of fly ash and ground granulated blast furnace slag in combating adiabatic temperature rise. The experimental program was designed in two stages; the main experiment consisted of two massive concrete specimens with dimensions (50×50×50) cm. In first stage of experiment, an adiabatic rise in temperature of specimens was measured. In second stage, the mechanical properties of massive concrete specimens were measured at the ages of 8, 14, 28, 56 and 91 days. At the age of 91 days, surface core and central cores were extracted from the surface and the central part of massive concrete specimens to determine compressive strength and dynamic modulus of elasticity. In the massive concrete specimen without any additive, the peak temperature noted was 64.5°C at 7th h after casting. While in mineral substituted concrete the maximum adiabatic temperature was 49.6°C at 19th h after casting. Lower rate of temperature rise in mineral substituted concrete has resulted in higher value of ultrasonic pulse velocity and ultimate compressive strength of concrete.

Key words: Massive concrete, adiabatic temperature, industrial waste

INTRODUCTION

With the expansion of production scale in modern society, the contradiction between human beings' needs and the environment becomes more and more acute. This has lead to a huge burden on energy, natural resources and environmental pollution. All of these have threatened mankind's subsistence and development. Material is the physical base and the premise of society development and it is the milestone of the mankind advance, too. Not only it creates material civilization and improves the living condition, but also it accelerates energy consumption and environmental pollution. So the ecological degree of the material's whole life periodicity is an indication that can evaluate the environmental quality. The construction industry is not exempted from the governing ecological imbalance owing as a major contributor to air pollution and consumer of vast quantities of natural materials. For each ton of cement produced, one ton of carbon dioxide CO_2, a greenhouse gas, is released into atmosphere, accounting for almost 7% of the total CO_2 emission (Malhotra, 1999). There is still a huge difference between simply declaring concrete to be a green material and actually taking the steps necessary to achieve sustainable development. Portland cement is the key component of concrete that binds the other components together and gives the composite its strength. A considerable amount of work has been reported in the literature on how to use waste products of combustion or industrial processes as supplementary cementatious material. By utilising the pozzolanic and cementatious properties of fly ash (FA) and ground granulated blast furnace slag (GGBS), waste materials of coal burning power plant and steel industry, respectively, are successfully converted into value-added materials (Meyer, 2002).

When the Portland cement is mixed with water, heat is liberated as the result of an exothermic chemical reaction between cement and water. The heat generated by the hydration of cement raises the temperature of the concrete. During normal concrete construction, the heat is dissipated into the soil or the air and the resulting temperature changes in the structure are not significant. However, in some situations, particularly in massive concrete structure such as dams, mat foundation and piers, the heat can not be readily released. This situation leads to a temperature difference between center and outer part of the mass concrete element. Temperature difference is a cause for tensile strain, which in turn is a source for tensile stress causing cracks in concrete

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Corresponding Author: M. Ashraf, Department of Environmental Engineering, United Graduate School of Agricultural Sciences, Tottori University, 4-101 Minami Koyama-cho, Tottori 680-8553, Japan structure known as thermal cracks. These thermal cracks may cause loss of structural integrity and shortening of service life of the concrete element. Such cracking can be controlled by methods that limit the peak temperature to a safe level, so the tensile strains developed are less than the tensile strain capacity.

Fly ash appears to reduce the early heat of hydration in massive concrete structure. Use of slag is also considered to contribute in retarding hydration rate (Anton and Kevin, 2003). Keeping in view of the individual properties of these materials, an evaluation is made on their mutual beneficial role in combating adiabatic temperature rise in massive concrete.

MATERIALS AND METHODS

The experimental program was designed in two stages; the main experiment consisted of two massive concrete specimens with dimensions (50×50×50) cm. One specimen was normal concrete without any mineral additive (CTR) while in other specimen, ordinary Portland cement was replaced by 30% fly ash and 30% ground granulated blast furnace slag (FSC). Physical and chemical properties of ordinary Portland cement (OPC), fly ash (FA) and ground granulated blast furnace slag (GGBS) are shown in Table 1. Mix proportion of concrete types is given in Table 2. The optimum replacement ratios of FA and GGBS were selected from the study of Hassan *et al.* (2005).

In first stage of experiment, an adiabatic temperature rise in specimens was measured. An embedded thermocouple sensor in the central part of each massive concrete specimen was used to measure the rise in adiabatic temperature. During casting, massive concrete specimens were covered with 5 cm thick polystyrene foam to simulate the adiabatic condition. After having seen the inner temperature become equal to room temperature, polystyrene foam and moulds were removed and each specimen was covered by dabble sheets and kept in wet condition until 91 days.

In second stage, the mechanical properties of massive concrete specimens were measured at the ages of 8, 14, 28, 56 and 91 days. To measure ultrasonic pulse velocity (UPV), the massive concrete specimen was divided into three parts: outer, middle and central as shown in Fig. 1. At the age of 91 days, 21 surface core and 3 central cores were extracted from the surface and the central part of massive concrete specimens. Surface and central cores were used to determine compressive strength and dynamic modulus of elasticity.

Table 1: Chemical and physical properties of OPC, FA and GGBS

	Chemical composition (%)							Physical properties	
Constituents	CaO	Al_2O_3	SiO_2	MgO	Fe_2O_3	SO_3	LOI	Blaine area (cm^2 g^{-1})	Density (g cm^{-3})
OPC	66.8	5.6	18.4	1.4	3	3	2	3140	3.15
FA	1.3	22.7	56.2	---	8.8	0.9	7.4	3510	2.25
GGBS	42.1	13.1	34.2	6.2	0.9	1.8	0.6	6360	2.88

Table 2: Mix proportion of concrete

			W/B	s/a	W	C	FA	GGBS	S	G
Mix	Max size of agg (mm)	Slump (cm)	%		Unit weight (kg m^{-3})					
CTR	20	9.6	55	37.1	185.5	309.1	0	0	617	1106
FSC	20	11.9	55	37.1	185.5	154.6	77.3	77.3	617	1106

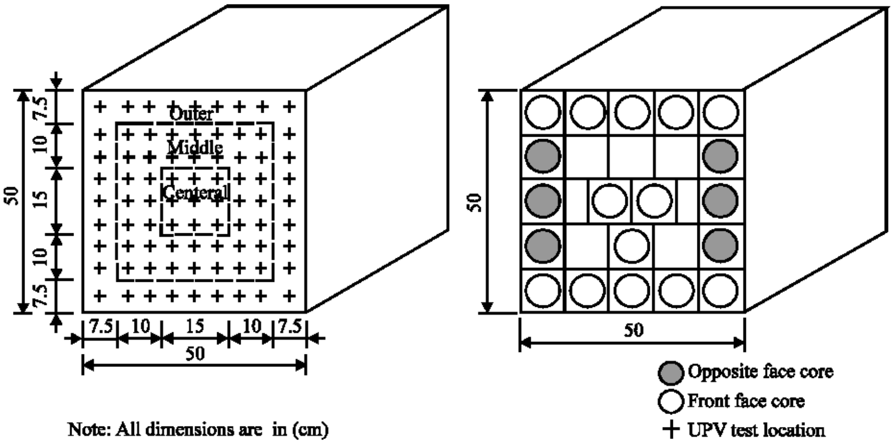

Fig. 1: Locality distribution and core extraction pattern of massive concrete specimen

RESULTS AND DISCUSSION

Adiabatic temperature: It was noted that hydration of specimen started after final setting and heat evolution was higher at earlier age in both specimens (Fig. 2). Figure 2 shows a steep rise of adiabatic temperature in CTR with respect to FSC. Peak temperature in CTR was 64.5°C measured at 7th h after casting. It took only 4 h to rise from ambient temperature to maximum temperature. After peak temperature point, the curve was found on declination. But this lowering of temperature was seemed to be hyperbolic form, i.e., with the lapse of time, rate of declination was slowed down.

In case of FSC, final setting time was little longer than CTR and hydration was delayed. Rate of temperature rise in FSC was much slower than CTR. The peak temperature was 49.6°C and noted at 19th h after casting. The peak temperature of FSC was 15°C lower and the time of maximum heat development was 11 h longer than CTR. In other means, the combination of FA and GGBS caused a reduction in peak temperature of 23% and delayed the peak heat evolution time by three folds. It has been reported that 50% fly ash substitution could help in peak temperature reduction by 23% and moderate level of fly ash (20-30%) alone may not cause any significant reduction in the heat evolution of concrete (Cengiz, 2002). The use of cementitious and pozzolanic materials contributes to the dual effects, by lower the peak temperature on one hand and delaying the rise in temperature on other hand. Etsuo (2005) has well explained the reaction phenomena of FA in concrete. Fly ash does not react for 7 days, independent of glass content and replacement ratio. Therefore, it can be assumed that the mineral and chemical compositions or glass contents of fly ash do not influence the effect by which the heat of hydration is reduced in massive concrete. However, replacement of OPC with FA may lower the cement content in concrete, which could be responsible for low heat evolution.

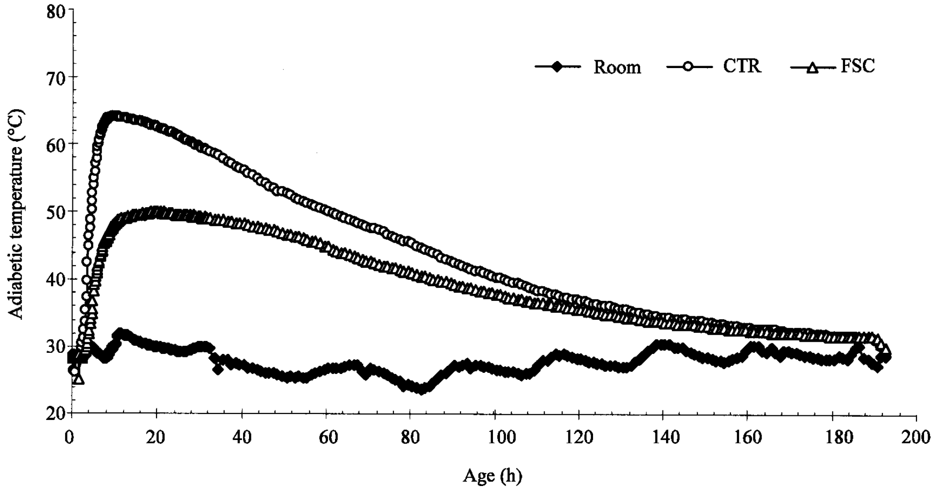

Fig. 2: Rise in adiabatic temperatures

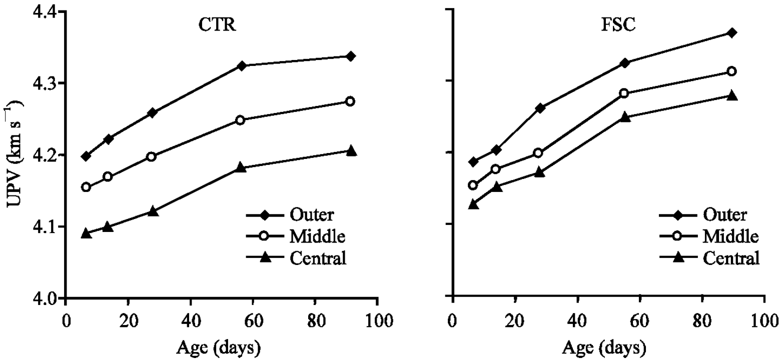

Fig. 3: Ultrasonic pulse velocities of massive concrete specimens

When the temperature difference between the surface and the interior of concrete is greater than 20°C approximately, there is a risk of external or internal cracking (Neville, 1995). The difference in surface and interior temperature of CTR recorded was 34.5°C, whereas in the case FSC, the difference was minimal, about 19.4°C. After reaching the climax, a quick fall of temperature was observed in CTR as compared to FSC. Such lowering trend could cause internal stress that might have detrimental effect to the durability of concrete and could reduce the life span of concrete. The effect of FA and GGBS in controlling the temperature rise is obvious and therefore, such a replacement may be considered when a low-heat cement is required.

Mechanical properties of massive concrete: Evaluating the mechanical properties of massive concrete within 91 days could be difficult. However, the ultrasonic pulse velocity (UPV) was considered as one of the non-destructive test methods for examining strength development successfully (Sato *et al*., 1999). Massive concrete specimen was divided into three parts as the central, middle and outer as shown in Fig. 1. The values of UPV are presented in term of km s^{-1} with respect to age of specimen. The values of UPV in both specimen are in following order: outer > middle > central. However, the difference among the values in CTR was more than FSC. An elevated curve of UPV value in outer portion of specimen is attributed to less thermal stresses and much curing. Development of curve in CTR specimen showed steepness in early days of its age but after 56 days it became mild. This mildness showed the final state of hydration of the specimen.

In FSC specimen, the value of UPV at early age was comparatively low, but the development rate of UPV was far better than CTR. From development rate it could be concluded that at the age of 91 days FSC concrete was yet to reach its complete hydration as UPV values were still showing increasing trend. This showed that the pozzolanic activity of FA and GGBS was slow at early age but with time improved the hydration product (Ranganath, 1998). The quality of concrete is categorized in following manner: UPV > 4 km s^{-1} is assumed to be good concrete, 4 km s^{-1} > UPV > 3 km s^{-1} is modrate concrete and UPV < 3 km s^{-1} is considered to be poor concrete (Malhotra, 1976). In case of this research, the UPV values for all specimens and at all ages were above 4 km s^{-1}, proving farely good concrete.

Mechanical properties of cores: To determine accurately, the effect of FA and GGBS as substitute materials on the mechanical properties of concrete, destructive method were employed for surface and central cores extracted from massive concrete specimen at the age of 91 days. Results of compressive strength and dynamic modulus of elasticity (DME) are presented in Fig. 4 and 5, respectively. Low compressive strength of central cores was measured as compared to surface cores in both specimens. However, values of strength in FSC were marginally higher than CTR. Higher strength in FSC could be attributed to pozzolanic activity of mineral additives. The difference in strength of surface core and central core

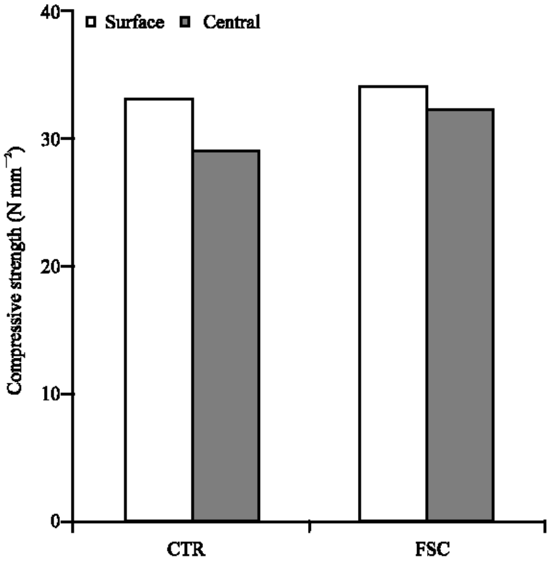

Fig. 4: Compressive strength of cores of massive concrete specimens

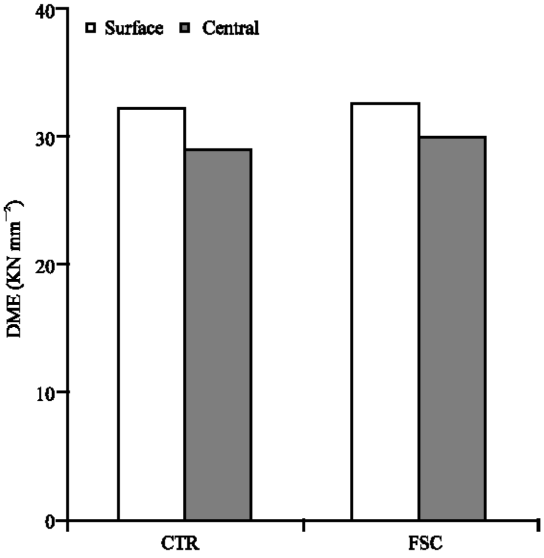

Fig. 5: Dynamic modulus of elasticity of cores of massive concrete specimens

in FSC was also minimal. Low heat of hydration might have resulted lesser difference between surface and central cores values. The compressive strength of slag concrete depends primarily upon the type, fineness, activity index and the proportions of slag used in concrete mixtures (Malhotra, 1987). In general, the strength development of concrete incorporating slag is slow at 1-5 days when compared with that of the control concrete. Between 7 and 28 days, the strength approaches that of the control concrete; beyond this period, the strength of the slag concrete exceeds the strength of control concrete (Admixtures and Ground Slag for Concrete, 1990). It was reported that the fly ash enhances the homogeneity of the concrete matrix and improves strength at later age but with blast furnace slag phenomenon always occurred earlier and at higher pace (Joshi and Lohtia, 1997). It was indicated that pattern of DME in both specimens was same as that was of compressive strength; however the values of DME were at the par of 30 KN mm^{-2} as shown in Fig. 5.

CONCLUSIONS

Based on the results obtained in this study, it has been shown that heat evolution was higher at earlier age in both specimens. In the massive concrete specimen without any additive, the peak temperature noted was 64.5° at 7th h after casting. While in mineral substituted concrete the maximum adiabatic temperature was 49.6°C at 19th h after casting. The combination of fly ash and ground granulated blast furnace slag caused a reduction in peak temperature of 23% and delayed the peak heat evolution time by three folds. Lower rate of temperature rise in mineral substituted concrete has resulted in higher value of ultrasonic pulse velocity and ultimate compressive strength of concrete.

REFERENCES

Admixtures and Ground Slag for Concrete, 1990. Transportation Research Board National Research Council Washington, Transportation Research Circular No. 365.

Anton, K. Schidler and Kevin J. Folliard, 2003. Influence of supplementary cementing materials on the heat of hydration of concrete. Advances in Cement and Concrete, Colorado, USA.

Cengiz, D.A., 2002. Heat evolution of high-volume fly ash concrete. Cement and Concrete Res., 32: 751-756.

Etsuo Sakai, Shigeyoshi Miyahara, Shigenari Ohsawa, Seung-Heun Lee and Masaki Daimon, 2005. Hydration of fly ash cement. Cement and Concrete Res., 35: 1135-1140.

Hassan, K., K. Hattori, H. Ogata and M. Ashraf, 2005. An assessment of incorporating proportions of fly ash and ground granulated blast furnace slag as cement substitute. 10th International Conference of Civil, Structural and Environmental Engineering, Rome, Italy, Paper No. 141.

Joshi, R.C. and R.P. Lohtia, 1997. Fly ash in concrete production, properties and uses. University of Calgary Alberta, Canada, 269.

Malhotra, V.M., 1976. Testing hardened concrete: Non-destructive Methods. ACI. American Concrete Institute Monograph No. 9: 187.

Malhotra, V.M., 1987. Properties of Fresh and Hardened Concrete Incorporating Ground Granulated Blast Furnace Slag. In: Supplementary Cementing Materials for Concrete, Malhotra, V.M. (Ed.) Ottawa, Canadian Government Publishing Centre, pp: 291-331.

Malhotra, V.M., 1999. Making concrete greener with fly ash concrete. Concrete Intl., 21: 61-66.

Meyer, C., 2002. Concrete and sustainable development' American Concrete Institute, ACI Special Publication SP-206, Concrete Materials science to application. A Tribute to Surendra P. Shah.

Neville, A.M., 1995. Properties of Concrete. 14th Edn., Longman Group Limited, London, 324.

Ranganath, R.V., B. Bhattacharjee and S. Krishnamoorthy, 1998. Influence of size fraction of bonded ash on its pozzolanic activity. Cement Concrete Res., 28: 749-761.

Sato, S., K. Hattori, H. Ogata and R. Takada, 1999. Effect of curing and compaction development of strength in various kinds of concrete test pieces. Trans. JSIDRE., pp: 83-88.