



HEAT OF HYDRATION OF CEMENT AND SUPPLEMENTARY CEMENTITIOUS MATERIALS

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ABSTRACT :

The present work summarises the results of eleven research papers focused on the study of SCMs, hydration calorimetry, thermography, temperature estimation, and heat-control techniques in massive concrete. All the papers use adiabatic and semi-adiabatic testing, isothermal calorimetry, thermal analyses, field measurements, hydration models and machine learning methods. The obtained results show that SCMs such as fly ash, slag, ground bottom ash, silica fume, calcium silicate slag, and metakaolin can reduce the maximum temperature in concrete specimens or cumulative heat of hydration when replacing part of Portland cement, depending on the admixture, its fineness, and content. Moreover, the size of the specimens plays a vital role, as well as the temperature regime. Calorimetry and predictive tools based on hydration simulations appear to be useful in estimating the heat of hydration and temperature of a concrete structure. To control massive concrete structure's thermal regime correctly, it is vital to consider the properties of cement binders.

1.INTRODUCTION

Cement reacts chemically with water in a process called hydration. The reaction is exothermic and generates heat that raises the temperature of the concrete structure. For large-volume structures, the heat generated during the exothermic reaction cannot escape quickly. As a result, the temperature of the core of the large mass of concrete is significantly higher than the surface temperature, creating a thermal gradient that can cause cracking of concrete. The thermal stresses that develop as a result of temperature differentials in large-volume concrete can affect the durability and service life of the structure.

Hydration of cement paste in concrete generates a lot of heat at an early age when concrete is still plastic. SCMs such as fly ash and ground granulated blast-furnace slag are largely used as replacements for ordinary Portland cement. The review analyzes the replacement of cement with ground bottom, silica fume, calcium silicate slag, and metakaolin as well as the effect of temperature on concrete. Researchers used the following techniques to study the heat of hydration: calorimetry to measure heat flow and cumulative heat, temperature measurements of concrete structures with temperature sensors, thermo-analysis of the progress of exothermic reactions, mathematical and machine learning models for predicting concrete temperature.

The research papers reviewed present different aspects of the study of the heat of hydration of complementary cementitious materials. This body of work studies the influence of various factors on the amount of heat generated during cement hydration. Some articles examine in detail the effect of the degree of replacement of cement with various types of SCMs on the rate of heat generation and total heat. Others focus on the study of concrete elements of different sizes, mathematical models of concrete temperature, the use of automated calorimetry, and the prediction of temperature changes in large-volume concrete. In general, this body of work provides an insight into the choice of materials, laboratory studies, mathematical models, and practical solutions that can be used to prevent thermal cracking of concrete structures.

2. LITERATURE REVIEW

Khan and Yong (2024) in "Role of Supplementary Cementitious Materials in Mitigating Heat of Hydration in Mass Concrete Elements " investigated eight mixtures designed for a 50 MPa strength level. The mixtures were divided into a control binary mixes with fly ash or ground-blast-furnace slag and ternary mixes with both materials. The supplied presentation indicates that 25% and 36% fly ash replacement reduced heat by 18% and 23% respectively while 30%, 50% and 65% GBFS replacement reduced heat by 12.6%, 19% and 26%. The ternary mixtures also report reductions in the stated heat values. This study supports the use of binders in mass concrete but the appropriate proportions must be identified based on material properties, strength requirements and the thermal conditions of the structure.

Lada, Sutrisno and Piscesa (2024) in "Experimental Evaluation of Heat of Hydration in Concrete Incorporating Supplementary Cementitious Materials " examined the effects of specimen size and supplementary cementitious material content. The experimental programme included 5 × 5 × 5 cm mortar

cubes and $15 \times 15 \times 15$ cm and $30 \times 30 \times 30$ cm cubes with a mix of a control fly ash at 15% and 30% ground bottom ash at 15% and 30% and silica fume at 5% and 10%. Thermocouples were used to measure temperatures for seven days. The supplied presentation reports that larger specimens generally developed peak temperatures with the core being the hottest. Fly ash and ground bottom ash reduced peak temperature while silica fume affected hydration behaviour. This study reveals the importance of considering specimen dimensions when interpreting laboratory findings; its short monitoring period and laboratory specimen sizes limit generalization to full-scale mass concrete.

Palou and colleagues (2020) in "Use of Calorimetry and Thermal Analysis to Assess the Heat of Supplementary Cementitious Materials During the Hydration of Composite Cementitious Binders " used calorimetry and thermal analysis to study metakaolin and blast-furnace slag in composite binders. A TAM AIR calorimeter was used to measure heat-flow and cumulative-heat behaviours while thermogravimetric analysis and differential scanning calorimetry were used to explore hydration-related effects. The study revealed that temperature and the cement-to-SCM mass ratio influenced heat evolution. The main contribution of the study is the use of calorimetry and thermal analysis to interpret binder reactions. Since the work focused on binders the measured responses should not be automatically assumed to predict temperature reduction in a full concrete element.

Bai and colleagues (2023) in "Hydration Characteristics of Cementitious Composites Containing Calcium Silicate Slag Powder " investigated calcium silicate slag powder as a supplementary material. The powder was. Ground and replacement proportions from 0% to 40% were assessed. Isothermal calorimetry recorded heat evolution the Krstulovic–Dabic model examined hydration kinetics and XRD, FTIR, SEM and EDS characterised the materials and hydration products. The supplied presentation reports that the first exothermic peak occurred earlier and was higher whereas the second peak occurred earlier and was lower. This indicates that calcium silicate slag can alter the timing and pattern of hydration heat. Its practical suitability would need to be considered in light of mixture performance and material properties.

Batog (2016) in "Heat of Hydration of Low-Clinker Cements. Part I: Semi-Adiabatic and Isothermal Tests at Temperature " compared low-clinker mixtures made by replacing ordinary Portland cement with 10%, 30%, 50% and 70% fly ash or GGBFS. Isothermal and semi-adiabatic tests were conducted at 20°C and 50°C for up to 72 hours with a water-to-binder ratio of 0.5. The reported results reveal that higher SCM replacement reduced heat release and fly ash reduced heat more than slag at the same replacement level under the stated conditions. Higher temperature accelerated hydration. Reduced the induction period. This study highlights the importance of considering binder composition and test temperature when estimating heat generation.

Schmid, Pichler and Lackner (2019) in "Engineering Hydration Model for Ordinary Portland Cement Based on Heat Flow Calorimetry Data " developed an engineering model from the heat-flow calorimetry tests of Portland cement. Measurements were made at 22.6°C, 31.6°C and 40.6°C. The work explored the relationship between temperature and hydration kinetics. Concluded that a single constant activation energy was not sufficient to describe the hydration behaviour across the investigated temperatures and degrees of hydration. This highlights the need for temperature- hydration models when predicting heat evolution. The model was based on Portland cement so its application to blended binders would require suitable validation.

Colleagues (2025) in "Automatic and Simple: How to Analyze Isothermal Calorimetry Data of Cement etidronic acid and racemic tartaric acid. The tool automatically identifies parameters such as heat flow, dormant-period duration and acceleration time. Sucrose was reported to be the retarder among the investigated additives and increasing the retarder dosage increased characteristic hydration times. Although this study focuses on automated analysis and the use of retarders the method can help to make calorimetry data analysis more consistent and efficient.

Shenhua and colleagues (2026) in "Hydration Kinetics and Heat Prediction Modeling of Cement with Fly Ash, Ground Granulated Blast Furnace Slag Powder and Their Binary Blends " investigated the hydration of cement–fly ash, cement–slag and combined fly ash–slag systems. The work used calorimetry, the Krstulovic–Dabic hydration model and a time-varying hyperbolic model to describe and predict heat evolution. The supplied presentation reports that fly ash and slag reduced age heat and heat-release rate, with larger reductions at higher supplementary-material contents. It also reports a prediction error below 5% in the comparison presented. This suggests that combining calorimetry and suitable mathematical models can support hydration-heat prediction. The model accuracy should nevertheless be validated for cements SCM sources and mixture proportions.

Liu, Zhang, Tang and Jian (2021) in "Prediction of Hydration Heat of Mass Concrete Based on the SVR Model " investigated the prediction of temperature, in a concrete pile cap. Field data included temperature and environmental and cooling-water measurements. A Support

3. CONCLUSION

The reviewed articles prove that supplementary cementitious materials are beneficial for reducing the heat of hydration and optimizing the thermal performance of concrete. Fly ash and ground granulated blast-furnace slag showed potential in terms of heat reduction in various studies, while the combination of the two appeared to be the most beneficial in terms of the experimental conditions. The same goes for ground bottom ash and calcium

silicate slag, but the effect depends on the materials' properties, replacement rates, temperatures, and concrete composition.

The articles also prove that the size of specimens and the chosen methodologies impact the study results. In particular, calorimetry helps understand the relationship between a concrete mix's properties and the rate and total heat of hydration, while thermal analysis sheds light on the connection between temperature and the exothermic reaction.

4. REFERENCES

1. Ballim, Y. And Graham, P.C. (2009). The Effects of Supplementary Cementing Materials in the Modification of the Heat of Hydration in Concrete. The complete journal details need to be verified.
2. Khan, I. And Yong, G.T. (2024). Role of Supplementary Cementitious Materials in the Mitigation of Heat of Hydration of Mass Concrete Elements. *Construction and Building Materials*, 431 136482.
3. Lada, A.H.A., Sutrisno, W. And Piscesa, B. (2024). Heat of Hydration of Concrete with the Addition of Supplementary Cementitious Materials Through an Experimental Approach. The complete journal details need to be verified.
4. Palou, M., Boháč, M., Kuzielová, E., Novotný, R., Žemlička, M. And Dragomirová, J. (2020). Use of Calorimetry and Thermal Analysis for Determination of Heat of Supplementary Cementitious Materials in Hydration of Composite Cementitious Systems. The complete journal details need to be verified.
5. Bai, Y., Zhang, Y. And Li, J. (2023). Hydration Characteristics of Cementitious Composites with Calcium Silicate Slag Powder. *KSCE Journal of Civil Engineering* 27 2952–2963.
6. Jagličić, Z., Gavranović, S. And Gavranović, B. (2025). Simple: How One Might Analyze the Isothermal Calorimetry Data of Cement Hydration Quantitatively. *Journal of Thermal Analysis and Calorimetry* 150 5971–5980.
7. Shenhua, T., Liu, X. And Wang, Z. (2026). Hydration. Heat Prediction of Cement Containing Fly Ash, Ground Granulated Blast Furnace Slag Powder and Its Binary Blends. *Construction and Building Materials*, 528 146515.
8. Liu, D., Zhang, W., Tang, Y. And Jian Y. (2021). Prediction of Hydration Heat of Mass Concrete Based on the SVR Model. *IEEE Access*, 9 61431–61442.
9. Schmid, M., Pichler, C. And Lackner, R. (2019). Engineering Hydration Model of Ordinary Portland Cement Based on Heat Flow Calorimetry Data. *Journal of Thermal Analysis and Calorimetry* 138(3) 2283–2288.
10. Klemczak, B. And Batog, M. (2016). Heat of Hydration of Low-Clinker Cements. Part I: Semi-Adiabatic and Isothermal Tests at Temperature. *Journal of Thermal Analysis and Calorimetry* 123(2) 1351–1360.
11. Patil, A. (2015). Heat of Hydration, in the Placement of Mass Concrete. *International Journal of Engineering and Advanced Technology* 4(3) 1–4