TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
ENVIRONMENTAL ENGINEERING | ŚRODOWISKO

2-Ś/2015

BOGUSŁAW ZAJĄC*

LABORATORY TESTING OF TRANSIENT HEAT FLOW IN CONCRETE

BADANIE LABORATORYJNE NIEUSTALONEGO PRZEPŁYWU CIEPŁA W BETONIE

A b s t r a c t

The article is a description of the laboratory testing of transient heat flow in small-size samples of concrete and analysis of the impact of spacers made of a polyurethane material to the flow and the temperature distributions in the sample. This problem affects the working of concrete structural members exposed to a wide range of temperatures, and the thermal stresses generated in them, especially when the heat flow is analysed by a combination made of a flexible connection. The results can be used in issues related to the durability of concrete elements and their connections.

Keywords: transient heat flow, concrete, temperature

S t r e s z c z e n i e

Przedmiotem artykułu jest opis badania laboratoryjnego nieustalonego przepływu ciepła w małogabarytowych próbkach betonowych oraz analiza wpływu przekładki wykonanej z materiału poliuretanowego na przepływ i rozkłady temperatury w próbce. Zagadnienie to ma wpływ na pracę betonowych elementów konstrukcyjnych poddanych działaniu szerokiego zakresu temperatury oraz generowanych w nich naprężeń termicznych, zwłaszcza gdy analizowany jest przepływ ciepła przez ich połączenie wykonane ze złącza podatnego. Wyniki badań mogą być wykorzystane w zagadnieniach związanych z trwałością elementów betonowych oraz ich połączeń.

Słowa kluczowe: nieustalony przepływ ciepła, beton, temperatura

DOI: 10.4467/2353737XCT.15.236.4622

* PhD. Bogusław Zając, Institute of Structural Mechanics, Faculty of Civil Engineering, Cracow University of Technology.

Symbols

Φ – diameter
A – surface area
l – length
T – temperature
ρ – density
α – thermal expansion coefficient
E – Young's modulus

1. Introduction

Concrete structures under conditions of use and operation are exposed to the impact of variable temperatures. These changes in diurnal and annual cycles cause dimensional changes which in turn leads to stress. Additional components made of other materials with other heat conductivities and other thermal capacity significantly impact on the temperature distribution in the whole structure creating additional stresses. These changes, combined with the influence of moisture and other factors have an important influence on the durability and longevity of the structure. Thermal stresses in the boundary area depend on the coefficients of thermal expansion (CTE) and the Young modulus of adhesive and bonded materials. Knowledge of all the parameters affecting the mechanical properties at the interface between different materials, and the environmental impact [1–3] and soil on them, allows for efficient numerical analysis [4] and design [5]. Polyurethane materials were used in vibration damping systems [6], and repair of historic structure [7] and concrete elements.

One of the latest methods for repairing and strengthening of concrete structures (Fig. 1) is the Flexible Joint Method, developed at the Cracow University of Technology, and is based on polyurethane polymers used as adhesive layers in the bonding of different engineering materials and FRP composites to concrete and masonry substrates [8]. Analysis of the work of flexible connections in a wide temperature range is a further development of this method.

2. Experiments

2.1. Measurement of a transient heat flow in concrete

Two concrete slabs 100 × 100 × 500 mm were prepared for testing. Samples were made two years ago for a series of other endurance tests. As surplus to requirements they remained unused in the research and were kept in a dry warehouse. It was decided to use them in a study of temperature. To place the thermometers in the samples, holes were made with a depth of 50 mm and diameter of 6 mm along the axis (Fig. 2, cross-section α-α) with a distance of 30, 50, 75, 100, 150, 200, 250, 300 and 400 mm from the top of the sample. Next, holes with a depth of 20 [mm] were made at a distance of 100 and 200 mm (Fig. 2, cross-section β-β). Thermometers mounted in the cross section α-α were used to measure the

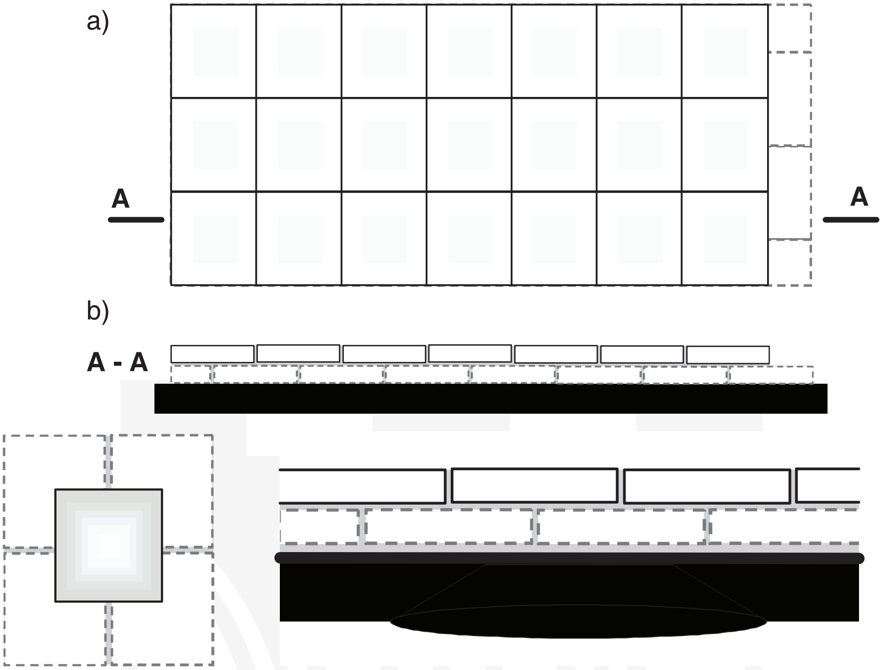
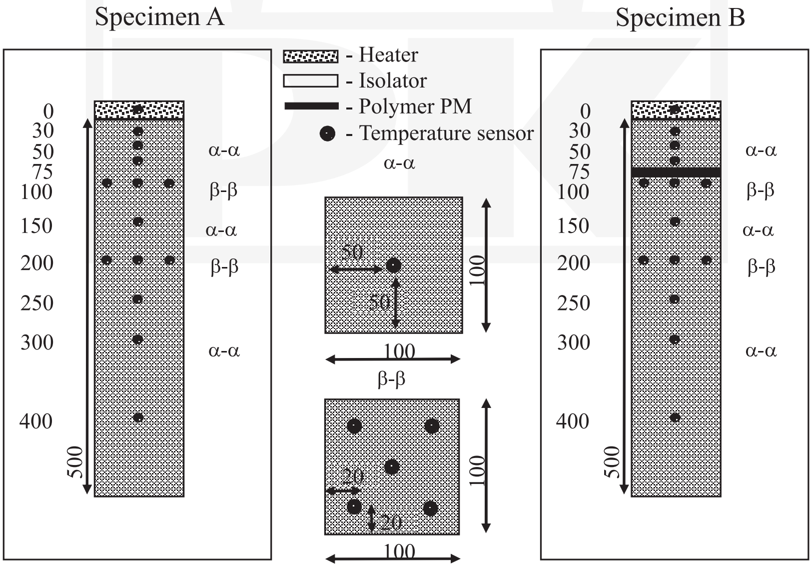


Fig. 1. Schematic diagram of laying concrete panels using the Flexible Joint Method – after [8]



All dimensions in milimeters

Fig. 2. Schematic arrangement of thermometers in the test samples, sample A – reference, sample B – with polymer PM layer

temperature distribution along the axis of the sample, and an additional four thermometers in cross section β-β were used to verify the differences in the temperature distribution in the analysed cross section. The first sample remained to test as a whole, while sample B was cut at a distance of 87.5 mm from the beginning. An intersection was introduced with a 10 mm layer of polyurethane PM. The two-component polyurethane PM was properly prepared in accordance with the recommendations of the manufacturer's data sheet. In liquid form, it was introduced into the void 10 mm between the transected pieces of concrete sample B. After hardening the whole sample received polymer spacer again. To determine the temperature distribution DS18B20 (Maxim Dallas Semiconductors) in TO-92 a package were used as thermometers. The DS18B20 digital thermometer provides Celsius temperature measurements with an operating temperature range of –55°C to +125°C and is accurate to ± 0.5°C over the range of –10°C to +85°C. Each DS18B20 has a unique 64-bit serial code, which allows one microprocessor to be used to control many DS18B20s distributed over a large area [9]. They were placed in the holes and covered with cotton isolation material. The temperature was measured continuously at two second intervals. As the heating element an aluminium plate with dimensions of 100 × 100 × 5 mm was used. Heat was generated by power transistors fixed to the aluminium plate controlled by a thermoregulation unit. The samples were placed in 100 mm thermal insulation made of polystyrene foam (Fig. 2).

2.2. Measurement of basic mechanical properties of polymer PM

The basic mechanical properties of the polyurethane PM in tension and compression were measured using a ZWICK 1450 universal testing machine and digital extensometer at room temperature according to EN ISO 527-1 [10] and are presented in Table 1.

Table 1

Basic mechanical properties of polyurethane PM determined during laboratory static tests at room temperature, according to ISO 527-1 [11]

Material	Young's modulus [MPa]	Tensile strength [MPa]	Elongation [%]	Coefficient of thermal expansion (CTE) [10^{-6}/°C]
PM	4	1.4	140	150

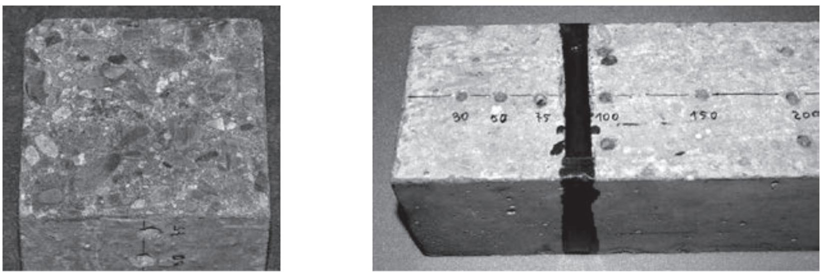


Fig. 3. Cross-section of the concrete sample and general view of sample B with the layer of polyurethane PM

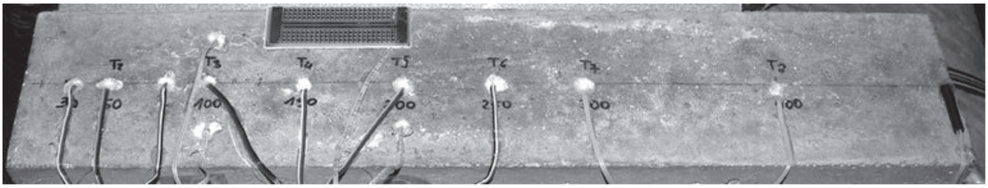


Fig. 4. General view of sample A

2.3. Heating testing program:

- Heating up to 40ºC and constant 40ºC for 1 hour,
- Heating up from 40º to 60ºC and constant 60ºC for 1 hour,
- Heating up from 60º to 80ºC and constant 80ºC for 1 hour,
- Cooling to start temperature approx. 16 hours.

3. Results

3.1. Temperature displacement

Figure 5 presents a diagram of the temperature distribution in sample A without the polymer spacer as a function of time. Fig. 6 presents the temperature distribution in sample B with the polymer spacer.

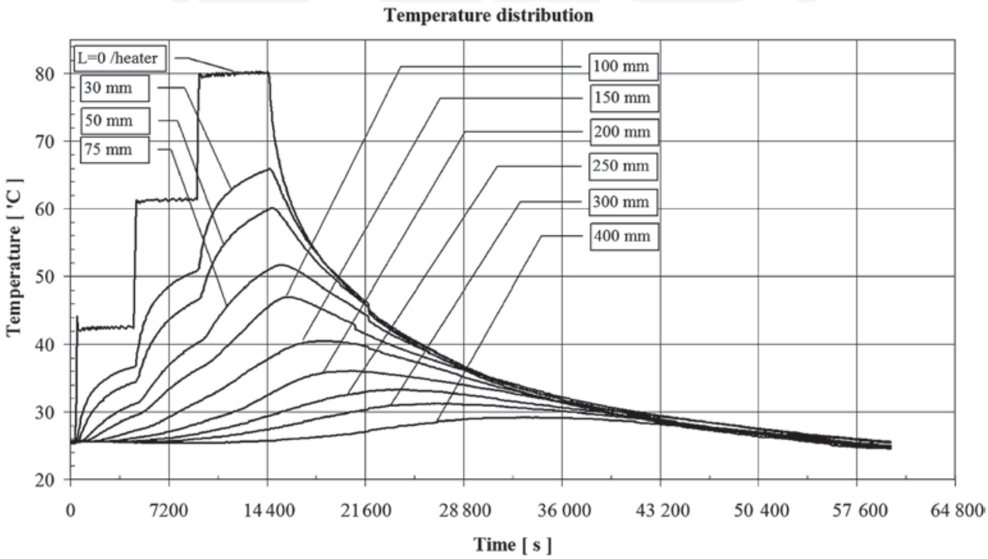


Fig. 5. The temperature distribution in concrete specimen A as a function of time

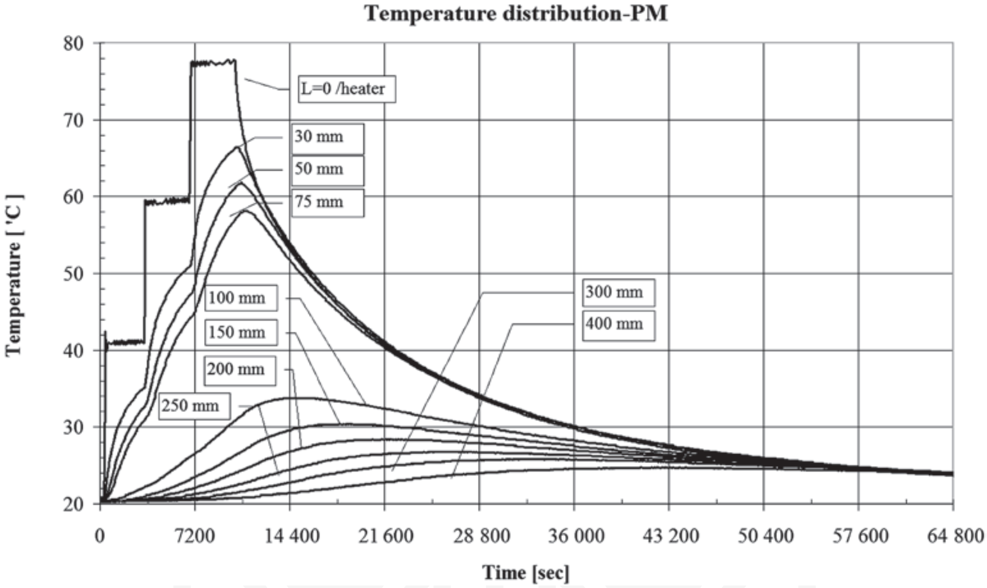


Fig. 6. The temperature distribution in concrete specimen B with polymer PM spacer as a function of time

For sample A the temperature distribution is related to the thermal conductivity and specific heat of the concrete. There is a time shift in the maximum temperature of the sample length. For a length of 400 mm, this is about 10 hours after the end of heating. The sample returns to the starting temperature after about 18 hours.

For sample B there is a significant effect of the polyurethane spacer on the distribution of the temperature in the length of sample. The upper section of sample B heats up more than the part beyond the polyurethane spacer. The polyurethane spacer of 10 [mm] caused a temperature difference of 25ºC due to its low thermal conductivity. The sample returns to the starting temperature after about 26 hours.

4. Conclusions

The study showed that:

- Research has shown uniform heat flow through the sample,
- A homogeneous temperature distribution within the cross section,
- Polyurethane PM spacer is a thermal transition barrier,
- Increased delay to achieve a maximum temperature of the sample length,
- Polyurethane PM spacer increases the temperature inertia of the system.

The numerical data of the laboratory testing was used for numerical modelling by Grodecki M. presented in another paper in this monograph.

Symbol: **PM** (and others, not mentioned in this paper) is a name of two component polyurethane applied in the Flexible Joint Method, developed at a Institute of Structural

Mechanics of the Cracow University of Technology. Various technologies using the Flexible Joint Method, applied in civil engineering, are protected by patents PL207028 (B1), PL214295 (B1) and PL384411 (A1).

References

[1] Dębska D., *Wpływ środowiska ciekłego na trwałość betonu cementowego z kruszywem dolomitowym*, Ochrona przed Korozją (Corrosion Protection), SIGMA-NOT, 56, 4, 2013, 134–143.

[2] Dębska D., *The impact of liquid environments containing* Mg^{2+} *and* SO_4^{2-} *ions on the durability of cement concrete with limestone aggregates*, Ochrona przed Korozją (Corrosion Protection), SIGMA-NOT, 57, 4, 2014, 124–128.

[3] Dębska D., *Wpływ siarczanu sodu i magnezu na trwałość betonów z kruszywem węglanowym*, Przegląd Budowlany, 5, 2014, 14–17.

[4] Truty A., *Sztywność gruntów w zakresie małych odkształceń. Aspekty modelowania numerycznego*, Czasopismo Techniczne z. 3-Ś/2008.

[5] Grodecki M., Truty A., Urbański A., *Modelowanie numeryczne ścianek szczelnych*. Kwartalnik AGH Górnictwo i Geoinżynieria, r. 27, z. 3–4, 2003, 297–303.

[6] Kwiecień A., Chełmecki J., Zając B., *The inertancy function in dynamic diagnosis of undamaged and damaged structures*, XXV Konf. Nauk. Metody Komputerowe w Projektowaniu i Analizie Konstrukcji Hydrotechnicznych, Korbielów 2013.

[7] Falborski T., Kwiecień A., Strankowski M., Piszczyk Ł., Jankowski R., *The influence of temperature on properties of the polymer flexible joint used for strengthening historical masonries,* Structural Analysis of Historical Constrictions – Jerzy Jasieńko (ed), DWE, Wrocław 2012, 816–822.

[8] Kwiecień A., *Polimerowe złącza podatne w konstrukcjach murowych i betonowych.* Monografia nr 414, Wydawnictwo Politechniki Krakowskiej, Seria Inżynieria Lądowa, Kraków 2012.

[9] Maxim Integrated Products, Inc.: DS18B20 Programmable Resolution 1-Wire Digital Thermometer. Maxim Integrated Products Inc. 2008 http://datasheets.maximintegrated.com/en/ds/DS18B20.pdf

[10] EN ISO 527-1 (1993) Plastics-determination of tensile properties – Part 1: General principles.