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Review

# Post-fire assessment of mechanical properties of concrete with the use of the impact-echo method

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## HIGHLIGHTS

- The impact-echo device was used to test concrete damage due to high temperature exposure.
- The resonance frequency of obtained signal decreases with higher thermal damage.
- The propagation velocity slows with higher level of thermal damage of concrete.
- The formulas for concrete mechanical properties evaluation by impact-echo method were established.

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## ABSTRACT

The paper presents the nature of elastic wave transition obtained in the time domain and the wave propagation velocity for the impact-echo method employed on the surface of concrete cubes $0.15 \times 0.15 \times 0.15\ m^3$ subjected to heating in the temperature range of 200–1000 °C. The relations between the characteristics of the obtained impact-echo signal and the mechanical properties of concrete subjected to high temperature were presented as regression curves. The paper proposes certain formulas to be employed while assessing fire-damaged concrete element. The results obtained on fire damaged concrete slab $1.2 \times 1.0 \times 0.3\ m^3$ indicate a strong relation between the impact-echo parameters and the mechanical properties of concrete.



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## 1. Introduction

Post-fire assessment of concrete quality is relevant due to the need to take a decision on the possibility of further operation of the facility after fire accident. During fire the temperature increases even to 1000–1100 °C [1]. Since concrete is a heterogeneous material, an increase of temperature influences both the aggregate and the cement paste. It is well known that during heating the aggregate grains expand in volume, while the cement paste experiences a considerable shrinkage [2]. The incompatibility of thermal strains between the cement paste and the aggregate leads to formation of micro-cracks in the interfacial transition zone and, as a result, to degradation of the mechanical and physical properties of the material (compressive strength, modulus of elasticity, density, etc.). A shrinkage of cement paste is associated with evaporation of water from pores during heating as well as with the process of dehydration of hydrates (i.e. C–S–H gel). Both these factors contribute to an increase of porosity in the cement matrix and thus result in decreasing the density of the material [3,4]. The transformations taking place in microstructure of concrete while exposing it to elevated temperature provide the input for employing certain non-destructive methods in the post-fire assessment of concrete structure.

Correctly performed material tests allow determination of the extent of damage as well as enable the determination of mechanical strength in the damaged material. The non-destructive testing methods (NDTs) are commonly used nowadays in order to complement the information obtained with the use of destructive methods. The review of testing methods used for fire damage assessment of concrete elements may be found in numerous publications [5–14].

One of the commonly used non-destructive testing method is the impact-echo (IE) test that employs elastic stress wave propagation through the material. The IE method is mostly used to detect flaws in concrete and to determine the thickness of concrete elements [8,15–21]. Recently, the IE method has been studied with a view to estimating its applicability in determination of the dynamic elastic modulus of concrete [22–25] as well as in post-fire assessment of concrete [26–28]. All those research projects proved that the impact-echo method is an effective technique for assessing the post-fire condition of material. However, there is very little available data on application of the impact-echo method in the post-fire assessment of concrete.

The goal of this study was to establish the differences in the nature of the signal (analysis of resonance frequency and velocity of elastic wave propagation), which were briefly described in [29] and further investigated in this paper, in the course of testing concrete exposed to high temperatures typical of fires. The experimental tests focused on the problem of post-fire assessment of concrete.

## 2. Testing method and material

### 2.1. The impact-echo method

The phenomenon of elastic wave propagation through medium is based on the differences in acoustic impedance exhibited in particular medium, where the acoustic impedance is defined as an ability to transfer the elastic wave from one medium to another. The wave propagates easily through the medium of a high acoustic impedance ($Z$ [kg m$^{-2}$ s$^{-1}$]), such as concrete, $Z = 7–10{\cdot}10^6$ kg m$^{-2}$ s$^{-1}$ [15], and is reflected fully or partially from the medium when its acoustic impedance is equal to or close to zero, e.g. air, $Z = 0.4$ kg m$^{-2}$ s$^{-1}$ [15]. The acoustic impedance of a particular concrete type is calculated by multiplying the elastic wave velocity in this concrete and its density. As presented in [7] and [30], both parameters are dependent on the temperature to which the concrete was exposed. It can be assumed that the decrease of both multiplying values observed in high temperature results in a reduction of acoustic impedance of concrete and changes the nature of elastic wave propagation through the material.

In compliance with standard ASTM C1383-04 [31], procedure B of testing with the use of impact-echo method was used in the presented research, Fig. 1a. In this procedure, a pulse is triggered on the surface of concrete in order to provide an elastic wave propagation through the material. While encountering a medium with much lower acoustic impedance (e.g. air, $Z = 0.4$ [kg m$^{-2}$ s$^{-1}$]), the wave is almost completely reflected and returns to the surface in the form of vibrations. The receiver located on the surface of the tested element captures and stores the vibration signal in the time domain. Using the Fast Fourier Transformation it is possible to obtain the resonance frequency $f$, and then the wave propagation velocity $V_p$, with the following formula (1):

$$V_p = 2Tf/\beta, \tag{1}$$

where $T$ is the thickness of the tested element, $f$ is resonant frequency, and $\beta$ is a shape factor equal to ratio between thickness and width of element [36].

The research was carried out with the use of the Vu-Con equipment, produced by the NDT James Instruments. A steel spherical impactor Ø 8 mm was used in the test. Fig. 1b. presents the complete measuring set up enabling all the tests presented in this paper.

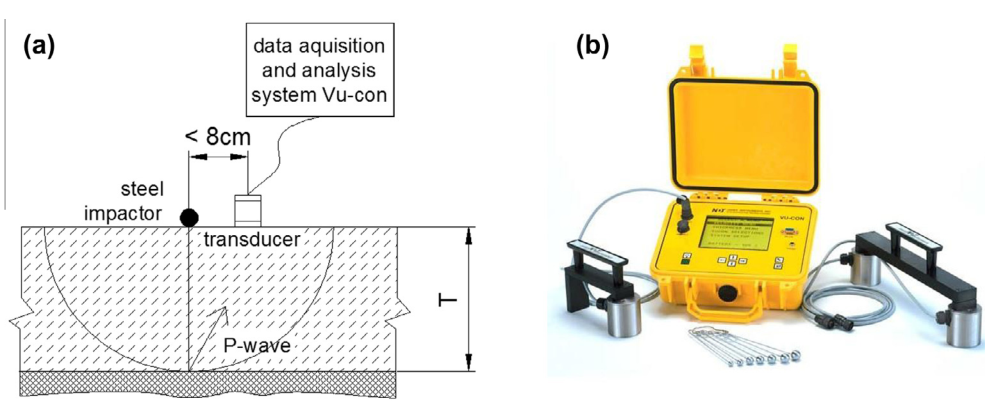


**Fig. 1.** (a) Diagram of procedure B of performing tests with the use of the impact-echo method; (b) the complete Vu-Con set for the impact-echo test [34].

**Table 1**
The mix composition of the tested concrete.

| Cement CEM I 42.5 R (kg/m$^3$) | Water (dm$^3$/m$^3$) | w/c ratio | Riverbed quartz sand 0–2 mm (kg/m$^3$) | Riverbed 2–8 mm (kg/m$^3$) | Riverbed 8–16 mm (kg/m$^3$) | Plasticizer (% mc) | Super-plasticizer (% mc) | Content of cement paste (dm$^3$/m$^3$) | Content of mortar (dm$^3$/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 482 | 289 | 0.60 | 663 | 610 | 558 | 0.90 | 2.10 | 300 | 550 |