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Effect of microwave heating damage on the electrical, thermal and mechanical properties of fibre-reinforced cement mortars

R. Borinaga-Treviño [a,*], A. Orbe [a], J. Norambuena-Contreras [b], J. Canales [a]

[a] Department of Mechanical Engineering, University of the Basque Country UPV/EHU, Plaza Ingeniero Torres Quevedo 1, 48013 Bilbao, Spain
[b] LabMAT, Department of Civil and Environmental Engineering, University of Bío-Bío, Concepción, Chile

HIGHLIGHTS

- Microwave heating harm on steel fibre-reinforced and plain mortars was measured.
- Microwave heating reduces flexural strength on non-reinforced mortars.
- Steel fibres reduced mechanical damage on reinforced mortars.
- Thermal and electrical tests did not detect the mechanical damage in any case.

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ABSTRACT

Nowadays, refurbishing of existing structures has gained interest in order to reduce both the construction materials used and the construction and demolition waste production. For that purpose, there are several methods for demolishing the damaged parts, but most of the alternatives involve high noise and dust production, which are in contraposition when structures are in urban areas. Among all the existing methods, this paper studies the possibility of using microwave heating as a demolition method, either by damaging the bulk material or the mortar to concrete interface. With that in mind, the effect of microwave heating time (range 120–600 s) on the physical, thermal, electrical, mechanical and bonding properties of steel fibre-reinforced and non-reinforced cement mortars was analysed. The aim of the paper is to establish possible correlations between the mentioned properties and the damage level caused by microwave heating. Although the results prove that pore pressure increment due to microwave heating can cause the reduction of flexural strength up to the rupture of the specimens, this fact cannot be extended to all the properties or mortar types. The fibre reinforcement plays a key role to restrain the damage. Thermal conductivity and electrical resistivity are obviously different in reinforced and non-reinforced mortars due to the inclusions of the metallic fibres. However, after undergoing microwave heating those properties were not noticeably altered nor follow a trend linked to the heating time. It is assumed that the water migration and evaporation processes are the main cause. Although the flexural strength reduction was gradual for non-reinforced mortars until total failure, the reinforced specimens only showed a 13% of reduction for the first 120 s, remaining almost constant afterwards. Although it was proved that the fibres increase the temperature on the specimen surface and its adhesion to the matrix is altered, their crack bridging effect overcomes further damage.

1. Introduction

In order to reduce the construction and material costs on the construction industry, reuse of old structures for new uses has gained interest. For that purpose, structures have to be restored and/or reinforced. For concrete structures, the existing concrete and reinforcement condition must be evaluated. If any of the materials involved does not fulfil the requirements imposed by the existing EN-1504 standards, they need to be replaced in order to guarantee a minimum quality of the refurbished structure. In any case, concrete must be removed either because of its own damage, or to reach and remove the corroded rebars. For the surface concrete removal, there are numerous alternatives [1–3], such as: (1) by impact: chiselling, hammering, by explosives; (2) by cutting it: drilling, sawing, by shear; (3) by bursting it: by explosives,

* Corresponding author.
E-mail address: roque.borinaga@ehu.eus (R. Borinaga-Treviño).

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Nomenclature

MW	*microwave*
EN	*European Standard*
R	*non-reinforced reference mortar*
S	*brass covered steel fibre reinforced mortar*
F_b	*maximum load registered during the contact bonding surface test* (N)
σ_b	*contact surface bonding stress* (MPa)
β	*bonded surface to load direction angle* (°)
ρ	*mortar dry apparent density* (kg/m^3)
ρ_w	*water density* (kg/m^3)
N	*mortar water accessible porosity* (–)
m_{sat}	*mortar water-saturated mass* (g)
m_{dry}	*mortar oven-dried mass* (g)
m_{dry}	*mortar mass submerged into water* (g)
λ	*mortar apparent thermal conductivity* (W/(m K))
α	*mortar apparent thermal diffusivity* (mm^2/s)
P_0	*heating rate used to determine thermal conductivity* (W)
a	*radius of the HOTDISK M1 sensor* (mm)
t	*time since the beginning of the thermal conductivity test* (s)
τ	*dimensionless time* (–)
ρ'	*electrical resistivity* (Ωm)
r	*electrical resistance* (Ω)
L	*length of the 40 × 40 × 160* mm^3 *prismatic specimen*
s	*cross section of the 40 × 40 × 160* mm^3 *prismatic specimen*

expansive cement and chemical agents, by hydraulic expanding devices; (4) abrading methods: sand blasting, shot blasting, milling; (5) low to high pressure hydro-demolition methods; and (6) thermal methods: flame lance, laser beam, electron beam, arc heating, high-voltage pulses, microwave heating, induction heating, microwave-drilling.

Usually, refurbishments are to be done in urban areas, where noise and vibrations are a real concern and thus must be minimised. In that case, expansive methods, hydro-demolition and thermal methods have proven to be successful. Nevertheless, most of the expansive methods require drilling, which still causes disturbances and the hydro-demolition requires water, which is a valuable resource that is not always available in the amount required [3].

Among the existing thermal methods, this paper focuses on the use of microwave heating to locally damage concrete. In that way, Ong and Akbarnezhad [3] and Makul et al. [4] summarised the different uses of microwave energy on cement-based materials. Microwaves have been studied as a non-destructive method for evaluating damage on concrete and reinforcing bars [5–10]. Different studies proved that microwaves could be used to improve the early strength of mortars by accelerating its hardening process [11–19], but they decreased the 28 day compressive strength of concretes. However, microwaves have also been used to remove contaminated superficial concrete [3]. Jerby et al. [20] used high intensity microwave heating to locally melt concrete, providing a non-abrading drilling method. Other authors [21–23] have also used microwave energy to eliminate cement paste from the crushed construction and demolition wastes in order to improve the quality of the aggregates enabling their use in new concrete manufacturing.

Once the damaged superficial concrete is removed, old concrete is replaced by specially designed mixes for repairing structures. The main goal is to protect the old and new reinforcement while contributing its compressive strength on the repaired area. Thus, steel fibre-reinforced mortars and concretes are widely used to repair structures and industrial pavements, but also in the concrete precast industry due to their higher toughness and durability [24]. Particularly, fibre-reinforced cementitious materials are used on pavements, tunnel dowels, railway precast slab tracks and so on. Hence, the use of fibre-reinforced composites is increasing, but its demolition could be more problematic precisely due to its higher impact resistance. However, there is scarce literature related to the demolition of fibre-reinforced concretes.

This paper aims to evaluate the effect of damage caused by microwave heating on the electrical, thermal and mechanical properties of fibre-reinforced cement mortars. For that purpose, a commercial floor slab repairing mortar was used with, and without, steel fibre-reinforcement. Thermal, electrical, mechanical and bonding properties of the cement mortar specimens were evaluated for different microwave heating times in order to determine the damage caused by the heating procedure.

2. Materials and methods

This section describes the materials and experimental programme followed in this study. Fig. 1 shows the different test methods used on the cement mortar specimens with, and without, steel fibres.

2.1. materials and mix proportions

The Mapei Planitop HPC mortar used in this study is a class R4 repair mortar, which is compliant with EN 1504-3 [25] and EN 1504-6 [26] standards. It consists of a brass-covered steel fibre-reinforced mortar specially designed to repair damaged concrete pavements and structures without the need for reinforcing steel

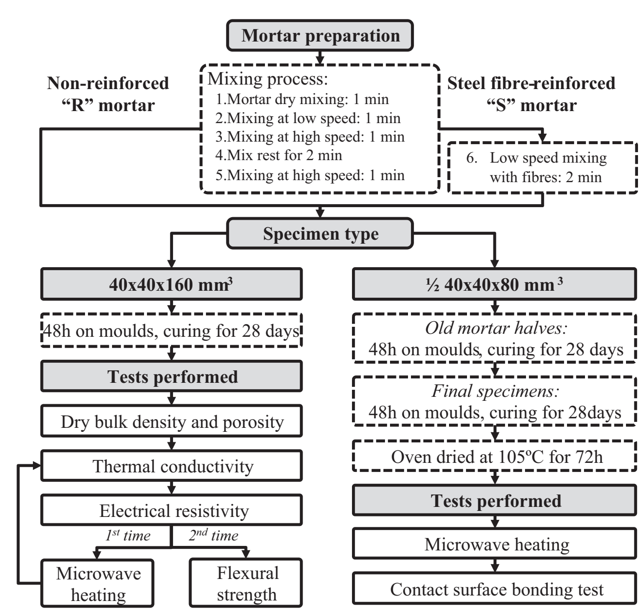

Fig. 1. Experimental programme followed in this study.