Microwave-Assisted Removal of Tiles from Concrete Floors and Walls

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ABSTRACT

The renovation of interior finishes of residential buildings usually starts with a soft strip stage involving the removal of the existing fittings, furniture, and finishes, especially floor and wall finishes. Tiles are among the most common types of floor and wall surface finishes used. Such existing finishes are required to be removed before new ones are installed in their place. Removal of the floor and wall finishes is normally carried out through mechanical hacking and other similar demolition techniques which are accompanied usually by noise and dust generation, disruptive to neighbouring occupants and may even be hazardous to the health of affected persons. The present work addresses the need for methods that are able to remove the tiles attached to concrete floors and walls with minimal noise and dust generation. The present study proposes a method for the removal of tiles from the floors and/or walls in the buildings, by exposing the tile and its interface with the floor/wall to microwaves and thereby generating a localized field of high thermal stresses to separate the tile from the floor/wall. Numerical simulation and preliminary experimental tests results verify the efficiency of the proposed method.

Keywords – Microwave Removal, Concrete, Tiles

1 Introduction

The renovation of the interior finishes of residential buildings starts with a soft strip stage involving the removal of the existing fittings, furniture, and finishes, especially floor and wall finishes. Ceramic and stone tiles are among the most common types of floor and wall surface finishes used. Such existing finishes are required to be removed before new ones are installed in their place. This is especially so if building regulations stipulate against indiscriminate increase in floor loading arising from unremoved old floor and wall finishes. Besides the actual tiles themselves, levelling grout and adhesives have also to be similarly removed when renovation work are carried out. While dismantling of existing equipment and furniture is usually easy, removal of the floor and wall finishes is normally carried out through mechanical hacking and other similar demolition techniques. The latter is accompanied usually by noise and dust generation, disruptive to neighbouring occupants and may even be hazardous to the health of affected persons.

Minimizing the noise and dust generated during finish removal requires minimizing the mechanical hacking and other such actions involved in the process. A number of non-mechanical techniques for the removal and demolition of dielectric materials such as ceramics have been proposed in available literature. These include sponge blasting, CO_2 blasting (dry ice blasting), electro-Hydraulic scabbing, shot blasting, soda blasting and laser ablation [1]. Among such techniques, microwave-heating based selective demolition techniques seem promising for large scale on-site applications due to the availability of relatively cheap microwave sources commercially, localization of damage to only the exposed zone, and control over depth of demolition and duration of demolition through regulation of microwave frequency and power [2, 3].

Microwaves have been used to develop selective demolition tools for applications in the decontamination of concrete, drilling into concrete, and demolition of hard rocks.[4-6] In such applications, the rapid attenuation in microwave power at higher ISM (Industrial, Scientific and Medical) frequencies with distance from the concrete surface is used to generate a field of high thermal stresses and pore pressure within a thin layer underlying the surface of the concrete being treated, leading to the delamination of the surface layer. ISM frequencies refer to a frequency band allocated officially to microwave heating applications to avoid interference with communication devices. Among the ISM frequencies, 915 MHz, 2.45 GHz, 10.6 GHz and 18 GHz, with wavelengths from 1 to 10 cm, are the most commonly used frequencies for microwave heating applications.[7]

Microwave selective demolition can considerably improve the efficiency and selectivity of the demolition process and reduce the associated noise and dust generated. However, previous applications of microwave selective demolition have been limited to demolition of hard materials such as concrete and hard rock. This paper proposes the use of microwaves for detaching a surface layer of wall/floor finish that is bonded to the concrete substrate with relatively less bond strength. The bond strength between tile and concrete is typically about 1 MPa which is considerably less than tensile strength of a typical concrete which varies from 2 to 4 MPa (for concrete with compressive strength of 30 to 70 MPa).[8] Therefore, the energy needed to overcome the relatively weaker bond between the finishes and the concrete substrate is expected to be considerably less than that needed to break up the concrete substrate core compared to other microwave based methods used in demolition works. The results of a series of preliminary experiments as well as the results of a numerical study are presented to demonstrate the effectiveness of the proposed method. In addition, the main components of a typical microwave-assisted tile removal system are described.

2 Microwave-Removal System

One possible configuration of the proposed microwave-assisted tile remover is shown in Figure 1. A basic microwave-assisted tile finish removal system should include a microwave generator, a microwave attenuator system, a cooling system, a microwave applicator and a control system. The microwave generator comprises a power supply and microwave source (e.g. a magnetron). The power supply provides the considerably high voltage required by the magnetron to produce the microwaves. Typically microwave generator systems produce microwaves at a specific microwave frequency and at range of variable powers. The power is then transferred through a set of waveguides to the microwave applicator. An attenuator is generally needed to prevent potential damage to active microwave components due to reflected waves.

The applicator design plays an important role in ensuring process efficiency. The main components of the applicator are shown in Figure 2. A thermal camera is attached to the applicator for real-time monitoring of the surface temperature. This is needed to regulate the speed of travel of the equipment. Leakage monitoring is performed using an RF leakage meter and automatic shutdown features are incorporated to stop operations immediately in case of excessive leakage. It is proposed to equip the applicator with a specially designed water spray system that is activated to absorb microwaves in the event of excessive leakage. An attached vacuum system will be used to minimize the risk of microwave leakage through reducing the gap between the applicator's gaskets and the floor/wall surface being treated by generating a negative pressure in the vicinity of the applicator. The proposed frequency range for the applicator is 2.45GHz to 18 GHz. The removal rate is expected to increase considerably at higher frequencies. The higher frequency microwave sources are generally more expensive and not commonly available for off-the-shelf purchase. 2.45 GHz generators are considerably cheaper due to mass production for use in domestic microwave ovens. The recommended operation power is between 6 to 10 kW.

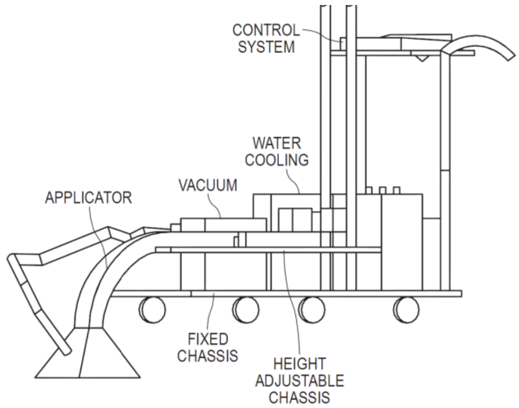

Figure 1. Configuration of the proposed microwave-assisted tile removal equipment

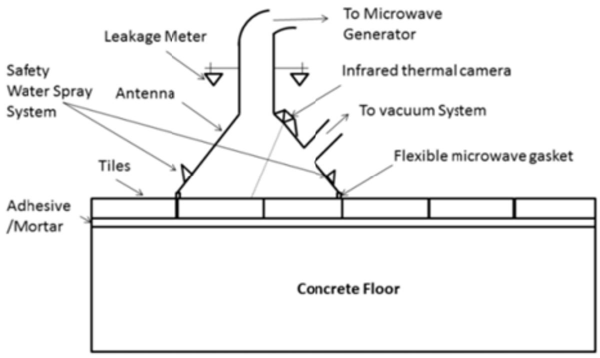

Figure 2. Applicator design for a typical microwave-assisted concrete finish remover

For illustration, the recommended operating procedure for the removal of ceramic tiles from concrete floors and walls using the microwave-assisted concrete finish remover is shown in Figure 3. It is recommended that the surface of the concrete/tiles be drenched with water prior the start of the removal process. The increase in the water content of the tile and adhesives tends to increase the dissipation of the microwave power within the surface, comprising the heated zone, leading to a more localized heating and increased efficiency of the removal process. As shown in Figure 3, the microwave removal process starts with selection of the type of tile finish and adhesive used, from a predefined list of materials with known electromagnetic and mechanical properties, stored in the material database of the control system. Based on the type of the material, the control system performs the preliminary simulation analyses to estimate the optimal microwave frequency and power. When the equipment settings are adjusted as recommended, the applicator is positioned above the wall/floor surface to be treated. A vacuum system attached to the applicator is activated to develop negative pressure, thereby ensuring a tight seal at the applicator gaskets and the portion of floor/wall surface being treated. Microwave heating is then started and the temperature developed on the concrete surface is continuously monitored using an infrared thermal camera attached to the applicator. In addition, as shown in Figure 2, a leakage meter attached to the applicator is used to continuously check for microwave leakage to ensure safety during operations. In the event of excessive microwave leakage, the control system stops operation, activating a water spray safety system to reduce microwave leakage to allowable limits. Under the IEC standard, which is applicable to equipment operating in the frequency range of 300 MHz to 300 GHz, power density is measured at least 5 cm from any accessible location on the equipment and should be limited to 5 mW/cm^2 during "normal" operations and 10 mW/cm^2 during abnormal operations.

3 Working Principles and Numerical Simulation

Concrete surface finishes and the levelling grout/adhesives used are all dielectric materials and thus are heated up when exposed to microwaves. Unlike conventional heating, microwaves heat the materials selectively based on their dielectric properties. The amount of the microwave energy dissipated through dielectric loss and the pattern of heating (determined by penetration depth of microwaves) varies significantly with the electromagnetic properties of the material being heated and the microwave frequency. The property which describes the behaviour of a dielectric under the influence of a high frequency field is the complex relative permittivity which is an indicator of the material's ability to polarize in response to the field present compared to when in a free space. Complex permittivity is defined as:

$$\varepsilon_r = \varepsilon_r' - i\varepsilon_r'' \qquad \text{Equation (1)}$$

where, ε_r is the relative permittivity, ε_r' is the dielectric constant and ε_r'' is the loss factor of the material. The dielectric constant is a measure of how much energy from an external electric field is stored in a material and the loss factor is a measure of how dissipative or lossy a material is to an external field.[9] A number of fairly straight forward techniques are available to measure the

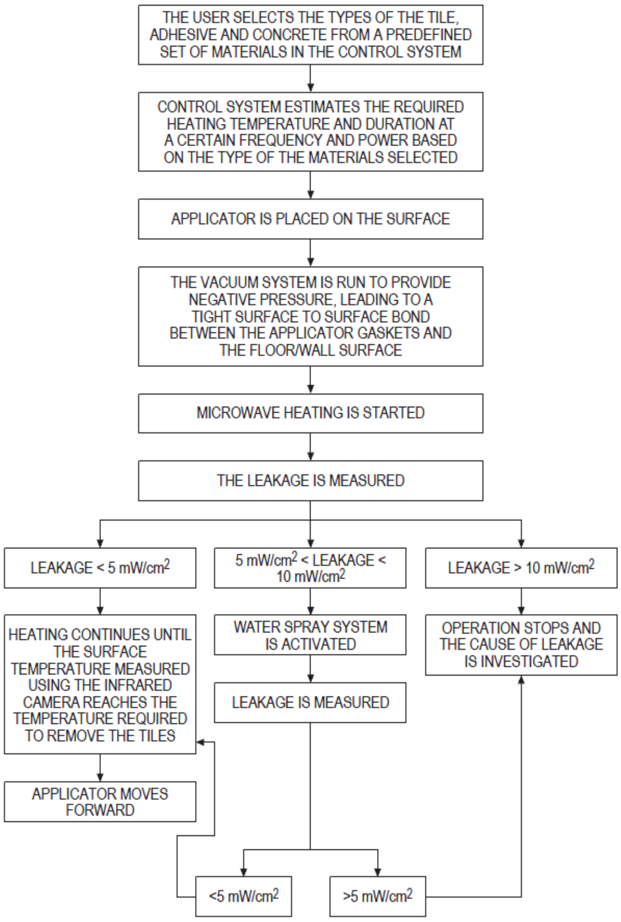

Figure 3. A method (framework) of using the proposed mobile microwave-assisted concrete finish remover

dielectric constant and loss of materials.[9] The power dissipated in heating the microwave exposed material at a given exposure time can be estimated using the loss factor and electric field intensity based on Equation 2.

$$P^M(r) = -Re(\nabla . S) = \frac{1}{2}\omega\varepsilon_0\varepsilon_r''|E|^2 \qquad \text{Equation (2)}$$

Here, E is the electric field intensity and ε_0 is the permittivity of the free space (= 8.85418782 × 10^{-12}).

Equation 2 shows that the radiative microwave power dissipated per unit volume is directly proportional to the square of the norm of the electric field intensity. The electric field intensity in a microwave heated material can be estimated using Maxwell's equations. Maxwell's equations express the relationships between the fundamental electromagnetic quantities including the electric field intensity E, the electric displacement or electric flux density D, the magnetic field intensity H, the magnetic flux density B, the current density J and the electric charge density ρ_q. The electric field in particular is an important parameter in microwave heating because it is the main source of energy transfer to the material. Maxwell's equations can be expressed as:

$$\nabla \times H = J + \frac{\partial D}{\partial t} \qquad \text{Equation (3)}$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad \text{Equation (4)}$$

$$\nabla . D = \rho_q \qquad \text{Equation (5)}$$

$$\nabla . B = 0 \qquad \text{Equation (6)}$$

Equations 3 and 4 are also referred to as Maxwell-Ampere's law and Faraday's law, respectively. The last two equations, on the other hand, are two forms of Gauss' law, the electric and magnetic form, respectively. Another fundamental equation required to understand the relationship between the fundamental electromagnetic field parameters is the equation of continuity, which can be expressed as follows:

$$\nabla . J = \frac{\partial \rho_q}{\partial t} \qquad \text{Equation (7)}$$

Solving the above series of equations requires considering the constitutive relations which describe the macroscopic electromagnetic properties of the medium. These relationships follow:

$$D = \varepsilon E = \varepsilon_r \varepsilon_0 E \qquad \text{Equation (8)}$$

$$B = \mu H = \mu_r \mu_0 H \qquad \text{Equation (9)}$$

$$J = \sigma E \qquad \text{Equation (10)}$$

Here, ε is the permittivity of the medium, ε_r is the permittivity of medium relative to vacuum, ε_0 is the permittivity of vacuum, μ is the permeability of the medium, μ_r is the permeability of the medium relative to vacuum, μ_0 is the permeability of vacuum, and σ the electrical conductivity of the medium. By solving the above set of equations, subject to the appropriate boundary conditions, the electric and magnetic parameters associated with any electromagnetic field can be calculated.

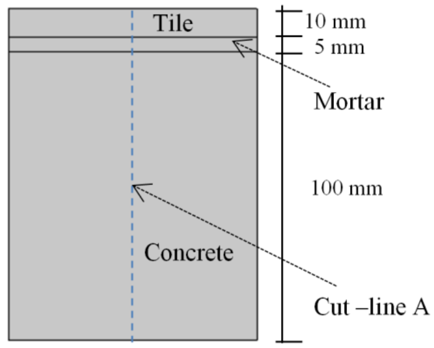

Figure 4.Geometry of the numerical simulation model.

Table. 1 Dielectric and thermal properties assumed for numerical simulation

	Concrete/Mortar	Porcelain Tiles
Dielectric Constant	8.1	5.5
Dielectric Loss	0.7505	0.165
Electrical Conductivity (S/m)	0.086	0.02246
Thermal Conductivity W/(m.K)	1.5	1.5
Heat Capacity (J/kg.K)	971	1085

In this study, to investigate the phenomenon leading to the separation of tiles attached to a concrete surface, these equations were solved using Comsol Multi-physics software after being coupled with the heat transfer equations required to estimate the temperature rise due to microwave heating [10, 11]. The geometry of the model is shown in Figure 4. As shown, the model includes a 5 mm thick layer of glazed ceramic tile attached to a concrete floor using a 5 mm layer of cementitious binder. The dielectric and thermal properties of the different materials are summarized in Table 1. To investigate the effects of microwave power, two different microwave generator powers of 6 kW and 10KW were considered. The model was solved to investigate the rise in the internal temperature and the resulting temperature gradient.

4 Preliminary Experiments

To verify the capability of the proposed microwave-assisted technique to remove tiles attached to the surface of concrete, 10 different specimens were prepared by laying 10 mm thick glazed ceramic tiles on concrete using a cementitious mix of Sydney sand, Portland cement and water. The thickness of the cementitious mortar adhesive was approximately 5 mm. The specimens were left in the laboratory for about 40 days prior to testing to ensure that the tile-concrete interface reaches its full bond strength. All specimens were soaked in water for 10 minutes before heating to simulate the effect of drenching with water prior to microwave heating. All faces of the concrete specimens, except for the tiled surface, were covered by a layer of aluminium foil before placing in the microwave oven. This ensures that microwave heating occurs only from the top tiled surface. The specimens were heated individually in a heavy duty commercial microwave oven operating at 2.45 GHz frequency at a maximum microwave power of 1.9 kW. The microwave heating duration required to separate/break the tiles was recorded.

5 Results and Discussion

The results of the preliminary experiments conducted confirmed that the proposed method is effective in removing the tiles from the surface of concrete with minimal noise and dust generation. In all the specimens tested, the tiles were detached after less than four minutes of heating. The average heating duration required to detach the glazed ceramic tiles at 1.9 kW microwave power and 2.45 GHz microwave frequency was recorded as 194 seconds with a standard deviation of 34.8 seconds. Out of the ten specimens tested, seven had the tiles detached cleanly without any visible damage to the tiles and three showed fracture of the fully detached tiles.

The effectiveness of the proposed microwave assisted technique was also confirmed by the results of numerical analysis. Figures 5(a) and 6(a) show the temperature profile of a specimen heated for 120 seconds using 6 kW and 10 kW microwave generators, respectively. As can be seen, 2 minutes of microwave heating may result in a significant rise in the surface temperature especially in the mortar layer as well as the upper surface layer of the concrete substrate. However, the key to the success of the proposed method is the development of localized high temperature gradients and thereby localized differential thermal stresses at the interface between mortar adhesive and tile.

The temperature gradient profile of the specimens heated at 6 kW and 10 kW for two minutes is shown in Figures 5(a) and 6(b), respectively. As can be seen, the temperature gradient reached a maximum at the interface between the cementitious mortar adhesive and the tile, leading to development of considerable thermal stress at this location. The differential thermal stresses resulting from such high thermal gradients can easily overcome the relatively weak bond between the mortar adhesive and the tile, leading to separation of tile with minimal damage, noise and dust. As shown in Figure 5(c) and 6(c), such high temperature gradients tend to be confined mainly to the interface between concrete and tile. Figure 6(c) shows that after 2 minutes of heating at 10 kW, the temperature gradients and thus resulting thermal stresses developed at the tile/mortar interface may be up to three times higher than those reached in the underlying concrete. Therefore, the thermal stresses developed in the underlying concrete substrate at the time of tile detachment are expected to be much lower than the tensile strength of the concrete which is typically at least twice that of the bond strength between tile and concrete. As a result, the proposed process is unlikely to lead to cracking of the underlying concrete substrate adjacent to the tile.

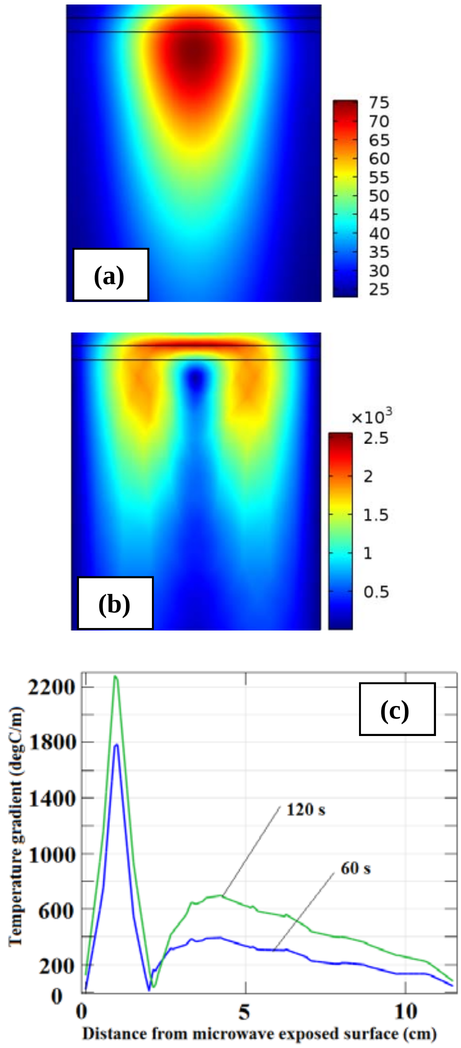

Figure 5. (a) temperature profile, (b) temperature gradient profile and (c) temperature gradient along cut-line A (as shown in Figure 4); of specimens heated for 120 seconds at 2.45 GHz frequency and 6kW incident power.

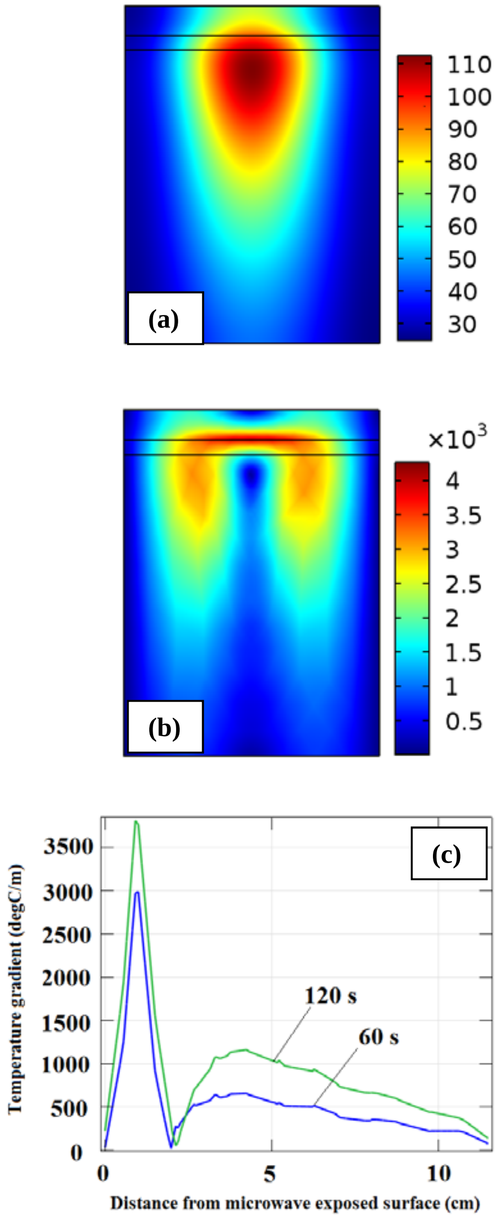

Figure 6. (a) temperature profile, (b) temperature gradient profile and (c) temperature gradient along cut-line A (as shown in Figure 4); of specimens heated for 120 seconds at 2.45 GHz frequency and 10 kW incident power.

6 Conclusions

A novel microwave-assisted technique for the removal of tiles attached to a concrete surface by a cementitious mortar adhesive was proposed in this paper. The proposed method takes advantage of the capability of microwaves to heat dielectric materials selectively leading to the development of significant temperature gradients and thus thermal stresses at the interface between tiles and concrete substrate, resulting in the detachment of the tiles with minimal noise and dust generation. The effectiveness of the proposed method was confirmed by the results of experimental and numerical studies conducted. Future research will involve simulation of the thermal stresses developed and investigating the effects of microwave frequency on the efficiency of the process. Further experiments should be conducted to investigate the effects of variations arising from the type of tiles, type of adhesive used, and relevant concrete properties on the effectiveness of the proposed method.

7 References

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