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Acoustic and Thermal Isolation Performance Comparison between Recycled and Ceramic Roof Tiles Using Digital Holographic Interferometry

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Abstract**—** Recycling, as part of any sustainable environment, is continuously evolving and impacting on new materials in manufacturing. One example of this is the recycled solid waste of Tetra Pak ™ packaging, which is a highly pollutant waste as it is not biodegradable since it is manufactured with different materials. The Tetra Pak ™ container consists of thermally joined layers of paper, aluminum and polyethylene. Once disposed, this packaging is recycled by completely separating the paperboard from the rest of the materials. The aluminum and the polyethylene remain together and are used to create the poly-aluminum, which is widely used to manufacture roof tiles. These recycled tiles have different thermal and acoustic properties compared with traditional manufactured ceramic and cement tiles. In this work, we compare a group of tiles using nondestructive optical testing to measure the superficial micro deformations of the tiles under well controlled experiments. The results of the acoustic and thermal tests show remarkable differences between the recycled tile and the traditional ones. These results help to determine which tile could be better suited to the specific environmental conditions in countries where extreme climates, ranging from tropical, desert-like, to very cold are experienced throughout the year.

Keywords**—**Digital holographic interferometry, nondestructive testing, recycled, sustainable, thermal study.

I. INTRODUCTION

THE reuse of domestic waste has increased as recycling technologies developed new processes in recent years. Recycling is an important part for any sustainable society since it helps to preserve the available natural resources and reduces pollution. The latter encourages the use of science and technology to carry out research with the mission to protect the human health and safeguard the natural environment. Recycling some materials has a positive impact by saving energy and avoiding waste accumulation, such as the discarded Tetra Pak containers. The Tetra Pak is a high-tech container designed to keep liquids fresh and airtight for long periods of time. This container is mainly composed of three layers consisting of paperboard (75%), polyethylene (20%) and aluminum (5%). Since it is not biodegradable a special process is required to dispose it. The Tetra Pak is constructed from 100% recyclable material, and there are several methods to achieve this where the polyethylene and the aluminum are retained. This mix material is also called poly-aluminum, which can be used for building construction, furniture manufacturing, truck bed boxes and roof tiles.

Interest in this material has grown for its potential to be a predominant construction material in the future. One particular case is observed in the manufacturing of roof tile panels for large exterior areas of buildings, the choice of which also impacts the building's internal temperature. For this reason, the right choice of roofing material is essential to create an energy efficient home. A study in the field of construction was concerned with the thermal and acoustic properties of the materials to be used [1]. The roof tiles acoustic insulation measures their ability to reduce transmitted sound from an external source through the roofing material to the interior living areas. Generally, roof tiles are the least concerned noise admission route; however, in locations subject to aircraft traffic, busy roads, railways and windy regions they become an important element to consider [2].

The key to maintaining a comfortable temperature inside a building is to reduce heat transfer with its surroundings during cold days, and reduce the heat transfer into the building on hot days. Heat is transmitted through confined air spaces by radiation, convection and conduction. Conduction is perhaps the most important source of heat transfer: it is the direct flow of heat over a material (physical contact) generating molecular motion, where molecules transfer their energy to adjacent molecules and the temperature is increased [3]. In this work an optical technique is proposed to analyze the effective thermal transfer of several roof tiles. Digital holographic interferometry (DHI) is an optical technique that has been widely used to study vibrations [4] and fast and non-repeatable deformations [5], along with many other applications. Some of the advantages to using this technique include: high sensitivity, high resolution and full field measurements [6], [7] avoiding any damage on the sample [8], even in an unrepeatable experiment [9]-[11]. DHI measures displacement maps that can be used to determine mechanical and thermal properties such as the Young's modulus, the Poisson ratio and the thermal expansion coefficient [12]. Thermal expansion could be measured by any strain sensor which may be accurate in the required range of temperatures [13], [14]. As proof of the principle, three roof tiles are analyzed: recycled Tetra Pak, ceramic and fiber-cement, under thermal and acoustic tests. Information on how the sample is fixed and tested, the

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interferometer parameters and a description of the recording and processing is presented in Section III. The results obtained for each tile are presented, described and compared in Section IV.

II. METHOD

DHI is a two exposure method where two image holograms are recorded before and after an object's deformation.

Each image hologram on the camera sensor includes the interference pattern from a reference and an object beam [15] expressed by:

$$I(x,y)=\left|R(x,y)+O(x,y)\right|^2 \tag{1}$$

where, R and O are the reference and the object beam, respectively, representing complex amplitudes, viz.,

$$O(x,y)=o(x,y)\,exp\left[i\varphi(x,y)\right] \tag{2}$$

$$R(x,y)=r(x,y)\,exp\left[-2\pi i(f_x x+f_y y)\right] \tag{3}$$

f is a spatial frequency in the x and y directions, while φ is the optical phase term representing the light scattered from the object's surface. Substituting (2) and (3) into (1) we have:

$$\begin{aligned} I(x,y)&=a(x,y)+c(x,y)\,exp\left[2\pi i(f_x x+f_y y)\right]+\\ &+c^*(x,y)\,exp\left[-2\pi i(f_x x+f_y y)\right] \end{aligned} \tag{4}$$

where * denotes the complex conjugate term, $a(x,y)=o^2(x,y)+r^2(x,y)$ and $c(x,y)=o(x,y)r(x,y)e^{i\varphi(x,y)}$ [16]. By means of the Fourier transform, equation four could be expressed as:

$$FT\{I\}=A(f_x+f_y)+C(f-f_x,f-f_y)+C^*(f-f_x,f-f_y) \tag{5}$$

A band pass filter is used to filter the lateral spectral lobe C and then an inverse Fourier transform is applied to retrieve the relative optical phase $\Delta\varphi$.

III. EXPERIMENTAL PROCEDURE

The experimental setup used is schematically shown in Fig. 1, where λ is a laser at 532 nm used as the illumination source. The laser is divided into the object and reference beams using a beam splitter (BS) 20:80 (R: T). The object beam is directed by mirrors M1 and M2 and then expanded to illuminate the roof tile under study. The reference beam travels through a single mode optical fiber (OF), which is combined with the object's backscattering with a beam combiner (BC) in front of the camera. The camera is PCO Edge with 2560×2160 pixels at 12 bits.

The thermal and acoustic responses under controlled tests for the three roof tiles were analyzed. The tiles were analyzed with the optical system one at a time under the same experimental conditions by means of a homemade thermo-acoustic insulating chamber. The chamber has the function of isolating heat and sound sources during each test. In all cases the field of view (FOV) of the optical system is focused on the central region of the roof tiles: 240 × 210 mm. The chamber is situated behind the observable area of the tile (external side) during the tests. In this way, the DHI system registers the deformation on the internal side of the tiles.

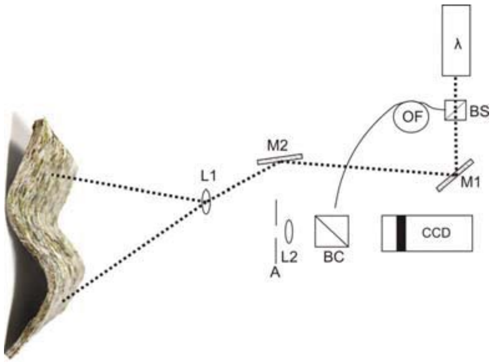

Fig. 1 Schematic view of the optical set up. L1 is 10X microscope objective and L2 has a focal length of 75mm

The first test analyzes the thermal behavior in a controlled situation using an infrared bulb of 250 W which induces a controlled temperature variation from 25° to 55° for each tile. This temperature range was selected considering an average temperature of an average day's solar radiation from 8:00 to 15:00 hrs. [17]. A temperature control is performed with a sensor and a microprocessor which sends the temperature readings into a personal computer.

The second test consists in the analysis of the acoustic behavior of the tiles by applying a sound wave through a speaker. The selected frequencies were below the human audible range, which typically ranges from 20 to 20,000 Hertz. These waves with very low frequencies are called infrasound and are produced by a variety of natural and manmade sources such as: volcano eruptions, earthquakes, meteors, storms, auroras; and nuclear explosions, mining and large chemical explosions, and aircraft takeoffs, respectively. Besides, low frequencies are mainly associated with mechanical variations, which is a subject of interest for these kinds of samples.

IV. RESULTS

Fig. 2 shows the temperature range registered during the heating time for each roof tile obtained with the sensor. From this figure, it is possible to observe that the ceramic tile is heated more rapidly.

The optical phase is presented as a wrapped phase map in Fig. 3, which shows the results for the thermal test when the temperature is 26°C for all tiles. From Fig. 3, it is possible to observe a different behavior for each tile. These images show the resulting displacement for each tile when the temperature changes from 25 to 26°C. As can be appreciated, the Tetra Pak tile shows more fringes, which in terms of optical metrology means greater displacement.

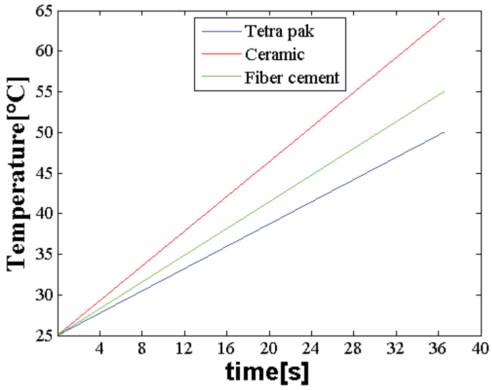

Fig. 2 Roof tiles temperature register

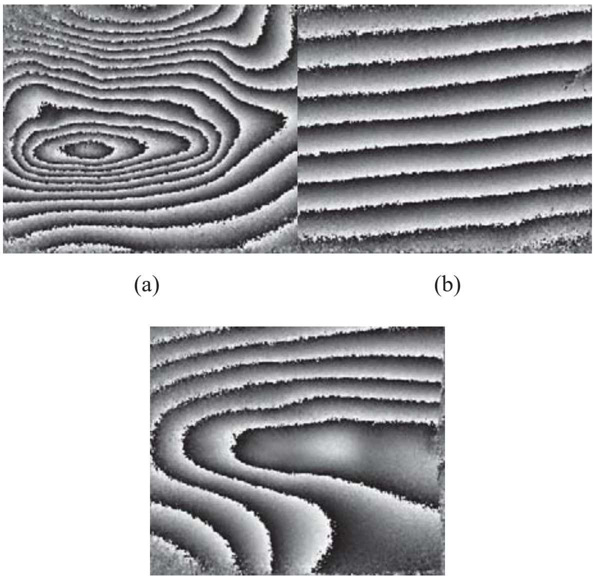
(a)
(b)
(c)

Fig. 3 Wrapped phase maps observed for (a) Tetra Pak (a) ceramic (a) fiber cement tiles at 26°C

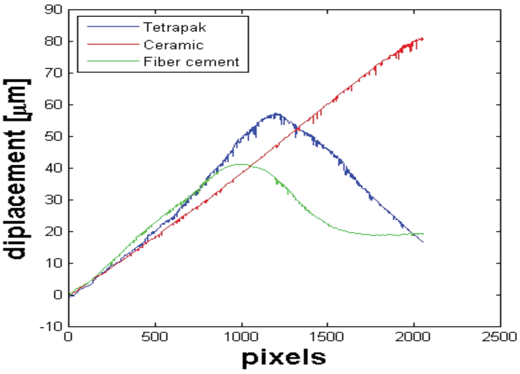

Fig. 4 Roof tiles profile comparison at 25°C with the unwrapped information

Fig. 4 shows a profile comparison for one central vertical line for each image shown in Fig. 3 once they are unwrapped. A larger deformation is observed on the surface of the Tetra Pak tile even when it takes more time to be heated. A similar but faster response is observed in the fiber cement tile. A remarkable difference is observed in the ceramic tile which is not specially affected in its central segment. This could be expected considering the material difference among them.

The acoustic test applies a sinusoidal signal of 5 Hz while the camera records at 50 frames per second to avoid under-sampling. A series of phase maps are shown in Fig. 5 for each tile. From this figure, a nearly oscillatory vibration for the Tetra Pak tile can be observed, a feature not observed in the ceramic tile. The fiber cement tile shows little deformation with a fast change. These images show a steady pattern for the Tetra Pak tile when the others have a changing pattern.

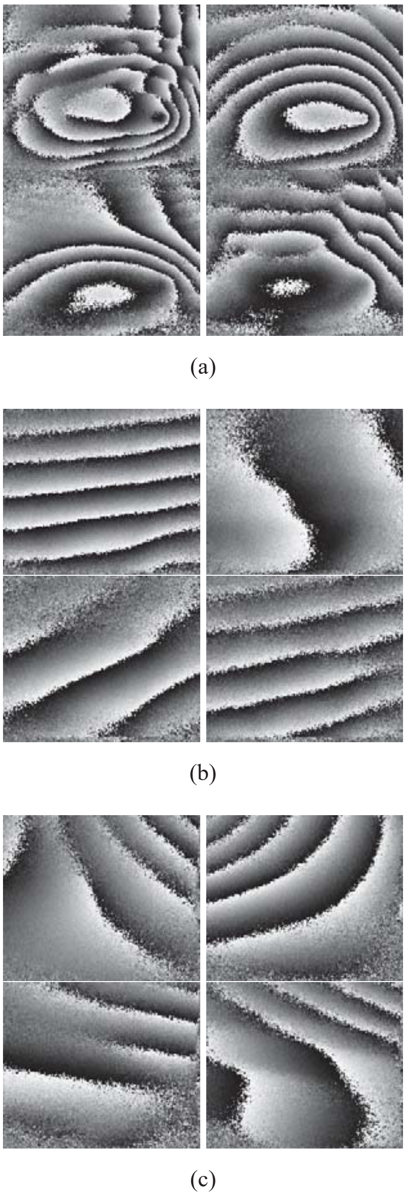
(a)
(b)
(c)

Fig. 5 Selected wrapped phase maps obtained during the acoustic test for the (a) Tetra Pak (b) the ceramic and the (c) fiber cement roof tiles.

V. CONCLUSIONS

Preliminary analysis of the thermal and acoustic response of roof tiles indicates advantages and disadvantages in different cases. The Tetra Pak tile is highly deformed with sound and heat, in the first case this may be a disadvantage, but in the second case it dissipates faster than the ceramic tile. The fiber cement tile is in some tests between these two tiles; however, the recycled nature of the poly-aluminum tiles gains more attention in new construction projects. Further studies over longer time periods are required to establish a clearer difference and estimate of the climatic conditions where one or other the tiles could best be utilized.

The mechanical properties for each tile plays a determinant role to establish where each could be used and in what conditions. The recycled tile, according to its density, will act like an isotropic panel with a well-known mechanical response that could be analyzed in different climates. However, a ceramic tile will change its properties according to the materials used to make it.

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REFERENCES

[1] R. M. E. Diamant, Thermal and Acoustic Insulation, Butterworth-Heinemann (2014).

[2] Osama A. B. Hassan, Building Acoustics and Vibration: Theory and Practice, World Scientific, 2009

[3] Matheos Santamouris, Solar Thermal Technologies for Buildings: The State of the Art, Earthscan, 2003.

[4] F. Mendoza Santoyo, G. Pedrini, S. Schendin, and H. J. Tiziani, "3D displacement measurements of vibrating objects with multi-pulse digital holography," Meas. Sci. Technol. 10, 1305–1308 _1999_.

[5] Carlos Pérez-López, Manuel H. De la Torre-Ibarra and Fernando Mendoza Santoyo, "Very high speed cw digital holographic interferometry", Opt. Express 14(21), 9709–9715 (2006).

[6] R. S. Sirohi and F. S. Chau, Optical Methods of Measurement: Wholefield Techniques (Marcel Dekker, New York, 1999).

[7] K. J. Gåsvik, Optical Metrology, (John Wiley & Sons Ltd., Chichester, 2002).

[8] P. K. Rastogi and D. Inaudi, Trends in Optical Nondestructive Testing and Inspection (Elsevier, Amsterdam, 2000).

[9] T. Saucedo Anaya, M. De la Torre, and F. Mendoza Santoyo, "Endoscopic pulsed digital holography for 3D measurements", Opt. Express 14(4), 1468–1475 (2006).

[10] Tonatiuh Saucedo-A., M. H. De la Torre-Ibarra, F. Mendoza Santoyo, Ivan Moreno, "Digital holographic interferometer using simultaneously three lasers and a single monochrome sensor for 3D displacement measurements", Opt. Express 18(19), 19867–19875 (2010).

[11] Araceli Sánchez A., M. De la Torre-Ibarra, F. Mendoza-Santoyo, S. A. Tonatiuh, Donato Reyes R., "Simultaneous 3D digital holographic interferometry for strain measurements validated with FEM", Opt Laser Eng 52, 178–183 (2014). DOI: 10.1016/j.optlaseng.2013.06.013.

[12] U. Schnars and W. Jueptner, Digital Holography, (Springer-Verlag Berlin Heidelberg 2005).

[13] Rapp, D., "The Dimensional Stability of Materials", JPL D-7667 (1990).

[14] Wolff, E.G., Introduction to the Dimensional Stability of Composite Materials, DEStech Publications, Lancaster PA (2004).

[15] T. Kreis, Hand book of holographic Interferometry (Wiley-VCH, Germany, 2005).

[16] M. Takeda, H. Ina, and S. Kobayashi, "Fourier-transform method of fringe pattern analysis for computer based topography and interferometry," J. Opt. Soc. Am. 72(1), 156–160 (1982).

[17] S.P Sukhatme and J.K Nayak, Solar Energy; Principle of Thermal Collection and Storage, Third Edition, Tata McGraw-Hill Publishing Company Limited. ISBN (13): 978-0-07-026064-1 (2008).