Artículo de Investigación

6

Influence Of Vibration Parameters On The Manufacture Of Micro Concrete Roofing Tiles.

Influencia De Los Parámetros De La Vibración En La Manufactura De Tejas De Micro Concreto

Autores

Sergio A. Marrero-Osorio
PhD. Mech. Eng. Universidad Tecnológica de La Habana (CUJAE)
smarrero@mecanica.cujae.edu.cu
https://orcid.org/0000-0002-5838-5455

Gabriel Martínez Licea
Civ. Eng. Universidad Tecnológica de La Habana (CUJAE)
gamarlic2709@gmail.com
https://orcid.org/0009-0007-9161-9739

Marietta Llanes Pérez
PhD. Civ. Eng. Universidad Tecnológica de La Habana (CUJAE)
marietta@civil.cujae.edu.cu , mariettallanes67@gmail.com
https://orcid.org/0000-0003-3917-8175

Nilvet Díaz-Rigueira
Mech. Eng. Universidad Tecnológica de La Habana (CUJAE)
https://orcid.org/0009-0008-3169-8620

Michel Albanés-Espinosa
Mech. Eng. Universidad Tecnológica de La Habana (CUJAE)
https://orcid.org/0009-0005-7990-3791

6

Artículo de Investigación

Influence Of Vibration Parameters On The Manufacture Of Micro Concrete Roofing Tiles.

ABSTRACT

"Vibrated Tiles" (TEVI) is a technology based on J.P.M. Parry & Associates equipment, whose essential component is a small vibrating table on which a 3 kg mass and 10 mm thickness roman-type concrete tile, is manufactured. TEVI technology was developed by the Center for Tropical Construction and Architecture Studies (CECAT) of the Technological University of Havana "José Antonio Echeverría" (CUJAE). Practical experience in tiles production and transference of the mentioned technology, allowed us to suspect that it was possible to improve the working regime of the vibrating table. The objective of this research was to determine how some vibration parameters influence the quality of the micro-concrete tiles manufactured with TEVI machines. An experiment was made, varying the set of values of operating frequency, vibration time and static mass moment of the centrifugal vibrator, keeping the energy necessary to manufacture a tile approximately constant. In an experimental production, variables associated with tiles quality and manufacturing process were measured and evaluated, such as the maximum diameter of the pores, permeability, and flexural resistance. The results lead us to the conclusion that it is possible, as the frequency increases from 3000 rpm (314 rad/s) to 12000 rpm (1257 rad/s), to duplicate tiles breaking load, to reduce the maximum pore size by 72 %, to diminish the tiles permeability by 57 % and to reduce by 55 % the vibration time, without increasing energy consumption.

Keywords: micro-concrete tiles, angular frequency of vibration, static moment of masses, permeability, flexural strength, porosity

RESUMEN

La tecnología de fabricación de cubiertas llamada "teja vibrada" (TEVI), posee como componente esencial una pequeña mesa vibratoria sobre la cual se fabrican tejas de hormigón tipo romana, de aproximadamente 3 kg de masa y 10 mm de espesor. La tecnología TEVI constituye una mejora realizada por el Centro de Estudios de Construcciones y Arquitectura Tropical (CECAT) de la Universidad Tecnológica de La Habana José Antonio Echeverría (CUJAE) a una tecnología original de la marca Parry. La experiencia práctica en la producción, el empleo y la transferencia de la tecnología TEVI, permitieron sospechar que es posible mejorar el régimen de trabajo de la mesa vibratoria, lo cual condujo a realizar la presente investigación, que persigue como objetivo determinar cómo influyen algunos parámetros de la vibración sobre importantes índices de calidad de la fabricación de tejas de microconcreto mediante máquinas TEVI. Se realizó un experimento basado en variar el juego de valores de frecuencia de operación, tiempo de vibrado y momento estático de masas del vibro-excitador centrífugo, manteniendo aproximadamente constante la energía necesaria para fabricar una teja. En una producción experimental se midieron y evaluaron variables asociadas a la calidad de la teja, tales como el diámetro máximo de los poros, la permeabilidad y la resistencia a la flexión. Los resultados permitieron llegar a la conclusión de que, elevando la frecuencia de vibración de 3000 rpm (314 rad/s) a 12000 rpm (1257 rad/s), es posible duplicar la carga de rotura por flexión de las tejas, reducir en un 72 % el diámetro máximo de los poros, disminuir la permeabilidad de las tejas en un 57 % y reducir en un 55 % el tiempo de vibrado, todo sin incrementar el consumo de energía..

Palabras Clave: tejas de microconcreto, vibración del concreto, potencia de vibración, mesa vibratoria, permeabilidad, resistencia a la flexión, porosidad.

Nota Editorial: Recibido: 2 de Julio 2025 Aceptado: 26 de Noviembre 2025

1. INTRODUCTION

Micro-Concrete Roofing (MCR) has been used for decades in developing countries to manufacture waterproof roofs in a sustainable manner [1, 2, 3]. The firm J.P.M. Parry & Associates developed a small vibrating table which, together with a set of plastic molds and other materials, allowed one person to produce more than 200 micro-concrete Roman tiles per day, with workers known to be able to produce up to 350 per day. In the 1990s, Acevedo Catá, Llanes Burón and other investigators of the Center for the Study of Tropical Construction and Architecture (CECAT) of the Technological University of Havana “José Antonio Echeverría” (CUJAE), in collaboration with Kurt Rhyner, member of *Sofonias Group*, developed a new machine accompanying a system for the production and strict quality control of the tiles, called *Vibrated Tiles* (TEVI) (Figure 1). The non-profit organization Ecosur (ecosur.org) maintains a global network that has been responsible of its successful dissemination in many countries of Asia, Africa and Latin America, highlighting its use in situations of natural disasters, as in the case of the earthquake in Haiti in 2010.

The TEVI vibratory table (figure 1) vibrates at a frequency of 3000 to 3600 rpm (314...377 rad/s), range commonly used for concrete mixes. This frequency range guarantees good compaction while allowing the motors and mechanical components to withstand continuous work and seeks to prevent defects such as bleeding and segregation which appear at higher frequencies [3]. An example of this can be seen in [4], where the frequency chosen for a vibrating table was close to 3000 rpm (314 rad/s). In [7], on the other hand, emphasis is placed on the vibrating time to strengthen the concrete, maintaining a relatively low frequency of 2400 rpm (251 rad/s). However, high frequencies have long been recommended [4], mainly for fine aggregates, and more recently high frequency vibration has been experimented during the concrete mixing process [9]. New design proposals of the TEVI machines have been made, for example, in reference [10], but innovation is focused on the process automation, not on the improvement of vibration parameters.

Because of the importance of modelling concrete molding process several models have been proposed to represent fresh concrete under vibration [11, 13, 14, 15, 16, 17]. From the studied literature we can conclude that, for fairly dry mixes, small thicknesses and also small concrete masses, it is possible to consider that the mortar and the vibrating table vibrate as a single body, detecting very little viscous damping in the oscillating system, especially once the mix begins to consolidate, when the larger air bubbles are expelled to the surface [11]. Taking in account the good practices on the use of concrete vibration [9, 13, 18], and since the TEVI vibrating table molds light (up to 3 kg mass) and thin (8 to 10 mm thick) elements, using small aggregates (up to 6 mm diameter), is justified the choice of the mentioned classical vibration model for this study. Subsequently, the aim of this work is to determine the influence of frequency on quality indexes of TEVI tiles and its manufacturing process, keeping constant the energy required for production.

***Fig.* 1**-*TEVI technology. a) TEVI roof tile production machine. b) TEVI tile roofing.*

2. MATERIALS AND METHODS

An experiment was planned to vary the angular frequency in four levels, in a range of 314 - 1256 rad/s, keeping approximately constant the energy required (612 J) for compaction and molding the concrete mixture when manufacturing a roof tile on the experimental machine. The output variables were: the maximum pore size, the permeability, the thickness of the element and its resistance to bending.

The experimental vibrating table (Fig. 2), has a 250 W motor with adjustable speed from 1500 to 9000 rpm (157 - 942 rad/s). A brake coupled to the motor is automatically activated when electricity is interrupted. A belt drive transmits power to the unbalanced rotor multiplying speed 1,5 times. The static momentum of the unbalanced mass was changed through four interchangeable discs with eccentric coupling holes, each of which guarantee a different value of that variable. The function of the brake was to minimize the stopping time of the centrifugal exciter to an insignificant value. To ensure the post-resonant working regime, elastic supports were installed, with a longitudinal stiffness of 80 N/mm and a transverse stiffness of 180 N/mm. The machine frame was connected by means of expansion bolts to a 250 kg concrete plateau.

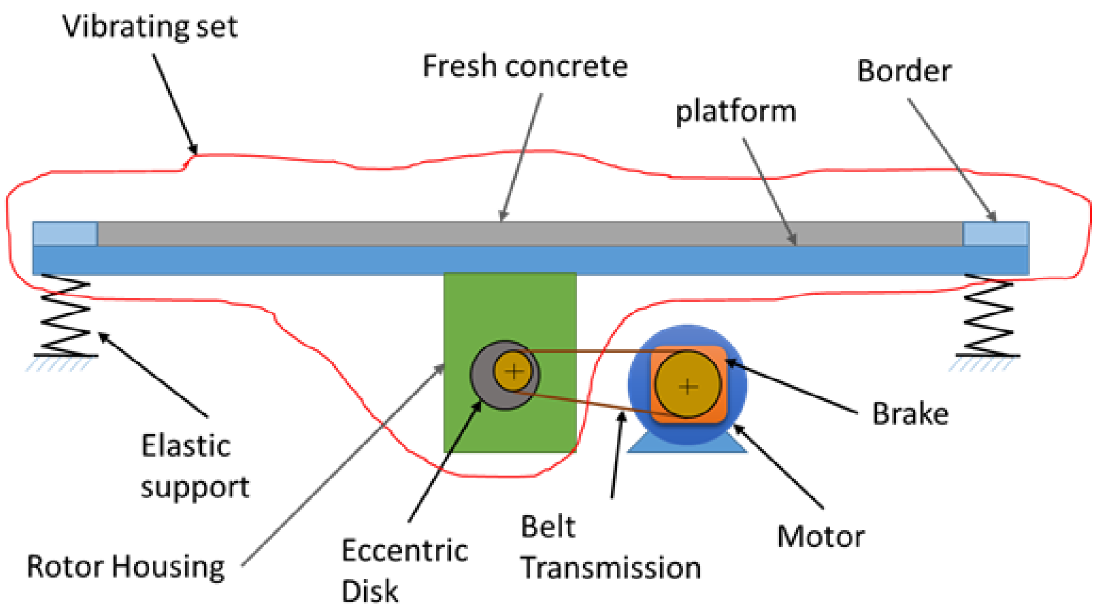

Fig. 2- *Experimental machine to produce TEVI tiles.*

In this research a classical mathematical model of mechanical vibration applied to concrete compaction [11] is adopted, whose equations and variables are summarized in Table 1 and Table 2. The goal is to calculate, for each frequency, variables as vibrating time, eccentric disk parameters and total required power, aiming to a fixed total energy consumption and keeping invariable the vibrating set. This is an undetermined problem, for which the optimization algorithm exposed in figure 3 has been used. The total vibration energy is taken as the target variable, trying to approximate its value to a reference value (612 J), i.e., the same total energy consumed by the TEVI experimental vibrating table working with the original eccentric disk rotating at 3000 rpm (314 rad/s). The changing variables in the problem are: vibration time, disk diameter, disk thickness, and disk eccentricity. Table 3 shows computed dimensions of the four eccentric disks with the static moments of mass they produce, as well as the four combinations of the experiment. Supposing that the oscillations are circular and occur under a post-resonant vibration regime, the vibration power can be approximately determined by equation 6, which assumes that the mixture, the platform, the frame, the vibro-exciter housing and the non-eccentric rotating parts vibrate as a whole.

Table 1- *Equations of the mathematical model used to optimize the eccentric disk parameters at each angular frequency.*

Equation	Nº	Equation	Nº
$Ms\_0 = r\_0 * m\_0$	(1)	$Pvib = 1/2 * F\_0 * x\_0 * \omega$	(6)
$Ms = x\_0 * m$	(2)	$m\_0 = \pi/4 * D^\wedge 2 * B * \rho$	(7)
$Ms\_0 = Ms$	(3)	$Mf\_R = f\_R * F\_0 * (dm\_R)/2$	(8)
$r\_0 = e\_0$	(4)	$P = (P\_vib + Mf\_R * \omega)/(\eta\_T * \eta\_m)$	(9)
$F\_0 = m\_0 * \omega^\wedge 2 * r\_0$	(5)	$E = P * tvib$	(10)

Table 2: *Variables of the mathematical model used to optimize the eccentric disk parameters at each angular frequency. The values shown correspond to the variables assumed to be constant.*

Variable	Value	Unit	Comment
ω	-	rad/s	Angular frequency of vibration
r_0	-	m	Eccentricity of the unbalanced mass
e_0	-	mm	Eccentricity of the disk
D	-	mm	Outside diameter of eccentric disc
B	-	mm	Eccentric disc width
$tvib$	-	s	Vibration time
m	19.1	kg	Total mass of the vibrating assembly
ρ	7850	kg/m^3	Density of eccentric disk material
dm_R	22	mm	Mean balls bearing diameter
f_R	0.005		Coefficient of rolling friction of the bearing
η_T	0.7		Transmission efficiency
η_m	0.8		Electric motor efficiency electric motor
x_0	-	mm	Amplitude of the displacement of the vibrating assembly
F_0	-	N	Centrifugal force on the rotor
m_0	-	kg	Unbalanced mass
Ms_0	-	kgm	Static moment of rotating mass
Ms	-	kgm	Static moment of mass of the vibrating assembly
$Pvib$	-	W	Power required for vibration (without considering friction)
Mf_R	-	Nm	Frictional torque in rolling bearings
P	-	W	Total power required for vibration
E	612	J	Total energy consumed for vibration

Table 3: *Values of angular frequency, static momentum (with the dimensions of the eccentric disk) and vibration time for the four runs of the experiment.*

Angular frequency ω [rad/s]	Eccentricity e_0 [m]	Eccentric disk width B [m]	Outside diameter of eccentric disc D [m]	Static moment M_so [kgm]	Vibrating time t_vib [s]
314	0.0090	0.0280	0.0390	0.002363	40
628	0.0025	0.0254	0.0380	0.000565	35
942	0.0020	0.0160	0.0348	0.000238	28
1256	0.0020	0.0160	0.0287	0.000162	18

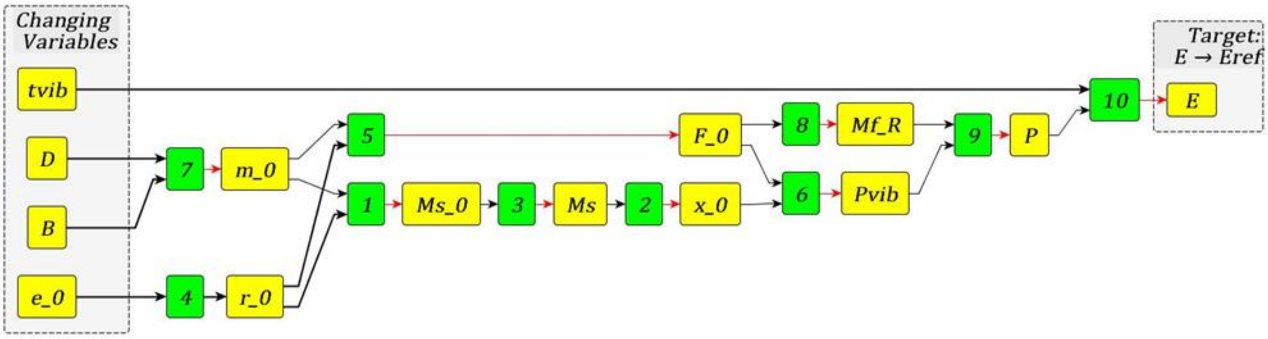

Fig. 3- *Algorithm for the optimization of the eccentric disc parameters and the vibrating time, under the condition of approaching the reference value $Eref$ of energy consumption. Green rectangles represent equations, yellow rectangles represent unknown variables, and arrows indicate direction in which calculations are made.*

Seven tiles were manufactured for each combination shown in Table 3, controlling vibration time by a manual chronometer and rotation speed by a stroboscopic tachometer. Portland P-350 cement manufactured in Siguaney factory was used. The employed sand (from the Arimao quarry) was conveniently dried, having the following particle size: 42 % of particles between 2 and 5.5 mm, 37 % between 0.5 and 2 mm and 21 % smaller than 0.5 %; with 2.4 % of clay and silt. A volumetric dosage of 1:2.5 of cement/sand ratio, and 0.60 water/cement ratio were used. Mixtures of consistency between 12 to 14 cm diameter were obtained, according to the shaking table test indicated in Cuban Norm NC 170/2002, which satisfies the requirements of the TEVI technology. Output variables of the experiment (all measured at 28 days) were the following: breaking load, maximum pore diameter, permeability and final tile thickness. Breaking load was measured using a CCF-02 device, described in [2, 19], by progressively applying a vertical force in the center of a tile supported on edges distanced 350 mm and recording force value at the moment of fracture. Permeability was calculated as percentage difference between mass of the dry and the 24 hours water-immersed tile, according to NC 697/2013. Although there are currently very sophisticated methods to study porosity [17], it was considered adequate for this research to evaluate the maximum diameter of the pores, measured in 10 areas of the cross section of the split and polished tile, using a scale microscope (magnification of 24 ± 5 %, field of view of 8.5 mm, maximum measurement diameter 6.5 mm and measurement error of ± 0.01 mm). The final thickness was calculated by averaging measured thickness at ten points of a fractured section approximately in the center of the tile.

Since the importance of the displacement amplitude x_0 on determination of consumed energy during vibration, it was necessary to compare the amplitude values calculated by the mathematical model shown in Tables 1 and 2 with reference measured values. The velocity amplitude v_0m in the vertical direction was measured, averaging the values taken at the four corners of the bottom surface of the mold, by means of a portable vibrometer (with range from 40 Hz to 20 kHz), determining the reference vertical displacement under the assumption that the oscillations are harmonic, through the expression $x\_0m = (v\_0m)/\omega$.

3.RESULTS

Calculated and measured values of vertical displacement amplitude are shown in figure 4. The obvious similarity of the values (relative error less than 10%) allows us to consider that the theoretical model used to optimize vibrating time and parameters of the eccentric disks is acceptable for the present case study, strengthening the initially made assumption that it is possible to keep compaction energy approximately constant despite frequency changes.

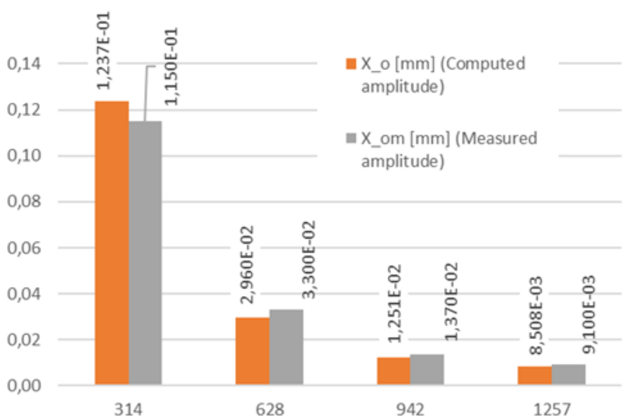

Fig. 4- *Computed and measured vibration amplitudes, depending on frequency*.

Table 5 shows the results of all the measurements performed on the tiles and the graphs in figure 5 show the relationship between the frequency and the response variables. No defects such as segregation or water displacement, typical of over-vibration, were observed when examining the tiles.

Table 5- *Direct measurement results as a function of angular frequency.*

ω [rad/s] (Angular frequency)	Q_R [N] Flexural ultimate load			D_{max}m] Maximum pore size			$perm$ [%] Tile permeability			s [mm] Final tile thickness		
	Measure	Mean	Standard Deviation	Measure	Mean	Standard Deviation	Measure	Mean	Standard Deviation	Measure	Mean	Standard Deviation
314	510	520	20	3.55	3.62	0.46	11.1	11.59	0.52	8.8	9.23	0.39
	510			3.65			11.9			9.5		
	500			4.25			12.3			9.4		
	530			3.75			11.8			9.8		
	500			4.05			11.9			9.3		
	540			3.15			10.9			9.1		
	550			2.95			11.2			8.7		
628	760	800	57	3.05	2.91	0.43	9.8	9.46	0.79	9.3	9.09	0.25
	750			2.85			8.5			9		
	900			2.05			9.9			9.5		
	770			2.9			8.2			9		
	780			2.95			10.1			9		
	780			3.15			9.5			8.7		
	860			3.45			10.2			9.1		
942	880	864	62	1.65	1.84	0.24	7.5	7.41	0.79	9	8.63	0.34
	770			2.05			6			8.2		
	950			1.95			7.2			9		
	890			1.75			8			8.9		
	810			2.15			6.9			8.5		
	910			1.85			8.1			8.5		
	840			1.45			8.2			8.3		
1257	850	1039	118	0.95	1.03	0.20	5.4	5.0	0.5	7	7.39	0.36
	980			0.85			4.8			7		
	1200			1.05			5.1			8		
	1000			0.75			5.9			7.2		
	1070			1.15			4.5			7.5		
	1010			1.1			4.5			7.4		
	1160			1.35			4.8			7.6		

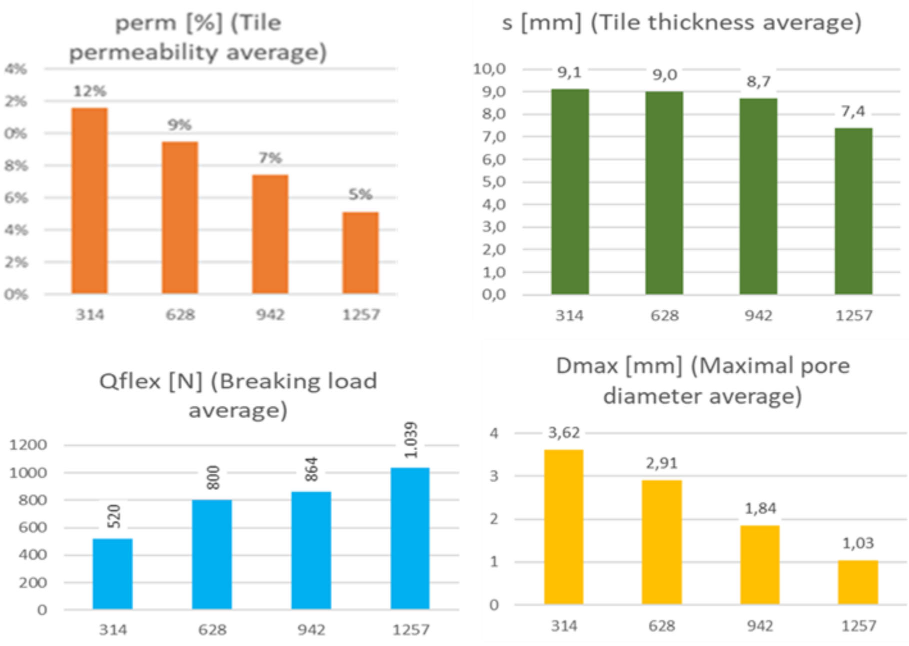

Fig. 5- Direct results of the measurements as a function of the angular frequency

From the above graphs it can be observed that, as the frequency increases, the maximum pore diameter and permeability decrease, and the flexural breaking load increases despite the decrease in tiles thickness, which is an indication of an improvement in the compaction of the mixture. The breaking load is doubled as the frequency increases to 12000 rpm (1257 rad/s). The maximum pore size is reduced by 72 % and, in addition, the tiles are 57 % less permeable compared to those vibrated at 3000 rpm (314 rad/s). These results were statistically processed, and it was obtained that the frequency has a significant influence on the four response variables studied, with a confidence level of 95 %.

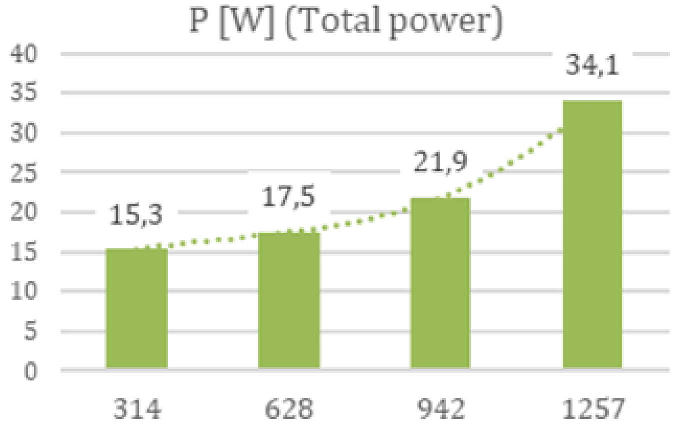

Fig. 6- *Total power consumed as a function of angular frequency*.

The graph in figure 6 shows the correspondence between the frequency and the power consumed by the machine. Total power consumed by the motor increases as the vibrating frequency increases; however, since energy remains constant and power values remain very low, it is perfectly possible to use renewable energy sources to produce roofing tiles.

4. CONCLUSIONS

The results confirmed the validity of the initially made assumption that it was possible to keep compaction energy approximately constant despite changing frequency. The variation of frequency significantly influences the compactness and flexural strength of the tiles, even when the compaction energy is kept approximately constant. The best properties of the tiles were obtained for the maximum studied frequency of 1257 rad/s, which duplicated the flexural strength and reduced 57 % permeability with respect to tiles formed with the reference frequency value of 314 rad/s. Moreover, no segregation or bleeding problems were detected, even at the highest tested frequency values. Reductions of the tile vibrating time by 55 % were obtained, which consequently increases the productivity of the technology. Despite the total power is increased at highest frequency, is kept the possibility of use of small renewable energy sources to operate the TEVI machine

5. ACKNOWLEDGMENT

Acknowledgment to Professor Orlando Espinosa Torredemert, who recently passed away, for his contribution to this research.

BIBLIOGRAPHIC REFERENCES

1. O. Ruskulis, “Micro-Concrete Roofing Tile Production. Technical Brief” Appropriate Technology magazine, vol. 23, nº 1, June 1996. https://www.humanitarianlibrary.org/sites/default/files/2014/02/ITDG_MicroConcreteRoofingTileProduction.pdf

2. R. M. BATHKE, “The viability of manually producing and using concrete roof tiles for low-cost housing in South Africa” 1998. https://wiredspace.wits.ac.za/items/2f492420-e00a-4026-b7c8-70e6824553a8

3. R. O. Lane, Behavior of fresh concrete during vibration, Michigan: ACI Committee Report, 1998. https://www.concrete.org/store/productdetail.aspx?ItemID=309108

4. E. A. M. T. K. D. K. Kadir Aztekin, “The Design, Analysis, and Manufacturing of Vibrating Table” International Journal of Scientific and Technological Research, Vols. %1 de %2Vol.5, No.4, 2019. https://iiste.org/Journals/index.php/JSTR/article/viewFile/47246/48790

5. I. I. NAZARENKO, M. M. RUCHYNSKYI, A. T. SVIDERSKYI, I. M. KOBYLANSKA, D. HARASIM, A. KALIZHANOVA y A. KOZBAKOVA, «Development of energy-efficient vibration machines for the buiding-and-contruction industry,» PRZEGLĄD ELEKTROTECHNICZNY, vol. R. 95 NR 4, 2019. https://pe.org.pl/articles/2019/4/10.pdf

6. I. Nazarenko, V. Gaidaichuk, O. Dedov y O. Diachenko, «Investigation Of Vibration Machine Movement With A Multimode Oscillation Spectrum,» Eastern-European Journal of Enterprise Technologies, vol. 90, nº 6/1, 2017. https://journals.uran.ua/eejet/article/download/118731/115022

7. D. Takehisa, I. Ide, S.-i. Hashimoto y S. Date, «Study on Improvement of Vibration Compaction Performance of Fresh Mortar,» International Journal of Structural and Civil Engineering Research, Vols. %1 de %2Vol. 7, No. 1, 2018. https://www.ijscer.com/uploadfile/2018/0309/20180309045036484.pdf

8. A. M. Alexander, «STUDY OF VIBRATION IN CONCRETE. MECHANICS OF MOTION OF FRESH CONCRETE. Report 3. Tecnical Report No 6-780,» Concrete Laboratory. US Army, Washington DC, September 1977. https://apps.dtic.mil/sti/tr/pdf/ADA045158.pdf

9. Z. W. y W. Rongfang, «Experimental Study on the Influence of High-frequency Vibratory Mixing on Concrete Performance,» Science and Engineering of Composite Materials, vol. 30: 20220199, 2023. https://www.degruyterbrill.com/document/doi/10.1515/secm-2022-0199/html?srsltid=AfmBOop7_xvg3Ml0tjPkmL19dHxdqbPQbfXtWb6vA6RR8Oz5VwjJB7uq

10. M. D. Basantes Valverde, «Automatización y optimización de la máquina tevi para la fabricación de tmc como aporte al proyecto de la Fundación Ecosur-Ecuador,» Riobamba: Universidad Nacional de Chimborazo, 2021. http://dspace.unach.edu.ec/handle/51000/7264

11. G. C. Zhuguo Li⁎, «Rheological behaviors and model of fresh concrete in vibrated state,» Cement and Concrete Research, nº 120 (2019), 2019. https://www.sciencedirect.com/science/article/abs/pii/

12. S. C. F. Mahmoodzadeh, "Rheological models for predicting plastic viscosity and yield stress of fresh concrete," Cement and Concrete Research, vol. 49, p. 1– 9, 2013. https://www.sciencedirect.com/science/article/pii/S0008884613000586

13. N. Roussel and A. Gram, "Simulation of Fresh Concrete Flow," RILEM Technical Committee 222-SCF. Springer, 2014. https://link.springer.com/book/10.1007/978-94-017-8884-7

14. Z. H. X. C. a. W. Y. DeFang Zou, «Numerical analysis and experimental research on the vibration performance of concrete vibration table in PC components,» Science and Engineering of Composite Materials, Vols. %1 de %231 (1), 20240038, 2024. https://www.degruyterbrill.com/document/doi/10.1515/secm-2024-0038/html?srsltid=AfmBOoq9LhoiKi8ufHv-2K7RJOmGpvmct1euJ5u88-UR43GhD9yem7r8

15. Ling, Yifeng, «Effects of Vibration on Concrete Mixtures,» National Concrete Pavement Technology Center. Institute for Transportation, Iowa State University, 2020. www.cptechcenter.org

16. M. Meléndez, O. Espinosa, K. Rhyner y M. Noboa, Un techo que cubre al mundo: la teja de microconcreto (TMC), Jinotepe, Carazo, Nicaragua: EcoSur, 2004 https://www.ecosur.org/index.php/es/todos-los-articulos/86-ecosur-e-magazine/edicion-10-febrero-2005/534-un-techo-que-cubre-al-mundo-la-teja-de-microconcreto

17. H. W. ·. C. K. ·. C. L. ·. W. Chu, «Deep learning in the advanced core sample porosity determination with XCT image,» Earth Science Informatics, vol. 18:17, 2025. https://link.springer.com/article/10.1007/s12145-024-01602-1