PAPER • **OPEN ACCESS**

Effects on the Compressive Strength and Thermal Conductivity of Mass Concrete by the Replacement of Fine Aggregate by Mussel Shell Particulate

To cite this article: J Figueroa *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **503** 012070

IOP Conf. Series: Earth and Environmental Science **503** (2020) 012070 doi:10.1088/1755-1315/503/1/012070

Effects on the Compressive Strength and Thermal Conductivity of Mass Concrete by the Replacement of Fine Aggregate by Mussel Shell Particulate

J Figueroa[1], M Fuentealba[2], R Ponce[3] and M Zúñiga[4]

[1]Facultad de Ciencias de la Ingeniería, Universidad Católica del Maule, Talca Chile. jfiguero@ucm.cl
[2]Facultad Ciencias Básicas. Universidad Católica del Maule, Talca, Chile. mfuentea@ucm.cl
[3]Ingeniero Constructor, Universidad Católica del Maule, Talca Chile. rodrigoponce1987@gmail.com2
[4]Área Procesos Industriales. Universidad Tecnológica de Chile, INACAP, Chile. mzunigac@gmail.com

E-mail address: mfuentea@ucm.cl

Abstract. The behaviour of mussel shell particulate as fine aggregate for mass concrete has been analysed. The shells were washed and mechanically crushed to obtain a particle size similar to that of the natural aggregate (fine) to be replaced, which was dried at 140 °C. The Faury-Joisel method was used to design the H-35(95)-20-6 structural mass concrete sample, with 0%, 10%, 30% and 60% replacements of fine aggregate by mussel shell particulates, performing compressive strength and thermal conductivity analyses at 7 and 28 days. The results indicate that in order to maintain the compressive strength of H-35(95)-20-6 structural mass concrete, the replacement percentage should not exceed 40%. On the other hand, as the mussel shell particulates in the concrete increase, the thermal conductivity decreases, turning into a material with a tendency to increase thermal insulation, which would help to improve the new demands on energy saving and efficiency in households, if used as coating. Hence, it can be concluded that it is feasible to replace fine aggregate with mussel shell particulate matter, which would be useful in increasing the recycling of this residue and in reducing its natural exploitation.

1. Introduction

Chile has an important mussel farming industry, which registered a total harvest of 337,000 tons of mussels (*Mytilus chilensis*) in 2017, with 100% carried out in the Region de Los Lagos [1]. This activity generates thousands of tons of sea shell by-products, taking into account that 33% of the animal's weight corresponds to the shell, which is treated as waste at present. Some attempts have been made to recycle these shells as conditioner, as well as to improve soil fertility by mixing mussel shells with cattle slurry [2]; furthermore, shells have also been used as animal feed [3], but none of these uses have been satisfactory in providing recycling viability and added value [4]. The most common method used for managing this residue is landfill disposal or sea disposal after the shelling of the mollusks, thus producing water enrichment with organic matter. However, this causes bad smells due to the

IOP Conf. Series: Earth and Environmental Science **503** (2020) 012070 doi:10.1088/1755-1315/503/1/012070

decomposition of the remaining meat in the shells or due to the microbial decomposition, generating H_2S, NH_3 and amines [5], which can negatively affect the quality of life of the nearby urban population and generate changes in the balance of the ecosystem [6,7].

On the other hand, the production, use and demand for concrete, the most used construction material worldwide, has been on a constant rise. Hence, in Chile, 80% of all construction is made with this type of material, which generates high pressure in the consumption of natural aggregates, since concrete requires a significant amount of resources, especially stone aggregates [8-11]. In recent years, the construction sector has become increasingly aware of the need to move towards sustainable construction; therefore, several studies have been carried out to analyse the use of different types of materials, including mollusc shells, dried bamboo leaves, recycled glass and debris as aggregates that can be incorporated into concrete or construction mortars [12-16]. In this way, by increasing the proportion of natural aggregates, a more sustainable type of concrete can be obtained, without necessarily losing its construction quality. Furthermore, it is important to take into account that the reduction in the extraction of stone materials from natural environments will reduce the environmental impact and the depletion of natural aggregate resources that come from natural riverbeds, as well as from quarries [17, 18].

The growth in concrete consumption, and therefore of cement, is directly related to world population growth and to urban development. The latest statistics provided by Index Mundi, in its report Hydraulic Cement: World Production, By Country, reported a production of 2.310 million tons of cement, with China being the world's largest producer [19]. Consequently, Chile, who is closely following this global trend, has increased its real-estate and construction industry, which has led to a high demand for concrete. Hence, this brings us to the question of what will happen to the preservation of natural aggregate sources, which is a valid reason for concern, along with the need for conserving and protecting the natural ecosystems these materials are extracted from. Therefore, the purpose of this work is to explore the use of mussel shell residue in the production of mass concrete by analyzing its resistance to compression and its effect on the thermal conductivity of mass concrete by replacing fine aggregate with mussel shell particulate.

2. Materials and Methods

2.1. Concrete and natural aggregates.

The concrete used in this study is high strength iron and steel class (NCh 148 Of. 68) [20]. The mussel shell residue, obtained from seafood restaurants in the city of Talca, Region del Maule-Chile, was washed and subjected to mechanical crushing (by means of a graduated grinder), and dried for 24 hours at a temperature of 140°C to obtain a particle size similar to the dimension of the natural aggregate (fine) to be replaced.

2.2. H-35(95)20-6 concrete test probes using the modified FAURY-JOISEL method.

Three test probes per substitution level (10%, 30% and 60%) were made to measure the compressive strength, two test probes per substitution level to determine thermal conductivity, and one test probe per substitution level to estimate docility through Abrams cone (NCh 1019 Of. 09, [21]). A total of eighteen experimental test probes were considered and six standard test probes. Table 1 indicates the number of items produced in each test and the number of items per individual concrete mixer. In the design mix of these test probes, the water-cement ratio was 0.41 and the dimensions were 15 x 15 x 15 cm, according to Chilean standard NCh 1037 Of 77 [22].

Table 1. Number of test probes considered in the experimentation.

Mussel shell particulate (%)	Number of test probes	Test probe dimensions	Type of test	Quantity (Liters)
0 %	3	15x15x15 cm	Compressive strength	50

	2	22x22x4 cm	Thermal conductivity	
	1	Cono Abrams	Docility	
10 %	3	15x15x15 cm	Compressive strength	50
	2	22x22x4 cm	Thermal conductivity	
	1	Abrams cone	Docility	
30 %	3	15x15x15 cm	Compressive strength	50
	2	22x22x4 cm	Thermal conductivity	
	1	Abrams cone	Docility	
60 %	3	15x15x15 cm	Compressive strength	50
	2	22x22x4 cm	Thermal conductivity	
	1	Abrams cone	Docility	

2.3. *Apparent density*.

The determination of the apparent density of the fine aggregate and the mussel shell particulate was carried out by using the methodology indicated in NCh 1116 Of 77 [23].

2.4. Mechanical test.

Compressive strength was measured at the ages of 7 and 28 days in the four test probes studied. Each series contains three cubic test probes of 15 x 15 x 15 cm, according to Chilean standard NCh 1037 Of 77 [22]. The design resistance was measured by using the Faury-Joisel method for mass concrete type H-35(95)-20-6 is 35 MPa. (Figure 1).

Figure 1. Compressive (left) and thermal conductivity test probe (right).

2.5. *Thermal conductivity test*.

A Modified Hot Plate Chamber was used to measure the thermal conductivity (K) according to NCh 853 Of 07 [24] (Figure 1). The method consists of placing the sample between 2 rectangular plates, one hot and the other one cold, where, due to the temperature gradient, heat transfer is produced through the sample [25-27].

The quantification was performed according to NCh 853 Of 07 [24], using Fourier's heat conduction law, whose equation is:

$$K = \frac{\emptyset \Delta x}{A(T2 - T1)}$$

Where k = Thermal conductivity, ∅Δ= Transmitted heat, x = Test probe thickness, A = Contact surface area, (T1 - T2) = Temperature difference between the hot and cold spots.

2.6. Docility.

The Abrams cone method was used to measure docility, applicable only to concrete whose aggregate size is less than or equal to 50 mm (2″) and which allows the measurement of the docility of fresh concrete through the decrease in height, experienced by a conical trunk molded with fresh concrete, according to Chilean standard NCh 1019 Of 09 [21].

3. Results and discussion

3.1. Chemical properties of natural aggregate and mussel shell particulate.

The chemical properties of natural aggregate and mussel shell particulate obtained by X-ray fluorescence analysis are presented in Table 2 and Figures 2 and 3.

Table 2. Quantitative elemental result as mass percentage of aggregate and mussel shell particulate.

Element	Natural aggregate (%)	Mussel shell particulate (%)
Si	56.8	1.3
Al	21.0	-
Fe	10.3	0.5
Ca	7.5	96.9
K	2.7	0.4
Ti	0.8	-
Ba	0.6	-
Mn	0.2	-
Sr	0.1	0.4
Zr	0.03	-
Zn	0.015	0.05
Rb	0.014	-
S	-	0.3
Sn	-	0.09
Cu	-	0.04

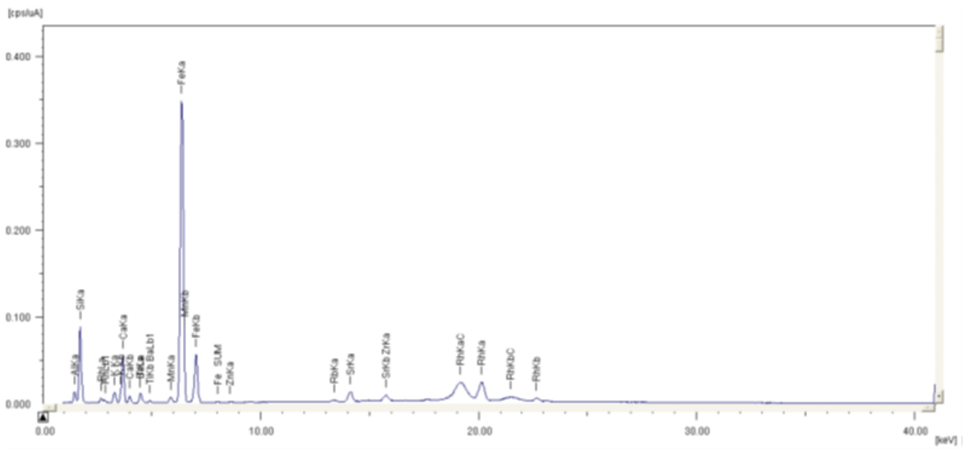

Figure 2. X-ray diffraction of natural aggregate.

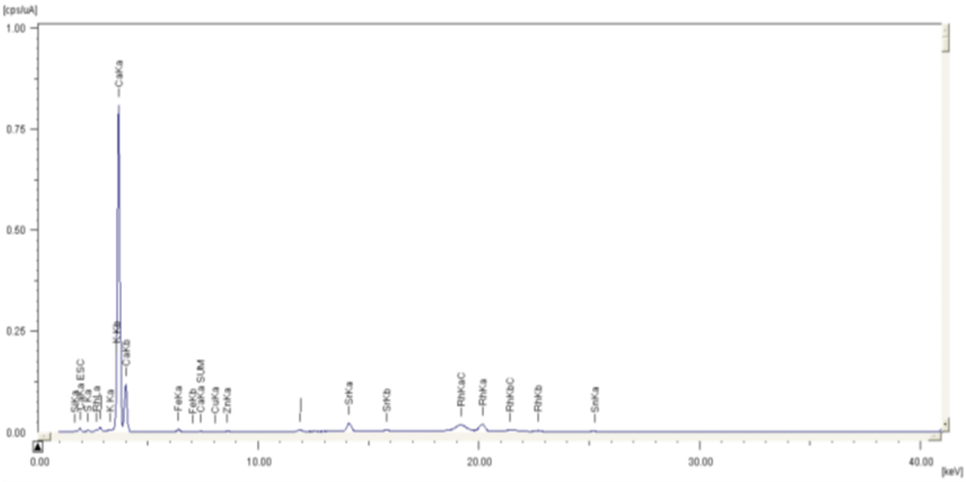

Figure 3. X-ray diffraction of crushed mussel shells.

3.2. Granulometry determination of the natural aggregate and mussel shell particulate.

The mussel shell particulate presented physical and visual characteristics that were very similar to the natural aggregate to be replaced (Figure 4).

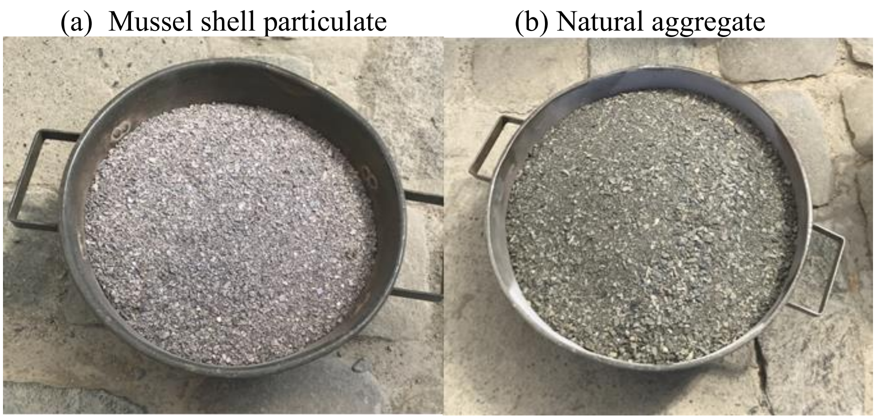

Figure 4. Physical appearance of (A) mussel shell particulate and (B) natural aggregate.

The grain size distribution of the natural aggregate and crushed mussel shells are given in Figure 5.

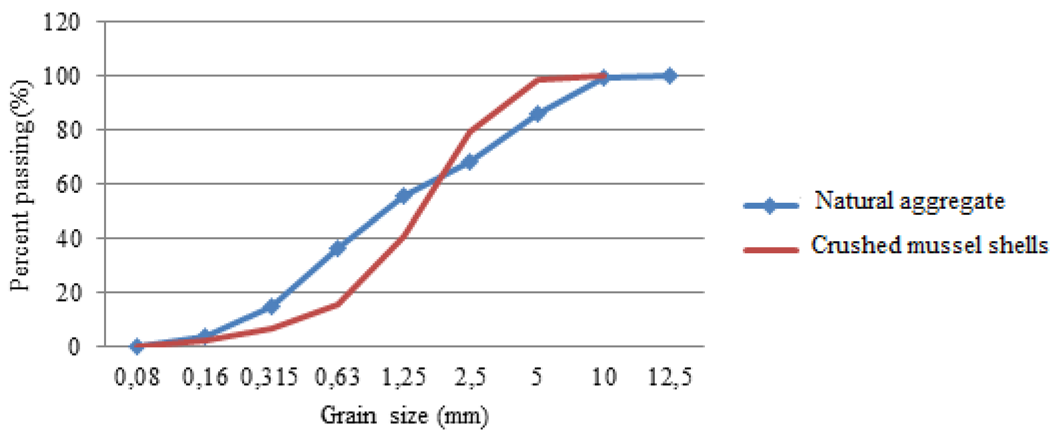

Figure 5. Grain size distribution of the natural aggregate and crushed mussel shells.

3.3. Construction dosage for 1m^3 of concrete.

Considering that the densities of the fine aggregate and the mussel shell particulate are different (Table 3), an estimation of materials was made to make 1m^3 of concrete with the values indicated in Tables 4, 5 and 6.

Table. 3. Fine aggregate density and mussel shell particulate.

Material	Density (Kg/m^3)
Fine aggregate	1656
Mussel shell particulate	1234

Table 4. Quantity dosage to make 1 m^3 of concrete (without the replacement of aggregates by mussel shell particulate).

Material	Quantity (Kg)
Gravel	1096
Sand	661
High-strength concrete	412
Water	207 (liters)

Table 5. Replacement quantities for one m^3 of concrete in different series.

Replacement percentage (%)	Mussel shell particulate (Kg)
10	49.3
30	147.9
60	295.7

Table 6. Apparent density in the different replacement series.

Mussel shell particulate (%)	Density (kg/m^3)
0	2419.7
10	2401.4
30	2362.1
60	2275.8

Dosage of materials for each replacement percentage sample of fine aggregate by mussel shell particulate of H-35(95)-20-6 concrete in fifty-liter test probes is indicated in Table 7.

Table 7. Volumetric replacement proportion in the control sample and different replacement percentages of mussel shell particulate.

Mussel shell particulate (%)	Material quantity (Kg)				
	Gravel	Sand	High-strength concrete	Water	Mussel shell particulate
0	54.8	33.1	20.6	10.4	0.0
10	54.8	29.8	20.6	10.4	2.5
30	54.8	23.1	20.6	10.4	7.4
60	54.8	13.2	20.6	10.4	14.8

3.4. Resistance to compression.

The studied test probe series were tested at the ages of 7 and 28 days from the start of their preparation (Table 8). The results indicate that in order to maintain the compressive strength of H-35(95)-20-6 concrete, the replacement percentage of fine aggregate by mussel shell particulate, should not exceed

40%, considering that 35 MPa is the design strength by the Faury method for this kind of concrete. Varhen et al. [6], studying the use of crushed Peruvian scallop shells as fine aggregate in concrete, also suggested a maximum of 40% replacement without compromising the mechanical properties of the concrete. Moreover, he noted that the replacement level may change due to the size and species of the particulate.

Table 8. Compression strength (Mpa) of cubic test probes
with different replacement percentages of mussel shell particulate at 7 and 28 days.

Replacement of Mussel shell particulate (%)	Time (days)	
	7	28
0	38.9	49.3
10	36.5	48.0
30	31.7	39.4
60	21.6	26.5

3.5. Thermal conductivity.

By increasing the replacement of aggregate by mussel shell particulate, a tendency to decrease thermal conductivity was observed." (Table 9, Figure 6). Thus, this implies that there is less heat transfer from one side of the face of the block to the other, turning into a material with a tendency to increase thermal insulation, which can be associated with the greater porosity contributed by the mussel shell particulate as a result of the aggregate´s angular shape and heterogeneous structure. Lertwattanaruk *et al*. [28] detected that the incorporation of mollusc shell powder as cement aggregate could reduce the thermal conductivity of the mortar. An increased open porosity decreases the thermal conductivity of the bricks, providing better temperature insulation [29]. On the other hand, Islam *et al*. [30] reported that mortars containing oyster shells as fine aggregate had better heat absorption than mortars without them; hence, recommending their use as top filler for reducing asphalt concrete surface heat. It can therefore be inferred that the replacement of natural fine aggregates by mussel shell particulate could help to improve the new demands for energy saving and efficiency in households, if used as coating.

Table 9. Thermal conductivity (W/m°K) in different test probes at 28 days.

Mussel shell particulate (%)	Thermal conductivity (W/m°K)
0	1.63
10	1.61
30	1.27
60	1.13

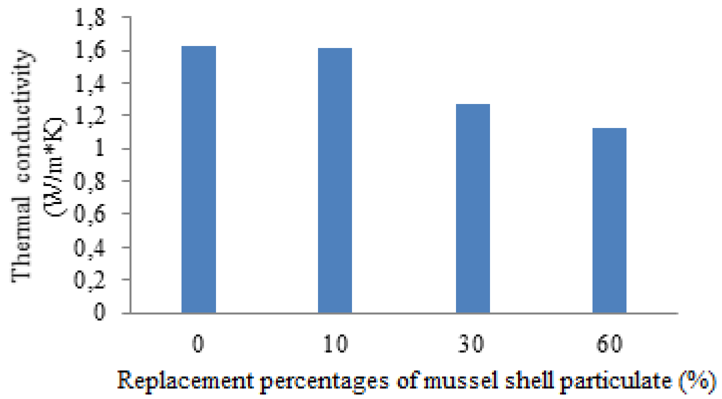

Figure 6. Thermal conductivity (W/m °K) in test probes with different replacement percentages.

3.6. Docility measured through Abrams cone method.

The settling result of the Abrams cone shows a decrease in concrete docility as the replacement percentage of fine aggregate by mussel shell particulate increases (Table 10). This is related to the tendency of the latter to absorb more water, which is attributed to the irregular flat form of the mussel shell particulate, thus, promoting particle friction and implying a decrease in the workability of the fresh concrete preparation [7,31]. Lertwattanaruk *et al*. [28] indicated that the specific surface area and size of the seashell particulate should be considered in the estimation of mortar docility. On the other hand, the four test probes presented plastic docility, according to NCh 170-1 Of. 2016 [32].

Table 10. Docility in different test probes at 28 days.

Mussel shell particulate (%)	Docitity (cm)
0	5.0
10	4.5
30	4.0
60	3.5

4. Conclusion

In order to maintain the compressive strength of H-35(95)-20-6 concrete, the replacement percentage of the mussel shell should not exceed 40%. Moreover, it was detected that by increasing the replacement percentage of mussel shell particulate by the fine aggregate, thermal conductivity decreases, turning into a material with a tendency for thermal insulation, which would help to improve the new requirements of saving and energy efficiency in households, if used as coating. This allows us to conclude that it is feasible to replace fine aggregates with mussel shell particulate material, and that this would have a positive influence on engineering properties and be a beneficial and significant contribution to the use of these residues by producing a reduction in the exploitation of fine aggregates. Hence, this would result in a decrease in the environmental impact of their use as construction material by contributing to sustainability. Therefore, the next step is to carry out an ecological and economic feasibility analysis in order to determine the viability of the commercial scale implementation of the replacement of fine aggregate by mussel shell particulate in mass concrete.

References

[1] Subsecretaria de Pesca y Acuicultura Gobierno de Chile 2018 *Informe Sectorial de Pesca y Acuicultura Enero 2018.* Departamento de análisis sectorial. 1-17
[2] Paz J, Baez D, Castro J, and García M 2012. Effects of mussel shell addition on the chemical and biological properties of a Cambisol *Chemosphere* **86** 1117–21

[3] Alvarenga RA, Galindro, BM, Helpa, CF, Soares, SR, 2012 The recycling of oyster shells: an environmental analysis using Life Cycle Assessment. *J. Environ. Manag* 102-109

[4] Nguyen DH, Boutouil M, Sebaibi N, Leleyter L and Baraud F 2013 Valorization of seashell by-products in pervious concrete pavers. *Construction and Building Materials* **49** 151–60

[5] Yoon GL, Kim BT, Kim BO and Han SH 2003 Chemical-mechanical characteristics of crushed oyster-shell *Waste Management* **23** 825–34

[6] Varhen C, Carrillo S and Ruiz G 2017 Experimental investigation of Peruvian scallop used as fine aggregate in concrete *Construction and Building Materials* **136** 533–40

[7] Falade F 1995 An investigation of periwinkle shells as coarse aggregate in concrete *Building and Environment* **30** 573–77

[8] Matias D, de Brito J, Rosa A and Pedro D 2014 Durability of Concrete with Recycled Coarse Aggregates: Influence of Superplasticizers *Journal of Materials in Civil Engineering* **26** 06014011.

[9] Pepe M, Toledo R, Koenders E and Martinelli E 2014 Alternative processing procedures for recycled aggregates in structural concrete *Construction and Building Materials* **69** 124–32

[10] Silva RV, de Brito J and Dhir RK 2014 Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. *Construction and Building Materials* **65** 201–17

[11] Gonzalez-Corominas A, Etxeberria M and Poon CS 2015 Influence of the Quality of Recycled Aggregates on the Mechanical and Durability Properties of High Performance Concrete. In WASCON 2015, Santander, 10–12 June 2015 pp 1–7

[12] Mo, KH, Alengaram UJ, Jumaat MZ, Lee SC, Goh WI and Yuen CW 2018 Recycling of seashell waste in concrete: A review *Construction and Building Materials* **162** 751–64

[13] Martínez C, González B, Martínez F and Carro D 2017 Performance of mussel shell as aggregate in plain concrete *Construction and Building Materials* **139** 570–83

[14] Benites CJ, Segura L and Jara W 2015 Resistencia de nuevos materiales para sustituir el cemento en concreto *Conocimiento para el Desarrollo* **6** 1-8

[15] Cuadrado-Rica H, Sebaibi N, Boutouil M and Boudart B 2016 Properties of ordinary concretes incorporating crushed queen scallop shells *Materials and Structures/Materiaux et Constructions* **49** 1805–16

[16] Chierighini D, Bridi R, Rocha A and Lapa K 2011 Possibilidades do Uso das Conchas de Moluscos *In International Workshop Advances in Cleaner Production* São Paulo-Brazil May 18th-20th pp 1–5

[17] Rakshvir M and Barai S 2006 Studies on recycled aggregates-based concrete *Waste Management and Research* **24** 225–33

[18] Wang HY, Kuo WT, Lin CC and Po-Yo C 2013 Study of the material properties of fly ash added to oyster cement mortar *Construction and Building Materials* **41** 532–37

[19] Espinoza E, Pulido E, Lugo F and Cruz L 2017 Adición de Tule (*Typha Dominguensis*) al Mortero Portland como refuerzo: Estudio de las propiedades Mecanicas *Revista Del Desarrollo Urbano y Sustentable* **3** 24–28.

[20] Instituto Nacional de Normalización 1968 *Norma Chilena NCh 148 Of. 68. Cemento – Terminología clasificación y especificaciones generales* INN Santiago-Chile

[21] Instituto Nacional de Normalización 2009 *Norma Chilena Oficial NCh 1019 Of.09. Hormigón – Determinación de la docilidad - Método del asentamiento del cono de Abrams* INN Santiago-Chile

[22] Instituto Nacional de Normalización 1977 *Norma Chilena Oficial NCh 1037 Of.77. Hormigón – Ensayo de compresión de probetas cúbicas y cilíndricas* INN Santiago-Chile

[23] Instituto Nacional de Normalización. Norma Chilena 1977 *NCh 1116 Of. 77. Áridos para morteros y hormigones. Determinación de la densidad aparente* INN Santiago-Chile

[24] Instituto Nacional de Normalización 2007 Norma Chilena Oficial *NCh 853 Of. 2007. Acondicionamiento Térmico - Envolvente térmica de edificios - Cálculo de resistencias y*

transmitancias térmicas INN Santiago-Chile p15
[25] Holman JP 1999 *Transferencia de calor* Décima Reimpresión McGraw Hill
[26] Alazmi B and Vafai K 2004 Analysis of Variable Porosity, Thermal Dispersion, and Local Thermal Nonequilibrium on Free Surface Flows Through Porous Media *Journal of Heat Transfer* **126** 389-99
[27] Sassi L, Mzali F, Jemni A and Ben Nasrallah S 2005 Hot-Wire Method for Measuring Effective Thermal Conductivity of Porous Media *Journal of Porous Media* **8** 97–114
[28] Lertwattanaruk P, Makul N and Siripattarapravat C 2012 Utilization of ground waste seashells in cement mortars for masonry and plastering *Journal of Environmental Management* **111** 133–41
[29] Felipe M, Eliche D, and Corpas F 2011 The use of solid residues derived from different industrial activities to obtain calcium silicates for use as insulating construction materials *Ceramics International* **37** 3019–28
[30] Islam MR, Satoru I and Masayoshi Y 2015 Surface Heat Reduction of Asphalt Concrete by Top Filling with Mortar Prepared by Oyster Shell Aggregate and Ground Granulated Blast Furnace Slag and Their Strength in Different Curing Condition *IDRE Journal* **296** 2–8
[31] Safi B, Saidi M, Daoui A, Bellal A, Mechekak A and Toumi K 2015 The use of seashells as a fine aggregate (by sand substitution) in self-compacting mortar (SCM) *Construction and Building Materials* **78** 430–438
[32] Instituto Nacional de Normalización 2016 *Norma Chilena Oficial NCh 170-1 Of. 2016. Hormigón -Requisitos generales* INN Santiago-Chile