Structural concrete modified with scallop shell lime
Concreto estructural modificado con cal de conchas de abanico

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Abstract

This research was conducted to determine the effect of the scallop shell lime (SSL) on the compressive strength of concrete made with Portland cement type Ico and natural aggregates from a quarry, where SSL was added at 3%, 4% and 5%. The physical and mechanical characteristics of the aggregates were determined based on the N.T.P. 400.037/ASTM C22 standard, and the mix design was carried out through the ACI method. The SSL was used due to the high calcium content present in the valve. Standard concrete controls were prepared and cured by adding 3%, 4% and 5% SSL (339.0183/ASTM C192M), which were analyzed at 7, 14 and 28 days of curing. The results showed that the compressive strength at 28 days was 242.63 kg/cm^2 when 3% SSL was added, increasing with respect to the standard control by 16%. With the addition of 4% SSL, the maximum strength reached was 245.25 kg/cm^2, and with 5%, the compressive strength reached was 261.17 kg/cm^2, increasing by 24%. In conclusion, the SSL positively affects the increase of concrete strength, and the percentage with the highest incidence is 5%.

Keywords: Seashells, lime, concrete, strength

Resumen

La presente investigación se realizó con la finalidad de determinar el efecto de la cal de conchas de abanico (CCA) en la resistencia a compresión del concreto elaborado con cemento Portland tipo Ico y agregados naturales de una cantera; se adicionó CCA en porcentajes de 3%, 4% y 5%. Se determinaron las características físico – mecánicas de los agregados según la norma N.T.P. 400.037/ASTM C22 y se realizó el diseño de mezcla por el método ACI. Se utilizó la CCA por contener altos contenidos de calcio en la valva. Se elaboraron y curaron los testigos de concreto estándar (concreto patrón) y con la adición de 3%, 4% y 5% de CCA (339.0183/ASTM C192M) para ser analizados a los 7, 14 y 28 días de curado. Los resultados mostraron que la resistencia a compresión a los 28 días fue de 242.63 kg/cm^2 al adicionar 3% de CCA, incrementándose con respecto al testigo patrón en un 16%. Para la adición de 4% de CCA la resistencia máxima alcanzada fue de 245.25 kg/cm^2, y con 5% alcanzó una resistencia de 261.17 kg/cm^2, incrementándose en 24%. Se concluye que la CCA tiene efecto positivo en el incremento de la resistencia del concreto, mostrándose que el porcentaje con mayor incidencia es el de 5%.

Palabras clave: Conchas, cal, concreto, resistencia

1. Introduction

The search for new materials to produce concrete is a trend, generally from waste materials from construction and industrial processes, which partly replace Portland cement or aggregates, mainly for issues related to cost, durability and good environmental performance. These reasons bring to the forefront advances in concrete technology, which have shown an unprecedented evolution with the use of superfluidizing, pozzolanic or cementitious admixtures such as silica fume, fly ash, rice husk ash and ground-granulated blast-furnace slag (Mehta, 2000). One of the natural materials that has gained importance is mollusk valves, particularly scallop shells (Argopecten purpuratus) since they present characteristics that favor their use as partial replacement of concrete aggregates (Nizama, 2014), depending on the effect of their particle size distribution, verifying that they have a greater incidence on the properties of fresh concrete when crushed, rather than in its hardened state (Saavedra, 2016). According to (Montejo et al., 2013), the valves have a high calcium content. This compound is very important in cement since calcium silicates (C_3S and C_2S) are the main component required because when they hydrate as calcium hydrated silicates, they are responsible for the mechanical strength and other properties of concrete.

C3S provides the short- and medium-term strength, and C_2S the medium- and long-term strength. Under this perspective, the use of concrete made with recycled materials will optimize and considerably reduce resources during the manufacturing process of its components. In this sense, this research evaluates the technical feasibility of incorporating by-products from scallop shells as materials to improve concrete properties.

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Many studies report the use of this material in the production of concrete. Thus, we have (Hung et al., 2018), who used waste from seashells of oysters, mussels and scallops, among other species, as a partial aggregate of up to 20% for workability and strength of concrete suitable for non-structural purposes. (Varhen et al., 2017) also evaluated the use of Peruvian scallop as fine aggregate in conventional concretes with 7, 28 and 90 days of curing and determined that the effects of the scallop depend on the size, shape and arrangement of the particles in the concrete mixture. The replacement percentage is variable, but a maximum of 40% is suggested for particle size between 1.19 and 4.75 mm, with the optimum being 5%. Also, (Castañeda, 2017) used crushed scallop shell waste as total aggregate in concrete mixtures and determined that the shape of the particles is elongated and flat in the coarse fraction and very angular in the fine fraction. This produces a decrease in the workability in the fresh state. Castañeda found out that when replacing 20% and 40%, the maximum strength of 273. 39 kg/cm^2 at 28 days of curing was obtained and recommended that it cannot be used as fine or coarse aggregate in its entirety because it would require more paste. (Saavedra, 2016) improved the strength of concrete by adding crushed scallop shell waste, with particle sizes of 4.76 and 1.19 millimeters. He made two concrete mixtures designed for a compressive strength of 210 kg/cm^2 by replacing the fine aggregate in weight percentage (5%, 20%, 40% and 60%), obtaining maximum strengths of 274 kg/cm^2, 247 kg/cm^2, 245 kg/cm^2 and 238 kg/cm^2 respectively at 28 days of curing. Finally, he determined that by adding a higher percentage of crushed shells, the compressive strength decreases.

Similarly, (Flores and Mazza, 2014) used waste lime from scallop shells (WLSS) at 5%, 10% and 15% to measure the compressive strength of concrete in specimens subjected to compressive loads at ages of 7, 14, 21 and 28 days. They determined that adding waste lime improves the strength but reported that the higher the addition of waste lime, the lower the strength and the slump in 1´´. In addition, (Wen et al., 2013) evaluated the use of oyster shell waste as a controlled low-strength material by replacing fine aggregate with 5%, 10%, 15% and 20%, and cement with 20% fly ash. They showed that there was no significant reduction in compressive strength up to 20% of sand replacement and an adequate amount of fly ash, concluding that oyster shell waste can be a resource to be used in adequate proportions when replacing fine aggregate.

(Eun-Ik et al.,2010) evaluated the use of crushed oyster shells (CO) as a partial replacement of saturated surface dry sand (fine aggregate), i.e., they investigated the mechanical properties and long-term durability of concrete. They showed that the long-term strength of concrete with 10% CO is almost identical to that of standard concrete. However, with 20% CO, it is significantly lower than that of standard concrete. They concluded that a higher CO substitution has a negative influence on the long-term concrete strength. The elastic modulus of concrete with the CO replacement decreases as the proportion of the replacement mixture increases. Specifically, the modulus decreases by approximately 10-15% when CO is used for 20% fine aggregate.

Another way to use this material is as indicated by (Farfán, 2015), who evaluates the use of crushed scallop shells as a mechanical soil stabilizer to improve the subgrade in roads with a high percentage of sand, demonstrating that these mollusks have a resistance similar to that of stone aggregates, which is an indicator of improvement for the CBR of sandy soils. Adding 45% shells improves the particle size distribution, providing coarse particles to soils with silts and sands, and providing voids that cannot be completely filled.

2. Discussion and development

2.1 Material and Methods:

The research has a pure experimental design with post-test only, and 48 specimens of 15x30 cm were analyzed, according to NTP 339.183 (2013), 12 for control specimens and 36 experimental specimens at 7, 14 and 28 days of curing with 3%, 4% and 5% of scallop shell lime. Pacasmayo Type Ico cement, aggregates from a quarry in the city of Trujillo, Peru, and scallop shell lime were used. To meet the objectives set, the characterization of fine and coarse aggregates was performed, and the concrete mix design for a strength of 210 kg/cm^2 was carried out using the ACI 2010 method. The four mixture types designed were: plain concrete (PC), PC plus 3% SSL (PC3SSL), plus 4% SSL (PC4SSL) and 5% SSL (PC5SSL). Slump tests were performed for each of the mixtures in the plastic state under NTP 339.035 2015 and ASTM C 143 2016 standards, and in the hardened state, the compressive strength was measured according to ASTM C39 2016 standard. The results of the compression tests were processed using the ANOVA (analysis of variance) to determine the differences in strength between groups of specimens. The Tukey test for multiple comparisons was then used to identify pairs of groups that are significantly different from each other, at a significance level of 5%.

2.2 Results

The results obtained from the actions defined in the work methodology are presented below: Physicochemical characterization of materials and mix design: To analyze the chemical composition of scallop shell lime (SSL), 200 g of this material were used. The results are shown in (Table 1).

Table 1. Chemical composition of SSL

Element	Result (%)	Method Used
Calcium, Ca	52.509	X-Ray Fluorescence
Oxygen, O	44.706	
Carbon, C	1.868	
Hydrogen, H	0.311	
Sulfur, S	0.383	
Strontium, Sr	0.098	
Iron, Fe	0.066	
Silicon, Si	0.054	
Zinc, Zn	0.004	

The particle size analysis of the fine and coarse aggregates showed that they do comply with the specifications of the Peruvian Technical Standard (from the Spanish Norma Técnica Peruana, NTP), as shown in (Figures 1) and(Figure 2).

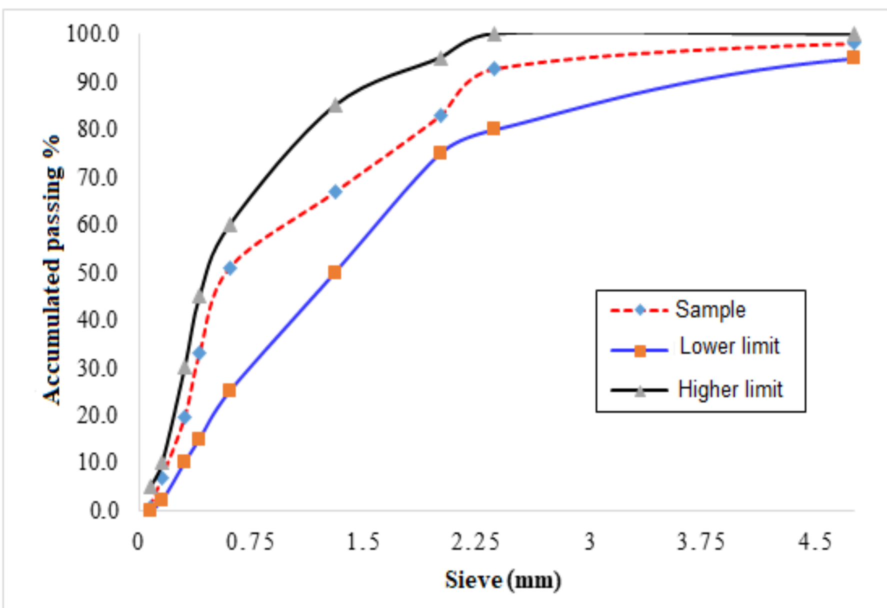

Figure 1. Granulometric curve of fine aggregate. Limits according to ASTM C33 2016.

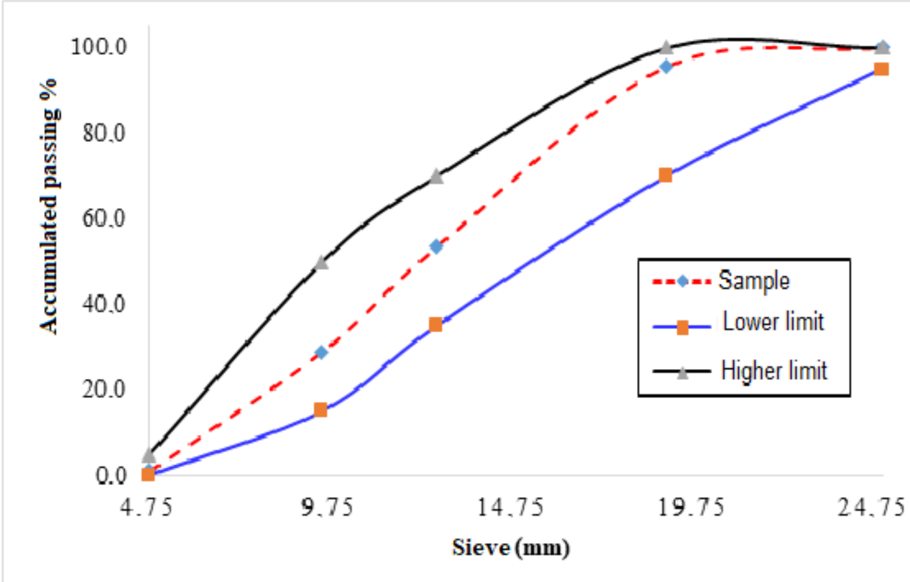

Figure 2. Granulometric curve of coarse aggregate. Limits according to ASTM C33 2016.

The concrete mix design was conducted following the ACI-2010 procedure, with the proportions used in the concrete mixture as shown in (Table 2).

Table 2. Plain concrete mix design for 210 Kg/cm^2

Material	Weight Ratio	Weights (Kg)	Mixture %
Cement	1.00	378.94	15.69
Water	0.61	232.53	9.63
Fine aggregate	2.20	823.36	34.09
Coarse aggregate	2.60	980.25	40.59
Total for 1m^3		2415.08	100.0

Tests in the fresh state and mechanical tests in the hardened state:
Tests of fresh state specimens are shown in (Table 3).

Table 3. Concrete slump in the fresh state

Mixtures	A/C Ratio	Maximum Slump (inches)	Variation %
PC	0.61	3.5	0%
PC3SSL	0.61	3.45	-1.43%
PC4SSL	0.61	3.53	0.86%
PC5SSL	0.61	3.58	2.29%

Compressive strength tests on hardened concrete are shown in (Table 4) and (Figure 3) and (Figure 4) for 150mm x 300 mm specimens.

Table 4. Compressive strength of hardened concrete specimens at different curing ages

Mixture	Compressive strength (Kg/cm^2)					
	7 days	Alc. %	14 days	Alc. %	28 days	Alc. %
PC	155.70	106%	182.82	102.4%	227.11	108.1%
PC3SSL	169.55	115%	220.51	123.5%	237.45	113.1%
PC4SSL	175.02	119%	221.96	124.3%	241.23	114.9%
PC5SSL	175.23	119.2%	227.10	127.2%	255.17	121.5%

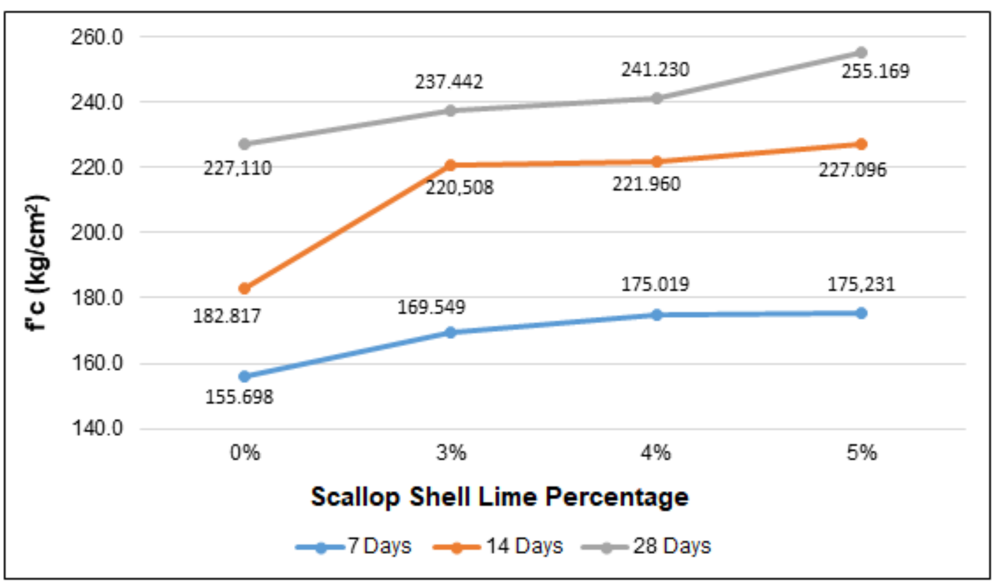

Figure 3. Compressive strength according to scallop shell percentage.

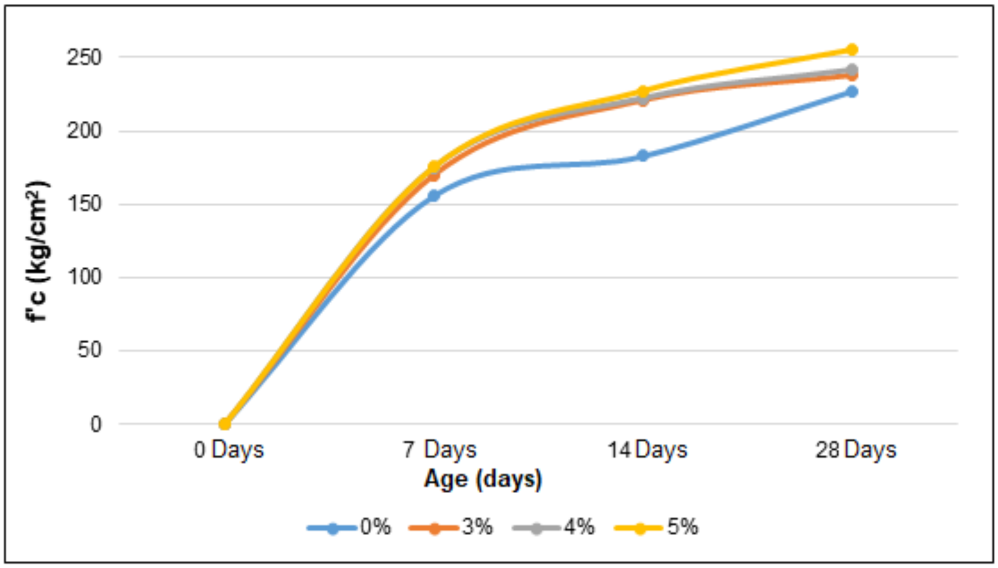

Figure 4. Compressive strength according to curing days of test specimens.

All the compressive strength data according to the age of the concrete specimens showed a normal distribution (p>0.05). Therefore, the variance analysis and the Tukey multiple comparison tests were performed. The results are shown in (Table 4) and (Table 5).

Table 5. Analysis of variance (ANOVA) for compressive strength data according to the age of concrete

Age of Specimens	Mean	Standard Deviation	F	Significance (p)*
7 days	168.88	9.81	9.291	0.002
14 days	213.10	19.10	40.999	0.000
28 days	240.24	11.08	28.524	0.000

*The difference in means is highly significant at the 0.01 level (p<0.01).

Regarding the effect of the percentage of SSL, according to the days of curing, (Table 5) shows thatthere are very significant differences (p<0.01) in the concrete specimens at different days of curing.

(Table 6) shows that at 7, 14 and 28 days of curing there are significant differences (p<0.05) between the strengths of the standard sample PC and the experimental samples PC3SSL, PC4SSL, PC5SSL.

Table 6. Multiple comparison between samples of concrete specimens according to their age

Samples	PC	PC3SSL	PC4SSL	PC5SSL
7 days				
PC	-----	0.030*	0.003**	0.003**
PC3SSL		-----	0.588	0.559
PC4SSL			-----	1.000
PC5SSL				-----
14 days				
PC	-----	0.000**	0.000**	0.000**
PC3SSL		-----	0.988	0.487
PC4SSL			-----	0.673
PC5SSL				-----
28 days				
PC	-----	0.025*	0.003**	0.000**
PC3SSL		-----	0.620	0.000**
PC4SSL			-----	0.003**
PC5SSL				-----

* The difference in means is significant at the 0.05 level (p<0,05)
** The difference in means is highly significant at the 0.01 level (p<0,01)

3. Analysis of Results

3.1 Fresh concrete slump

The slump in concrete mixtures with SSL contents from 3% to 5% had an increase of up to 2.29% and a decrease of 1.43% compared to plain concrete (PC), as shown in (Table 3). There are no studies where SSL has been used. However, (Flores and Mazza, 2014) verified that the workability decreased by an average of 1´´ as the use of scallop shell powder (SSP) increased. In this research, the workability of the PC reached the maximum value at 3.5´´, while those containing 4% and 5% SSL lost plasticity but kept workability within the range of 3´´ to 4´´.

3.2 Compressive strength

The compressive strengths observed in (Table 4) show that the concrete mixtures exceeded the design strength at the three ages under study. A similar situation was reported by (Flores and Mazza, 2014), who found out that the strength achieved at 14 and 28 days exceeded the strength under study using WLSS as a replacement for cement at 5%, 10% and 15%. Also, (Eun-Ik et al., 2010) showed that when the use of crushed oysters increases, the strength tends to decrease in the long term. Consequently, it is not advisable to use more than 10% of crushed oysters. Similarly, (Wen et al., 2013) used oyster shell waste combined with fly ash, up to a 20% ratio, and evidenced a strength according to the mix design they had set up.

For the samples with 3%, 4% and 5% SSL, the strengths found exceeded the design strength by 19%, 27% and 21% for ages 7, 14 and 28 days of curing, respectively. These results show that the increase in the compressive strength of the concrete would be due to the proportion of SSL used and the curing time because as the amount of SSL increases (Figure 3), the average strength reached by the mixtures under study increases for the three curing ages and is not lower than the design strength. In the case of 28 days of curing, the increasing trend is progressive, reaching its maximum strength at 5% SSL (255.2 kg/cm^2).

According to (Figure 4), the compressive strength increases at 7 and 14 days with short-term tests. Although, for 3% and 4% SSL, the strength tends to decrease gradually at an age above 14 days. In this sense, the compressive strength is affected and reduced by the addition of SSL, unlike the standard sample, which does not suffer this effect. This problem can be solved if an admixture is added, as it would ensure a reduction of water and provide a better consistency to the concrete.

3.3 Statistical analysis

Regarding the effect of SSL on the compressive strength of concrete, it was determined that there are highly significant differences ($p<0.01$) between the strengths of the samples at 7, 14 and 28 days of curing (Figure 4). Statistically, it is confirmed that concrete components and curing time play a fundamental role in this mechanical property. The multiple comparison determined that at 14 days of curing, the samples with a 5% proportion of SSL are the only ones that show significant differences ($p=0.017$) as these differences persist and are above those of the design (Figure 4). At 28 days, the samples with SSL have similar behavior to the standard concrete, showing no significant differences. Consequently, the presence of SSL as a functional component of concrete influences its compressive strength.

From (Table 3) and (Figure 3) and (Figure 4), we can infer that the sample with 5% SSL has a better performance than the standard sample, being able to develop a compressive strength with better results than the samples with 3% and 4% SSL, although these also exceeded the design strength, either at 14 and 28 days of curing.

4. Conclusions

- The optimum percentage of scallop shell lime to obtain the highest compressive strength of concrete (255.17 Kg/cm^2) is 5% at 28 days.

- Scallop shell lime provides concrete with better workability by increasing its proportion to the mixture, improving it by more than 2%.

- The study confirms it is feasible to use scallop shell lime to increase the compressive strength up to more than 20%. It also contributes to reducing the negative effects of valve waste on the environment.

- The cement tolerates its replacement in the concrete mixture with scallop shell lime in lower percentages without reducing its compressive strength as the lime contains a large amount of calcium in the form of calcium silicates.

- The scallop shell lime is a good alternative for replacing cement in the preparation of concrete and could be used even in structures with a moderate seismic response

5. References

ACI (2010). Concrete Mix Design. American Concrete Institute (ACI).

ASTM (2016). ASTM C33 Standard Specification for Concrete Aggregates. American Society for Testing and Materials (ASTM).

ASTM (2016). ASTM C143 Standard Test Method for Slump of Hydraulic-Cement Concrete. American Society for Testing and Materials (ASTM).

ASTM (2016). ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. American Society for Testing and Materials (ASTM).

Castañeda, David (2017). Análisis de la granulometría de la concha de abanico triturada para su uso como agregado en concretos. Thesis (Bachelor of Civil Engineering). Available in https://pirhua.udep.edu.pe/handle/11042/3011

Eun-ik, Yang; Myung-yu, Kim; Hae-geun, Park; Seong-tae, Yi (2010). Effect of partial replacement of sand with dry oyster shell on the long-term performance of concrete. Construction and Building Materials [online]. Volume 24, No. 5, May. [Accessed on: August 25, 2019]. Available in https://www.sciencedirect.com/science/article/abs/pii/S0950061809003699

Farfán, Pierre (2015). Uso de concha de abanico triturada para mejoramiento de subrasante arenosa. Thesis (Civil Engineering Degree). Available in https://pirhua.udep.edu.pe/bitstream/handle/11042/2333/ICI_218.pdf?sequence=1

Flores, Liz; Mazza, Julio (2014). Utilización de residuos de conchas de abanico como mejoramiento en las propiedades resistentes del concreto. Thesis (Civil Engineer). Available in http://repositorio.uns.edu.pe/handle/UNS/1912

Hung, Kim; Johnson, U; Zamin, Mohd; Cheng, Siew; Inn, Wan; Wah, Choon (2018). Recycling of seashell waste in concrete. Revista internacional de investigación [online]. February 2018, No. 162. [Accessed on: August 15, 2019]. Available in https://www.sciencedirect.com/science/article/pii/S0950061817324042

Mehta, P. (2000). Avances en la tecnología del concreto. Revista Construcción y Tecnología, octubre 2000. Instituto Mexicano del Cemento y del Concreto, A.C. Available in http://www.imcyc.com/revista/2000/octubre2000/concreto.htm

Montejo, Alonso; Montejo, Francy; Montejo, Alejandro (2013). Tecnología y patología del concreto armado. 1st edition. Bogota: Universidad de Colombia, 2013. 540 pp. ISBN: 9789588465500

Nizama, Douglas (2014). Valoración de residuos crustáceos para concretos de baja resistencia. Tesis Thesis (Civil Engineering Degree). Available in https://pirhua.udep.edu.pe/handle/11042/2194

NTP (2015). NTP 339.035 Concreto. Método de ensayo para la medición del asentamiento del concreto de Cemento Portland. 4th edition. Norma Técnica Peruana (NTP).

NTP (2013). NTP 339.183 Concreto. Práctica normalizada para la elaboración y curado de especímenes de concreto en el laboratorio. 2nd edition. Norma Técnica Peruana (NTP).

Saavedra, José (2016). Interacción de la concha de abanico triturada con los agregados triturados y redondeados en mezclas de concreto. Thesis (Bachelor of Civil Engineering). Piura: Universidad de Piura, 2016. 144. pp.

Varhen, Christina; Carrillo, Shirley; Ruiz, Gaby (2017). Experimental investigation of Peruvian scallop used as fine aggregate in concrete. Construction and Building Materials [online]. April 2017, No. 136. [Accessed on: November 18, 2018]. Available in https://www.sciencedirect.com/science/article/abs/pii/S0950061817300922

Wen-ten, Kuo; Her-yung, Wang; Chun-ya, Shu; De-sin, Su (2013). Engineering properties of controlled low-strength materials containing waste oyster shells. Revista internacional de investigación [online]. September 2013, No. 46. [Accessed on: November 15, 2018]. Available in https://www.sciencedirect.com/science/article/pii/S0950061813003437.