

Recycled Concretes Made with Waste Ready-Mix Concrete as Coarse Aggregate

Claudio Javier Zega¹ and Angel Antonio Di Maio²

Abstract: Using waste materials for new products is a global trend undergoing rapid development. Recycling materials allows for a more efficient life cycle and contributes to environmental protection. In the construction field, this trend has gained importance because of the shortage of natural resources and because of environmental problems caused by storing building-demolition wastes. This situation has led to the search for new applications for these wastes, and their use as aggregates in concrete is an interesting alternative. In this paper, some characteristics of recycled coarse aggregates obtained by crushing waste ready-mix concrete, as well as the mechanical and durability properties of recycled concretes made by using 25, 50, and 75% of these aggregates, are presented. Recycled concretes show lower compressive strength than conventional concrete for the higher strength level, whereas the durability properties of the two are similar. DOI: 10.1061/(ASCE)MT.1943-5533.0000165. © 2011 American Society of Civil Engineers.

CE Database subject headings: Recycling; Concrete; Aggregates; Compressive strength; Splitting.

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Introduction

Using different types of waste materials for new products is a growing global trend. Recycling has a twofold purpose: (1) to minimize the amount of waste to be deposited and (2) to preserve natural resources.

Recycling materials allows for higher efficiency throughout their life cycle and is consistent with environmental protection trends. At the end of its life cycle, a material becomes waste, which can be transformed into a new material to make new products or to be used in structural applications. Effective recycling is using a waste material to produce a new material of similar characteristics, thereby achieving higher efficiency in its life cycle (Vázquez and Barra 2002).

Because of different reasons such as shortage of natural resources (mainly aggregates), increasing demand for raw materials, and environmental problems caused by construction and demolition waste disposal sites, looking for new applications for these materials has become a major issue in civil engineering. Using old crushed concretes as aggregates for new concretes to partially or completely replace natural aggregates is a good example of higher efficiency in concrete life.

The concrete industry uses approximately 10 billion tons of sand and natural rock worldwide, and more than 10 billion tons of construction and demolition waste are produced every year (Mehta 2002). The European Union produces approximately 200–300 million tons per year of construction and demolition

waste, which is roughly equivalent to 0.5–1 ton per capita per year. Toward the end of the 1990s, 28% of the wastes of the European Union were recycled (Lauritzen 2005). In the United States, wastes are estimated at 250–300 million tons per year. In addition, 85 million tons of construction wastes were generated in Japan in 2000, 40% of which were concrete wastes (Kasai 2005).

The production of concrete waste is frequently linked to the repair and/or demolition of building structures and road surfaces, that is, concrete that has been duly compacted and cured. However, there is another peculiar source of such wastes that is often overlooked—the remains of ready-mix concrete. In countries where there are no specific regulations or penalties for the illegal deposit of such wastes, as in Argentina, these concrete remains are usually deposited at inappropriate sites, such as vacant lots or quiet suburban streets. Unlike demolition wastes, these concretes are deposited without adequate compaction and curing treatment. Consequently, if these will be used as recycled aggregates to manufacture new concrete, special attention should be paid to the changes that their properties can undergo because they are less stable than natural aggregates.

Studies have been carried out on the different properties of recycled concretes with crushed waste concretes of different origin (such as coarse aggregate), and highly satisfactory results regarding their strength properties have been reported (Topcu and Sengel 2004; Katz 2003; Poon et al. 2004). In Argentina, the LEMIT (Spanish acronym for Multidisciplinary Training Laboratory for Technological Research) is the only laboratory that has this subject as a line of research developed for approximately a decade, and the results obtained agree well with previous researches (Di Maio et al. 2001; Zega et al. 2005, 2006; Zega 2008).

The objective of this work is to illustrate the main characteristics of recycled coarse aggregates (RCA) obtained by crushing waste ready-mix concrete and to analyze the physical, mechanical, and durability properties of structural concrete made with such aggregates but characterized by different replacement percentages. Some properties of RCA are compared with those of natural aggregates, and different properties of the recycled concretes, both in the fresh and in the hardened states, are reported.

¹Civil Engineer, Research Fellow, CONICET-LEMIT, La Plata, Argentina.

²Mechanical Engineer, Professor, Civil Engineering Dept., Technological Univ. of La Plata (UTN) and Research Engineer, CONICET-LEMIT, La Plata, Argentina.

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Experimental Program

Six batches of concretes characterized by two strength levels (C17, $f'_c = 17$ MPa; C30, $f'_c = 30$ MPa) and three percentages of recycled coarse aggregate as replacement (25, 50, and 75% by volume) were cast. For the low-grade concrete (C17), the objective was to produce recycled concrete with characteristics similar to those of the source concrete. For the C30 concrete, the goal was to manufacture a recycled concrete with a satisfactory strength level and acceptable durability properties.

Materials and Mixtures

Because of limited space in concrete-manufacturing companies, the remains of ready-mix concrete are typically deposited at the company's site. Aside from its significant visual impact, this also reduces the space available to such an extent that there is not much space left. An example of such deposits is shown in Fig. 1.

The RCA was obtained by crushing one of the concrete remains shown in Fig. 1, which was identified when the mixture was dumped from the mixer and whose constituent materials were known. Then, 150 × 300 mm cylindrical specimens were cast and subjected to a standard curing ($T = 23 \pm 2^\circ\text{C}$; $\text{RH} = 95\%$). The tests were performed at the age of 28 days. The average compressive strength was 20 MPa.

The remaining concrete was deposited on the ground and exposed to the existing weather conditions ($T = 10^\circ\text{C}$; $\text{RH} = 75\%$) for approximately 2 months. It was then crushed in a jaw crusher to obtain the RCA, as shown in Fig. 2.

This RCA was used to cast different recycled concretes. The other materials added were composite portland cement (ASTM Type I), two natural siliceous sands, and natural granitic crushed

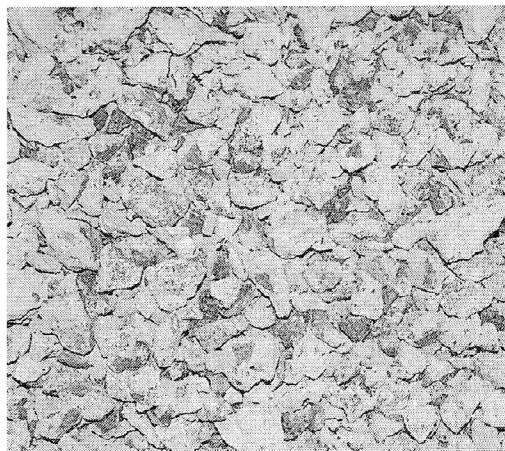


Fig. 2. Recycled coarse aggregate obtained from ready-mix concrete

sand. Granitic crushed stone (GCS) (6–20 mm), similar to that found in the waste ready-mix concrete, was used as a natural coarse aggregate. A plasticizer was also used to have the same slump in all concretes, especially in those with recycled aggregates because the RCAs were used in an air-dry condition. This is the state at which the aggregate is superficially dry but contains a certain percentage of humidity. The different properties of the natural and recycled aggregates used are presented in Table 1.

Compared with the natural granitic aggregate, the RCA had a lower specific gravity, a higher water absorption and abrasion weight loss, and a higher content of material finer than 75 μm .



Fig. 1. Deposit of remains of ready-mix concrete in a concrete-manufacturing company

Table 1. Properties of Natural and Recycled Aggregates

Properties	Siliceous sand 1	Siliceous sand 2	Granitic crushed sand	Granitic crushed stone	Recycled coarse aggregate
Maximum size (mm)	—	—	—	19.0	19.0
Fineness modulus	1.55	2.49	3.00	6.28	6.49
Specific gravity	2.65	2.63	2.70	2.72	2.44
Water absorption (%)	0.2	0.8	0.9	0.2	5.8
Material finer than 75 μm (%)	1.2	0.2	6.2	1.0	3.9
Los Angeles wear (%)	—	—	—	25.0	33.6

This is attributable to the mortar in the particles that constitute the recycled aggregate (Hansen 1986; Gómez et al. 2001; Zega 2008).

C17 concretes contain the same materials used to produce waste concrete (C17R0) from which the recycled coarse aggregate was obtained. The replacement percentages of the natural coarse aggregate by RCA were 25, 50, and 75% by volume. These concretes were named C17R25, C17R50, and C17R75. For C30, a conventional concrete (C30R0) was cast in the laboratory by using only natural aggregates; recycled concretes were also produced by replacing the natural coarse aggregate with recycled aggregates in the same percentages as previously described. The proportions of the other materials were kept constant, and these concretes were named C30R25, C30R50, and C30R75.

In all cases, natural and recycled coarse aggregates were used in an air-dry condition. Taking into account the high absorption of the RCA, two different work methods were applied to produce C17 and C30 concretes. For C17 concretes, the amount of mixing water was corrected as a function of RCA absorption, whereas for C30 concretes the amount of water was kept constant in all concretes, and the plasticizer dosage was increased for higher RCA percentages to obtain similar slumps in all concretes. In the latter case, the solid materials were premixed with 70% water, and the remaining 30% was later added with the plasticizer to prevent its absorption by the recycled aggregate.

Table 2 includes the mixture proportions corresponding to recycled C17 concretes and to conventional and recycled C30 concretes.

For each concrete batch, three 150 \times 300 mm cylindrical specimens were cast and cured in a fog room ($T = 23 \pm 2^\circ\text{C}$; $\text{RH} = 95\%$) for 28 days. Subsequently, the following mechanical properties were measured: compressive strength [C39-03 (ASTM 2003)], splitting tensile strength [C496-04 (ASTM 2004)], and static modulus of elasticity [C469-02 (ASTM 2002)]. Moreover, for the C30 concrete, the depth of water penetration under pressure was determined on cubic specimens of 200-mm side [IRAM 1554 (Instituto Argentino de Racionalización de Materiales 1983)].

Experimental Results and Discussion

Fresh Concrete

The fresh-state properties (slump, unit weight, and air content) of the different concretes are presented in Table 3.

With regard to slump, the work methods applied to C17 and C30 concretes were different, as mentioned before. When the amount of added water was increased according to the absorption of the recycled aggregate, a slump increase could be observed in the C17 mix. This may be because the recycled aggregate's absorption capacity inside the mixture is different when immersed in water.

Table 2. Mix Design of Different Concrete Batches

Materials (kg/m ³)	C17				C30			
	C17R0	C17R25	C17R50	C17R75	C30R0	C30R25	C30R50	C30R75
Total water	175	200	210	220	165	165	165	165
Cement	270	270	270	270	370	370	370	370
Total water-cement ratio	0.65	0.74	0.78	0.82	0.45	0.45	0.45	0.45
Effective water-cement ratio	0.65	0.65	0.65	0.65	0.45	0.42	0.40	0.38
Siliceous sand 1	750	750	750	750	175	175	175	175
Siliceous sand 2	—	—	—	—	690	690	690	690
Granitic crushed sand	250	250	250	250	—	—	—	—
Granitic crushed stone	900	675	450	225	1010	760	505	250
Recycled coarse aggregate	—	200	400	600	—	230	455	680
Additive	0.81	1.08	1.35	1.62	—	1.48	1.85	2.59

Table 3. Fresh-State Properties of Investigated Concretes

Properties	C17			C30			
	C17R25	C17R50	C17R75	C30R0	C30R25	C30R50	C30R75
Slump (mm)	80	110	170	70	50	30	25
Unit weight (kg/m ³)	2,297	2,244	2,186	2,417	2,385	2,373	2,317
Air content (%)	3.5	4.0	4.6	1.9	2.3	2.5	3.0

This is because inside the mixture, the aggregate is within the cement paste or mortar. On the contrary, in C30 concretes, in which the amount of mixing water was kept constant in all concretes, a slump decrease was noted when the replacement percentage was higher than 50% despite using a higher plasticizer dosage.

The unit weight decreased as the percentage of recycled aggregate increased, regardless of the concrete strength level, mainly because of the lower specific gravity of the recycled aggregate. For the same replacement percentage, recycled C30 concretes exhibited a higher unit weight than C17, as happens in conventional concretes characterized by different strength levels.

For naturally entrained air, a slightly increasing trend could be observed, depending on the percentage of RCA used. Furthermore, the plasticizer dosage was increased accordingly, which could have led to an increase in the entrained air content.

Hardened Concrete

Compressive Strength

The results of the compression tests carried out at age 28 days for the recycled C17 concretes and for the conventional and recycled C30 concretes for the different replacement percentages are shown in Fig. 3. Each of the reported values represents the average of three tests.

Fig. 3 shows that for C17 concretes, the compressive strength of recycled concretes are similar to that of the original concrete for a replacement of up to 50% (10% lower), showing a 19% decrease for the concrete made with 75% of recycled aggregate (C17R75). The lower strength of recycled concretes may be caused by excess water. Although the effective water-cement (w/c) ratio of the different C17 concretes seems to be the same, the amount of water added to compensate for the higher absorption of RCA could have been too much. Therefore, the free water content of the concretes would be different, and this may contribute to the lower compressive strength observed in higher RCA percentages.

For C30 concretes, the compressive strengths of recycled concretes are, on the average, 16% lower than that of conventional concrete (C30R0). This can also be attributed to the lower strength of recycled aggregates. Moreover, all recycled C30 concretes show similar strength levels regardless of the percentage of recycled aggregate added. This can be attributed to an improved quality of the C30 concrete matrix resulting from the decrease in the effective w/c ratio.

Splitting Tensile Strength

The splitting tensile strengths of recycled C17 concretes and of conventional and recycled C30 concretes as the average of three tests in each case are presented in Fig. 4.

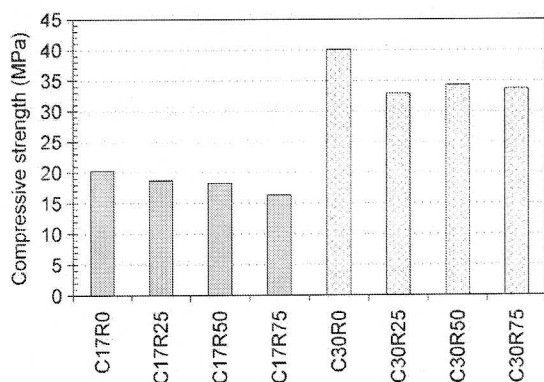


Fig. 3. Compressive strength of investigated concretes

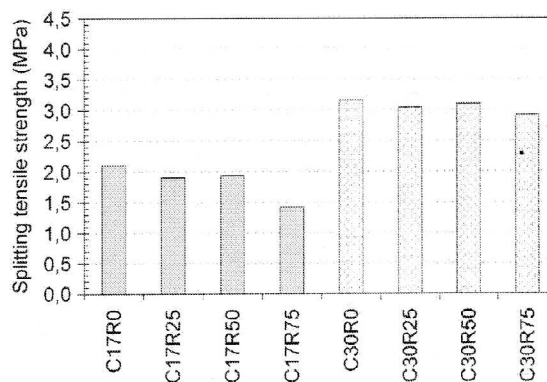


Fig. 4. Splitting tensile strength of investigated concretes

For C17 concretes, the splitting tensile strengths of recycled concretes C17R25 and C17R50 are very similar, whereas the concrete made with 75% of recycled aggregate exhibits a strength that is 25% lower. C30 concretes exhibit a different behavior compared with C17 concretes because the splitting tensile strength of recycled C17 concretes is similar to that of the conventional one, with C30R75 showing a decrease slightly below 10%. This can be attributed to an improvement in the transition zone of the mortar-recycled aggregate, to using recycled aggregates in an air-dry condition, and to their higher porosity. In this sense, the lower effective w/c ratio would contribute to the quality of the transition zone.

Static Modulus of Elasticity

The static modulus of elasticity obtained for recycled C17 concretes and for conventional and recycled C30 concretes is shown in Fig. 5; each value represents the average of three tests.

As observed in previous studies (Di Maio et al. 2002; Zęga et al. 2006), the static modulus of elasticity decreases with increasing percentage of recycled aggregate for both strength levels studied (C17 and C30). This can be attributed to the lower stiffness of the recycled aggregate compared with the natural one because of the presence of mortar in its constitution. However, the values are still high and thus satisfactory for structural applications.

Water Penetration Under Pressure

To assess the durability of recycled C30 concretes, the water penetration under pressure was measured on cubic specimens (200-mm side). The test consists of placing the concrete specimen under

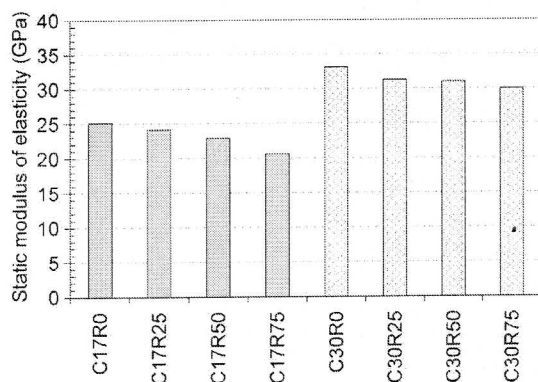


Fig. 5. Static modulus of elasticity of investigated concretes

varying water pressure for 96 h (48 h at 0.1 MPa, 24 h at 0.3 MPa, and 24 h at 0.7 MPa). Then, the cube is split to measure the water penetration depths in both halves. The value of water penetration is calculated by averaging the results of three tests.

The equipment used for the water penetration test and the penetration profile drawn on the specimen after testing are shown in Figs. 6 and 7, respectively.

This test is indicated by Argentina's draft regulations [CIRSOC 201-2005 (Instituto Nacional de Tecnología Industrial 2005)] as a requirement for durable concretes. According to this regulation, the results of this test must comply with two requirements: an average

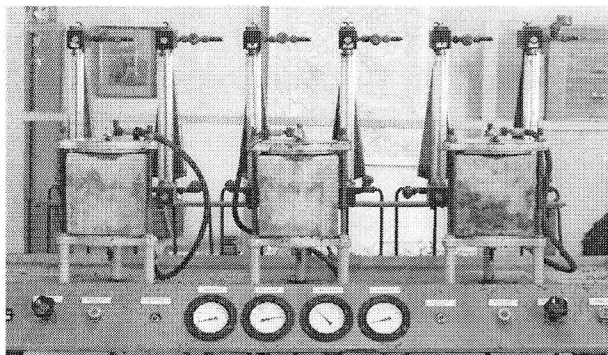


Fig. 6. Equipment for water penetration test

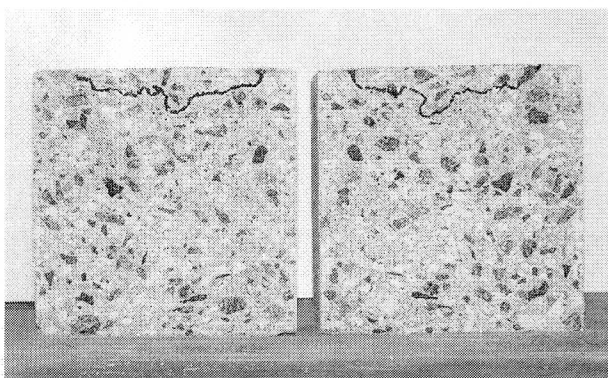


Fig. 7. Typical penetration profile drawn on one specimen after testing

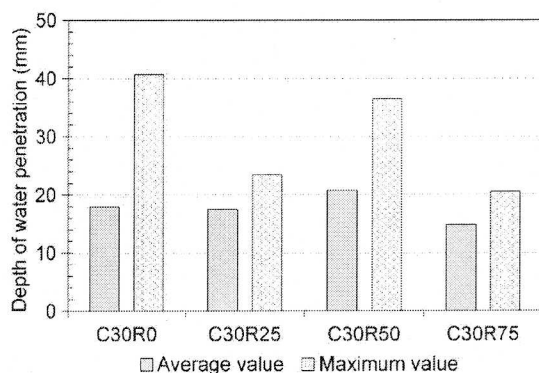


Fig. 8. Depths of water penetration

penetration value of lower than 30 mm and a maximum penetration value of lower than 50 mm.

The average and maximum penetration depths observed in the conventional and recycled C30 concretes are presented in Fig. 8.

It can be observed that the average values of water penetration of recycled concretes are similar to those of conventional concrete, whereas the maximum values of water penetration are lower for recycled concretes. This can be attributed to an improvement in the transition zone of the mortar-recycled aggregate, to their higher porosity, and to using recycled aggregate in an air-dry condition.

Conclusions

The recycled coarse aggregate obtained by crushing the remains of ready-mix concrete that was deposited outdoors without adequate compaction and curing treatment was of lower quality compared with natural aggregates. However, the recycled aggregate performed well when it was used to manufacture structural concrete by replacing 25, 50, and 75% of the natural aggregate. For the lower strength level (17 MPa), the compressive strength of recycled concretes was similar to that of the source concrete for up to 50% replacement. For the higher strength level (30 MPa), however, the compressive strength of the recycled concretes was 16% lower than that of the reference concrete for all the replacement percentages studied. In spite of this slight reduction, the durability properties of these concretes determined by the penetration of water under pressure was similar to, and in some cases better than, that of the reference concrete.

Therefore, it can be concluded that although the properties of the recycled coarse aggregate studied are not as good as those of the natural aggregate, the concretes made with it present an acceptable strength and durability, considering its origin.

References

- ASTM. (2002). "Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression." C469-02, West Conshohocken, PA.
- ASTM. (2003). "Standard test method for compressive strength of cylindrical concrete specimens." C39-03, West Conshohocken, PA.
- ASTM. (2004). "Standard test method for splitting tensile strength of cylindrical concrete specimens." C496-04, West Conshohocken, PA.
- Di Maio, A., Giaccio, G., and Zerbino, R. (2002). "Hormigones con agregados reciclados." *Cienc. Tecnol. Hormig.*, 9, 5–10.
- Di Maio, A., Gutierrez, F., and Traversa, L. P. (2001). "Comportamiento físico-mecánico de hormigones elaborados con agregados reciclados." *Proc., 14th Reunión Técnica de la Asociación Argentina de Tecnología del Hormigón*, Asociación Argentina de Tecnología del Hormigón (AATH), Olavarría, Argentina, 37–44.
- Gómez, J. M., Agulló, L., and Vázquez, E. (2001). "Cualidades físicas y mecánicas de los agregados reciclados de concreto." *Construcción y Tecnología*, 13(157), 10–20.
- Hansen, T. C. (1986). "Recycled aggregates and recycled aggregate concrete. Second state-of-the-art report developments 1945–1985." *Mater. Struct.*, 19(3), 201–246.
- Instituto Argentino de Racionalización de Materiales (IRAM). (1983). "Hormigón de cemento portland. Método de determinación de la penetración de agua a presión en el hormigón endurecido." *IRAM 1554*, Buenos Aires, Argentina.
- Instituto Nacional de Tecnología Industrial (INTI). (2005). "Proyecto de Reglamento Argentino de estructuras de hormigón." *CIRSOC 201-2005*, Buenos Aires, Argentina.
- Kasai, Y. (2005). "Recent trends in recycling of concrete waste and use of recycled aggregate concrete in Japan." *SP219: Recycling concrete and other materials for sustainable development*, T. C. Liu

- and C. Meyer, eds., American Concrete Institute, Farmington Hills, MI, 11–34.
- Katz, A. (2003). "Properties of concrete made with recycled aggregate from partially hydrated old concrete." *Cem. Concr. Res.*, 33(5), 703–711.
- Lauritzen, E. K. (2005). "Recycling concrete—An overview of challenges and opportunities." *SP219: Recycling concrete and other materials for sustainable development*, T. C. Liu and C. Meyer, eds., American Concrete Institute, Farmington Hills, MI, 1–10.
- Mehta, P. K. (2002). "Greening of the concrete industry for sustainable development." *Concr. Int.*, 24(7), 23–28.
- Poon, C. S., Shui, Z. H., Lam, L., Fok, H., and Kou, S. C. (2004). "Influence of moisture states of natural and recycled aggregates on the slump and compressive strength of concrete." *Cem. Concr. Res.*, 34(1), 31–36.
- Topcu, I. B., and Sengel, S. (2004). "Properties of concretes produced with waste concrete aggregate." *Cem. Concr. Res.*, 34(8), 1307–1312.
- Vázquez, E., and Barra, M. (2002). "Reciclaje y reutilización del hormigón." *Monografía CIMNE N°67: Desarrollo sostenible del cemento y del hormigón*, R. Gettu, ed., International Center for Numerical Methods in Engineering, Barcelona, Spain, 43–65.
- Zega, C. J. (2008). "Recycled concretes: Characterization of recycled coarse aggregates." Tesis de Magíster, Facultad de Ingeniería, Universidad Nacional del Centro de la Provincia de Buenos Aires (UNCPBA), Olavarría, Argentina (in Spanish).
- Zega, C. J., Taus, V. L., and Di Maio, A. A. (2006). "Comportamiento físico-mecánico de hormigones reciclados elaborados con canto rodado." *IMME Bol. Tec.*, 44(3), 17–26.
- Zega, C. J., Taus, V. L., Villagrán, Y. A., and Di Maio, A. A. (2005). "Comportamiento físico-mecánico de hormigones sometidos a reciclados sucesivos." *Proc., Int. Symp. Structural Concrete and Time*, International Federation for Structural Concrete (fib), La Plata, Argentina, 761–768.