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ORIGINAL ARTICLE

Feasibility of the Demolition Waste Incorporation as an Additive to Cement: Comparative Study According to Current Standards

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Abstract
In cement industry, clinkerization has caused serious harm to the environment. For this reason, nowadays, research aims to partial replacement of clinker with recycling solids wastes materials in cement building to improve more the productivity for the cement industry as well as to maintain the quality of the obtained products. The present study investigated the effect of demolition waste's incorporation in cement building as an additive on chemical properties of the new materials to determine its classification according to the EN 197-1 standard. Therefore, the compressive strength of the developed cement was successfully evaluated. As a result, all the types of studied wastes could be considered as ordinary cement of two classes: CEM I 42.5 N and CEM II AL 42.5 N. according to CEN 196-1 standard.

Keywords Cement Industry · Clinker · Demolition Waste · Chemical Properties, Mechanical Properties

1 Introduction

There is no specific date for the appearance of "waste" on our planet, but we can say that their production appeared in prehistoric times and manifested in antiquity [1]. At the end of the 19th Century, the industrial revolution made it possible for man to manufacture new products which improved his way of life, and particularly in the construction sector. Since the production is increasing each year with the increase of world population and the evolution of consumption habits which reflects on anthropogenic activities [2].

Hence, the urbanization of cities without forgetting natural disasters and wars from which billions of tons of waste generated by construction sites each year in the world [3].

A century later, the scientific community was alarmed by the first signs of environmental damage due to human activities, including the rise in planetary temperature, the depletion of energy resources, the abuse of raw materials, global warming, environmental pollution, these are the most discussed topics at present [4].

In view of the fact that the construction industry is one of the sectors in which raw materials are consumed the most. Therefore, we must minimize the inputs of the manufacturing processes, as well as reduce as much as possible the consumption of raw materials, the consumption of energy, the emissions and the use of space. For this reason, it is necessary to reduce the waste from construction and demolition activities in order to reduce waste problems effectively. Therefore, it is imperative to reduce the consumption of equipment and use efficiently natural resources by recycling the qualitative waste to be evaluated.

The recycling of construction materials represents a considerable stake in the field of building and public works. In addition to generating huge quantities of site waste that we will sought to be recovered, construction activities are themselves driven to use secondary raw materials, that is mean those that have already experienced a first life cycle in other industrial fields [5].

According to The Tunisian Ministry of Equipment and Housing, at least 800 000 tonnes of construction and demolition waste have been accumulated since 2000, 70% of which is located in the large coastal cities of the governorates of Tunis, Sousse and Sfax. Because of management waste problems and environmental reasons, cement

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industries, encourage researchers to recycle construction and demolition waste as much as possible. For this reason,, the main objective of this work is to investigate the feasability of reducing cement content by recycled six different types of demolition wastes separately including Concrete, Brick, Earthenware, Floor Tile, Marble, and Concrete Plaster as additives to cement at different proportions in order to determine the chemical, physical and mechanical characteristics of the new materials according to the current standards for predicting the best application of each type of waste as an additive to the developed Cement [6].

Interestingly, the present research paper is considered as a preliminary study which could be improved in the further work through an extensive experimental procedure using design of experiments methodology. As far as we know, there is no report on developing prediction model demolition waste from Tunisia via component analysis for determining the suitable replacement ratio of each type of demolition waste with different components at proportions according to the current standards for the development of cement with excellent mechanical properties.

2 Experimental Procedure

2.1 Materials

The clinker and gypsum were provided by cement factory of Bizerte, from Tunisia. This study was carried out using waste from the demolition of buildings and the sorting of this waste allowed us to obtain six types of samples (Concrete, Brick, Earthenware, Floor Tile, Marble, and Concrete Plaster). 10 kg for each type of sample was added to the clinker [7] and gypsum [8]. The raw materials are prepared by first using a jaw crusher [9] to reduce their size and then using a ball mill to allow grinding that reduces the particle size to less than 2.5 mm [10].

2.2 Chemical Analysis

Chemical analysis is determined by X-ray fluorescence spectrometer [11] to measure the concentration of chemical elements present in the different samples. Loss on ignition is determined by calcining a pellet obtained from a cement sample mixed with beeswax and placed in a platinum crucible in a muffle furnace that is temperature stabilized at 1000 °C. The percentage of mass lost after calcining the cement sample is used to estimate the nonvolatile organic content in the new sample [12].

2.3 Physical Measurements

The physical tests are carried out according to the EN 196-6 standard [13]. The fineness of the ground cement was measured using Blaine permeability. The density of samples was also measured [14].

2.4 Mechanical Measurements

The mechanical characteristics of new developed cements were evaluated from compression tests on prismatic specimens according to EN 196-1 [15]. The specimen was prepared by mixing 450 ± 2 g of cement, 1350 ± 5 g of standardized sand and 225 ± 1 g of distilled water (water/cement ratio = 0.5) [16]. The samples are stored in their molds in a humid atmosphere for 24 h. Once removed from the mold, the specimen was kept in water until the time of testing according to EN 196-1.

3 Preparation of New Cement Powder

The experimental procedure consists in preparing cements at laboratory scale in a mini ball mill gathering the equipment used at industrial scale.

For this purpose, all samples were prepared at the same experimental conditions including grinding and the quality of clinker and gypsum. Six different types of demolition wastes including Concrete, Brick, Earthenware, Floor Tile, Marble, and Concrete Plaster were incorporated to cement as additives at different proportions which varied from 1 to 20%. A sample which contains only clinker and gypsum without addition was prepared as a reference.

4 Results and Discussion

4.1 Chemical Composition

The chemical composition of each sample was performed using the X-ray fluorescence to determine the suitable incorporation of these materials as additives to cement according to EN 197-1 [17]. The obtained results are shown in Table 1.

4.1.1 Clinker and Gypsum

For clinker, the lime/silica ratio (CaO/SiO_2) is about 3.11 higher than 2 and the sum of calcium silicates is 84.84, so more than two thirds of the mass of clinker, on the other hand, the MgO content is less than 5%. So, the clinker meets the requirements of EN 197-1 standard. The used gypsum is characterized by a SO_3 content of 37.43%.

Table 1 Chemical composition of used materials in this study

	Mineral composition							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K2O	SO_3	L.O.I
Clinker	20.66	4.82	3.46	64.18	1.59	0.46	1.86	0.86
Gypsum	6.09	1.62	0.81	29.16	1.48	0.44	37.43	20.74
Concrete	38.28	2.25	1.57	31.03	0.68	0.35	0.54	24.06
Brick	57.61	10.77	4.89	31.01	2.37	1.97	0.09	1.90
Floor Tile	7.49	1.66	0.85	49.37	0.51	0.22	0.47	39.15
Concerte Plaster	55.44	1.93	1.59	23.01	0.57	0.10	0.89	15.00
Earthenware	59.37	13.75	6.40	9.92	1.52	2.28	0.00	2.49
Marble	5.37	0.37	0.30	53.50	0.46	0.29	0.13	38.49
Mixture	18.37	3.42	2.31	47.31	3.42	0.43	0.95	22.75

Table 2 Chemical composition of developed cements

Developed cement		Additives													
		Concrete		Brick		Floor Tile		Concrete Plaster		Earthenware		Marble		Mixture	
Component	Required	Max 20%	Min 1%	Max 20%	Min 1%	Max 20%	Min 1%	Max 20%	Min 1%	Max 20%	Min 1%	Max 20%	Min 1%	Max 20%	Min 1%
MgO	**< 5**	1.61	1.07	1.61	1.02	1.99	1.02	1.61	1.06	1,61	1.25	1.61	1.08	1.61	1.14
SO_3	**< 3,5**	2.42	1.88	2.27	1.88	2.27	1.87	2.37	1.76	2,18	1.71	2.28	1.71	2.20	2.02
L.O.I	**< 5 CEM I**	5.38	1.85	2.11	1.32	9.67	1.67	4.02	1.5	1,95	1.11	9.16	1.95	9.16	1.95
CaO/SiO_2	**> 2**	3.43	2.81	3.67	2.03	3.67	3.15	3.43	2.6	3,43	2.15	3.71	3.3	3.43	3.13

4.1.2 Concrete

Concrete [18] is generally composed of, at most, cement and water, 2/3 granules and 1/3 sand, so it is expected to be similar to limestone at 75% [19]. However, the CaO content was only 31.03, which is 55.41% of the $CaCO_3$ value below 75% which is the lower limit required by EN 197-1 [17].

4.1.3 Brick and Earthenware

The chemical analysis of bricks [20] and earthenware [21] is close to that of Calcined shale and its compressive strength was greater than 25 MPa as measured according to the the EN 196-1. Referring to the requirements of EN 197-1, type II cements made from these additions will be classified as CEM II AT [22] when the rate of brick exceeds 5%.

4.1.4 Floor Tile and Marble

The obtained results of chemical analysis of the floor tiles [23] and marbles [24] are similar to that of limestone. These materials could be used as additives to manufacture a cement type CEMII AL according to the requirements of the European standard EN 197-1.

4.1.5 Concrete-Plaster

Generally, Concrete-plaster contains cement and sand and other not identified additives in the commercial cement [25]. Its chemical analysis is in accordance with the requirements of the EN 197-1 standard because it is characterized by a CaO content of 23.01% which corresponds to 41% $CaCO_3$ with a low SO_3 content of 0.89% and MgO of 0.57% [26].

4.1.6 The Mixture

The mixture contains an unsorted waste, the XRF analysis showed a CaO content of 47.31% which corresponds to about 85% $CaCO_3$. The total organic carbon was 0.04% by the methylene blue test and according to NT 21.139, was 102 g / 100 g. These values showed that this mixture could be classified as limestone. Hence, the new developed cement with demolition waste produces higher than 5% of organic carbon without exceeding the rate of 20%. Accordingly, this cement will be considered as CEM II AL.

4.1.7 Prepared Cements

The prepared cements were analyzed by XRF. Table 2 illustrates the limit values of each component as required by EN 197-1.

The CaO/SiO2 ratio was higher than 2, this result proves that all the prepared cements are considered as ordinary cements.

According to the requirements of the European standard EN 197-1, the classification of these cements was performed based on the results of mechanical tests. Moreover, the classification of cements was divided into two parts according

Table 3 Compressive Strength at 2 days of curing for cements using different additives whose proportions varied from 0 to 5%

Sample	Rate of additives	Concrete	Brick	Floor Tile	Concrete Plaster	Earthenware	Marble	Mixture
0	**0%**	22.8						
1	**1%**	17.8	22.1	21.8	22.6	20.6	21.6	21.7
2	**2%**	17	21.6	21.1	22.3	19.3	20.3	20.4
3	**5%**	15.7	20.6	20.3	20.4	17.7	18.5	18.2

Table 4 Compressive Strength at 7 days of curing for cements using different additives whose proportions varied from 0 to 5%

Sample	Rate of additives	Concrete	Brick	Floor Tile	Concrete Plaster	Earthenware	Marble	Mixture
0	**0%**	45.4						
1	**1%**	34.7	47.4	45.6	45	30.4	46.8	28.8
2	**2%**	33.5	45.8	41,5	44.6	28	42.6	26.9
3	**5%**	31.4	43.1	41.2	39	25,1	42	266

Table 5 Compressive Strength at 28 days of curing for cements using different additives whose proportions varied from 0 to 5%

Sample	Rate of additives	Concrete	Brick	Floor Tile	Concrete Plaster	Earthenware	Marble	Mixture
0	**0%**	56.5						
1	**1%**	57.6	57.7	54.4	55.4	53.9	57.1	46.0
2	**2%**	56.9	56.5	43.3	54.7	51.1	51.4	44.9
3	**5%**	50.5	55.6	52.8	53.4	49.5	49.7	44.3

to their proportions: the first part for cements whose rate of addition is less than or equal to 5% and the second part for cements with a rate of addition is more than or equal to 5%.

5 Effect of Percentages of Different Additives less than 5% on Compressive Strength of Cement at 2, 7 and 28 Days of Curing

According to the European standard EN 197-1: These cements are classified as CEM I and their strength classes are as CEM I 32.5, CEM I 42.5 or CEM I 52.5 N or R.

5.1 Compressive Strength After 2 Days of Curing

In order to classify cements as normal setting (N) or rapid setting (R), it is important to measure their mechanical strength at 2 days of curing. Table 3 shows the effect of type and proportion of used additives on developed cement's mechanical strength at 2 days. It's noticed that cements which having a compressive strength value greater than or equal to 10 MPa, could be classified as CEM I 32.5 R or CEM I 42.5 N.

5.2 Compressive Strength After 7 Days of Curing

The compressive strength after 7 days was measured to approve the classification of cement in strength class 32.5 N. The obtained results were reported in Table 4.

According to the CEN 196.1 standard, cement could be classified in CEM I 32.5 N, when its compressive strength value is greater than or equal to 16 MPa.

5.3 Compressive Strength After 28 Days of Curing

This measurement is the most decisive for classifying cement. According to the European standard EN 197-1, cements were classified based on their compressive strength values as given below:

- Class 32.5: $32.5 \leq$ CR 28 days ≤ 52.5.
- Class 42.5: $42.5 \leq$ CR 28 days ≤ 62.5.
- Class 52.5: CR 28 days ≥ 52.5.

Table 5 illustrates the compressive strength of cements at 28 days of curing. As shown in the Table 5, the obtained values of mechanical strength for all cements are greater than 42.5 MPa without exceeding the value of 62.5 MPa, that's why, the 42.5 N class is ensured for all the developed cements.

As shown in Fig. 1, for all type of additives from 1 to 5%, all developed cements could be classified in 42.5R.These values could be improved by increasing the grinding time which could enhance the specific surface resulting to the improvement of cement's mechanical strength .

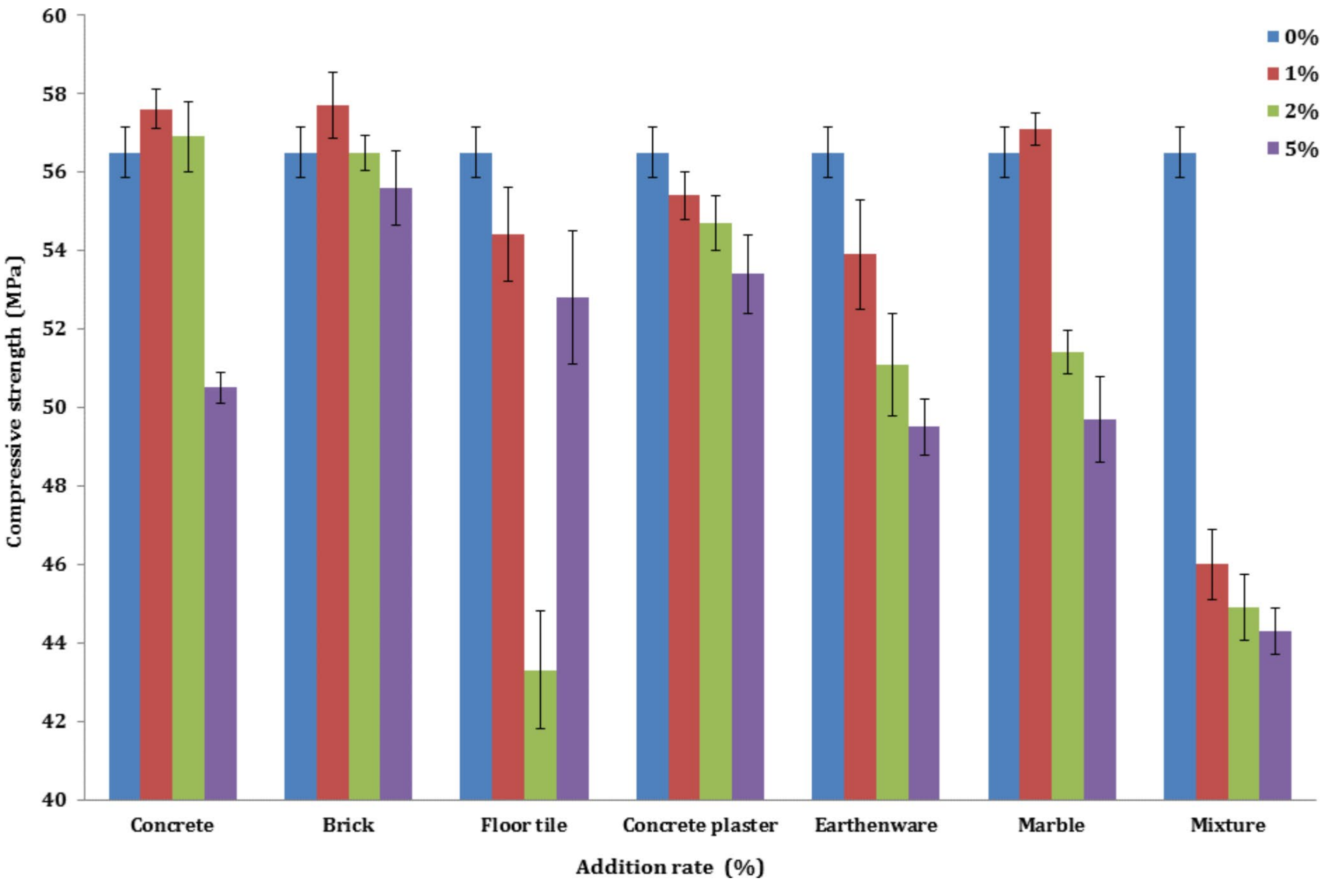

Fig. 1 Effect of percentage of different additives on the 28-days compressive strength of developed cements

Table 6 Compressive Strength at 2 days of curing for cements using different additives whose proportions varied from 5 to 20%

Sample	Rate of additives	Concrete	Brick	Floor Tile	Concrete Plaster	Earthenware	Marble	Mixture
4	6%	15.3	20.2	19.2	19,3	16,4	17,1	17,8
5	10%	14.5	19.7	19.2	18,7	14,1	15,9	15,1
6	12%	14.2	19.4	19.1	18,3	13,7	14,4	13,3
7	15%	13.1	19	18.7	18,1	12,9	13,7	12,7

6 Effect of Percentages of Different Additives from 5 to 20% on Compressive Strength of Cement at 2, 7 and 28 Days of Curing

According to the European standard EN 197-1: These cements are classified in CEM II. Based on their compressive strength values, cements could be classified accordingly in CEM II 32.5, CEM II 42.5 or CEM II 52, 5 N or R.

6.1 Compressive Strength After 2 Days

These tests were performed to classify CEM II cements in N or R. Table 6 shows the effect of type and proportions of different demolition waste on mechanical strength at 2 days.

The obtained results showed that up to 18%, the cement could be classified in CEM II 32.5 R and in CEM II 42.5 N. We noticed that the value of this compressive strength decreases significantly by increasing the proportions of additives; this could be explained by the slow pozzolanic activity at early age because of the lack of availability of hydration products C-S-H gel which makes the paste more homogeneous and more compact and resulting in improvement of mechanical strength [27].

Table 7 Compressive Strength at 7 days of curing for cements using different additives whose proportions varied from 5 to 20%

Sample	Rate of additives	Concrete	Brick	Floor Tile	Concrete Plaster		Earthenware	Marble	Mixture
4	6%	30.2	43.1	40.3	38.5	24.8	40.1	25.3	
5	10%	28.8	42.6	37.8	37	23.2	32.8	22.7	
6	12%	26.7	40.3	36.4	36.7	22.5	32.2	22.5	
7	15%	26.1	37.7	35.3	36.1	21.1	30.3	22.3	
8	18%	24.3	34.1	53.5	31.8	20.6	28.3	22.1	
9	20%	22.4	32.2	28.3	30.8	20	26.9	21.1	

Table 8 Compressive Strength at 28 days of curing for cements using different additives whose proportions varied from 5 to 20%

Sample	Rate of additives	Concrete	Brick	Floor Tile	Concrete Plaster		Earthenware	Marble	Mixture
4	6%	47.9	55.3	51.4	52.9	47.7	48.4	51.9	
5	10%	45.6	55.1	50.1	51.7	46.6	47.5	50.8	
6	12%	43.7	54.3	49.6	51.3	45.8	45.2	48.9	
7	15%	42.0	53.9	48.3	51.2	44.3	45.5	46.1	
8	18%	41.0	50.7	47.2	50.7	43.7	39.6	43.6	
9	20%	39.3	44.1	44.3	50.3	41.6	39.2	40.3	

6.2 Compressive Strength After 7 Days

According to the CEN 197-1 standard, cement with compressive strength value exceeding 16 MPa at 7 days of curing, could be classified as CEM II 32.5 N. As illustrated in Table 7 the obtained results shows that for all cements with proportions of different additives varying from 5 to 20%, compressive strength values are greater than 16 MPa. Therefore, this type of cement is classified as CEM II 32.5. Compared to 2 days of curing, we noticed that after 7 days, compressive strength improved significantly for all additives with different percentages. This result could be ascribed to the acceleration of pozzolanic reaction generating more and more hydration products C-S-H gel which are responsible for the enhancement of cement's mechanical strength [27, 28].

6.3 Compressive Strength After 28 Days

Compressive strength at 28 days of curing for developed cements with proportions of different additives that varying from 6 to 20%, are mentioned in Table 8.

For all types of additives, we noticed that increasing the percentage of additives from 6 to 20%, decrease not significantly the 28-days compressive strength. This finding could be explained by the fact that the particle surface, chemical and mineral composition of additives and the presence of some impurities which could influent on cement hydration process by inhibiting the formation of C-S-H gel responsible for the cement's mechanical strength [29].

Based on the CEN 19 – 1 standard, the manufactured cement could be classified in CEM II AL 32.5 N regarding to their compressive strength values which are varying between 32.5 and 52.5 MPa.

We noticed that using bricks or concrete plaster as additives to cement with percentages varied from 6 to 18%, the obtained values of compressive strength are higher than 50 MPa which could be ascribed to the richness of these additives in SiO_2 and CaO compounds that are required for pozzolanic activity which increases the formation of calcium-silicate-hydrates (C-S-H) [30]. This observation was confirmed previously by Mansour et al. (2022) who investigated the use of red Brick powder as partial replacement of cement and the obtained results revealed that the maximum strength of 65 MPa was achieved at 28 days using Brick powder at 15% by Weight in the Portland cement. In this litterature, the enhancement of the compressive strength compared to reference portland cement (40 MPa) (without additives) could be explained by the fact that brick powder is considered a natural pozzolan material which is responsible for the strength development of mortar [31].

The compressive strength of a concrete mixture using marble waste as additive in cement was also investigated in the present study. In fact, results revealed that incorporating marble with percentages from 6 to 18% improved the compressive strength compared to reference Portland cement (45 MPa) (without any replacement by minerals). Various previous studies have been reported on incorporation of waste marble aggregates in cement concrete and it was demonstrated that replacing a low percentage of the cement with marble dust, could lead to interesting characteristics in terms of strength [32–34]. Hebhoub et al.(2011) proved that the substitution of natural aggregates by waste marble aggregates resulted in a considerable increase in the compressive and tensile strength for 25%, 50% and 75% of substitution [35].

It's clearly observed that for all additives increasing of powder ratio in the cement could affect the strength of cement negatively. This finding was similar to those found elsewhere in the literature Who demonstrated that This reduction in strength may be a result of the lack of water that could limits the pozzolanic effect and thereby reduces the strength of concrete [31, 36].

Figure 2 shows the 28-days compressive strength of cements that are developed with demolition waste without sorting step with different percentages (from 6 to 20%).

of developed cements.

As depicted in the Fig. 2, the 28-days compressive strength are between 32.5 and 52.5 MPa and the majority are even higher than 42.5 MPa. Hence, this cement could be classified in CEM II AL 42.5 N but it could not reach the class CEM II AL 52.5 N.

Various previous studies have been reported on the feasibility of reducing cement content by incorporating demolition waste including fine recycled concrete aggregate RCA and mixed recycled aggregate MRA in mortars in order to improve the performance of the mortar as well as to provide a promising solution to the problem of demolition waste management [37–40]. As a result, it was demonstrated that 15% of MRA and 20%of RCA were considered the best incorporation percentages to improve mechanical properties of developed concrete [10]. Moreover, Braga et al.(2014) found that the incorporation of 15% of fine recycled aggregates increases the compressive strength of 30% compared to reference mortar. This increment was attributed to the combination of filler and pozzolanic effects of recycled aggregates [41].

7 Conclusion

This study investigated the potential use of demolition waste as recycling solids wastes materials in cement building to improve both the productivity for the cement industry and the quality of the developed cement. Based on European standard EN 197-1, cements were classified according to their chemical composition. Moreover, according to the CEN 196.1 standard and based on the compressive strength of all developed cements, all the types of studied wastes could be considered as ordinary cement of two classes: CEM I 42.5 N and CEM II AL 42.5 N. This finding confirms that demolition waste could be valorized in cement industries. Hence, this valorization encourages cement manufacturers

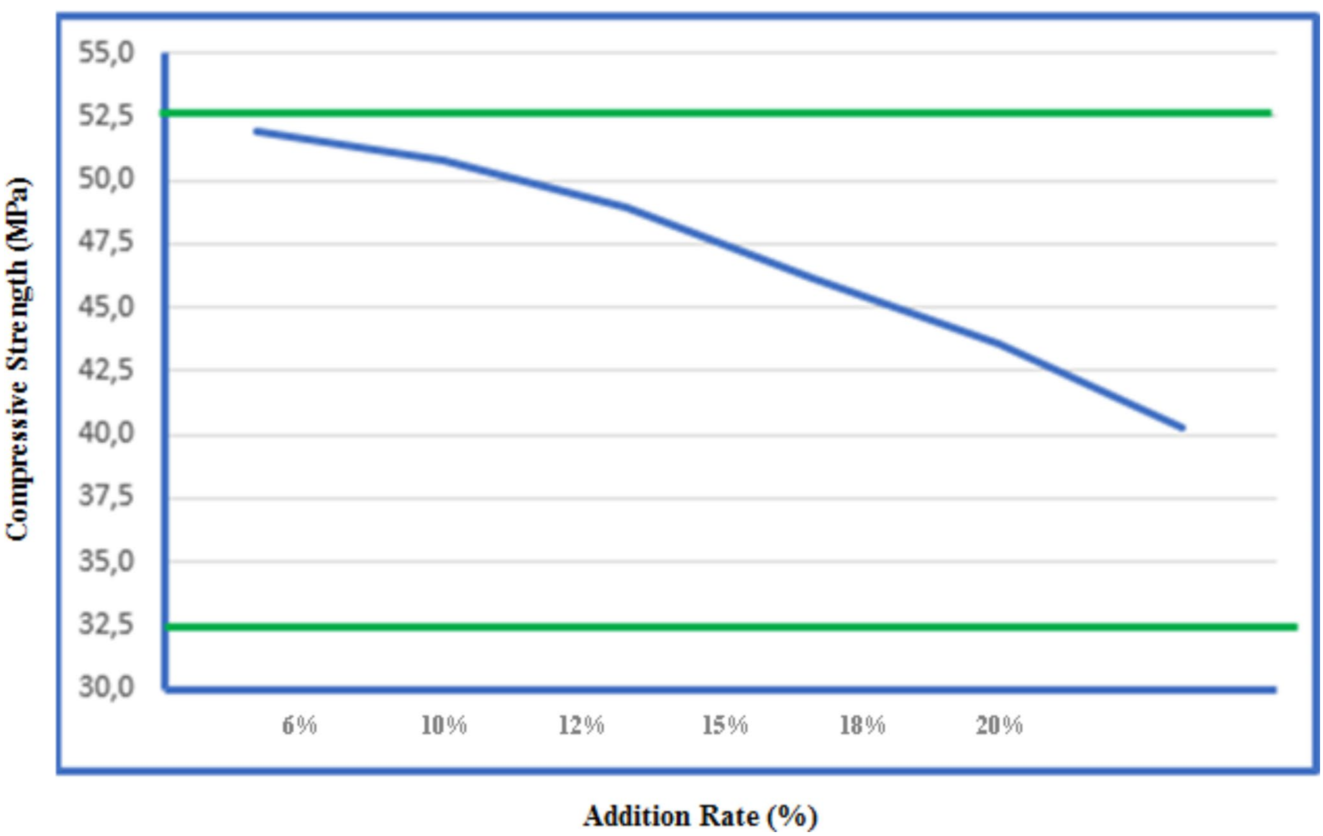

Fig. 2 Effect of mixture's percentage on the 28-days compressive strength of developed cements

to protect environment by recycling solid wastes and this could maintain an ecological balance of the system.

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Declarations

Conflict of interest There is no conflict of interests.

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