Kuwait J. Sci. 46 (2) pp 67-73, 2019

The use of concrete wastes as a limestone replacement in limestone-blended cement production

İlker B. TOPÇU[1], Hasan BAYLAVLI[2,*]
[1]*Dept. of Civil Engineering, University of Eskişehir Osmangazi, Turkey*
[2]*Dept. of Construction Technology, University of Hitit, Turkey*
[*]*Corresponding author: hasanbaylavli@hitit.edu.tr*

Abstract

The limestone used in CEM II B-L type cement production is routinely taken from nature by quarrying natural limestone resources which results environmental damage. This causes an ecological imbalance in the regions. To mitigate environmental damage caused by such quarrying, this study investigated the use of concrete wastes in cement. Experimental studies were carried out especially for their use in limestone-blended cement production. For this purpose, concrete samples (150x150x150 mm) with an average compressive strength of 65 MPa were milled after compression tests. Milled concrete wastes were used instead of a limestone additive in CEM II B-L type cement production. Their chemical and physical properties were investigated according to related cement standards. In addition, X-Ray diffraction analysis of cements was performed for the purpose of comparison. Mechanical performances of cements were evaluated at 2, 7 and 28 days under three-point flexural and compressive tests. The use of waste concrete as a limestone additive up to a 10% replacement ratio increased the flexural strength by 8%. The use of waste concrete up to 5% as a limestone additive also increased the compressive strength by 15, 8, and 9% at 2, 7 and 28 days, respectively. In conclusion, waste concretes can be successfully used instead of a limestone additive in CEM II B-L type cement production, thereby reducing environmental damaged caused by quarrying.

Keywords: Cement production; concrete waste; physical and chemical properties; strength.

1. Introduction

The construction industry can be consumed as a source consumer and waste producer (Cachim, 2009; Jianzhuang *et al.*, 2012). According to Rashad (2013), 0.94 tons of CO_2 and other greenhouse gasses such as SO_3 and NO_x (i.e. NO and NO_2) are released into the atmosphere while producing 1 ton of cement. Limestone used in cement production and aggregates used in ready-mix concrete industry are also routinely taken from nature by the quarrying of natural limestone resources (Mehta, 2002; Naik, 2007). Quarrying for limestone damages the environment and adds to greenhouse gas emission due to the gasses released into the air from heavy machinery used in the process. Figure 1 shows environmental damage over a 32-year period caused by limestone quarrying used in cement manufacturing in Çorum, Turkey.

Recently, high amounts of construction wastes

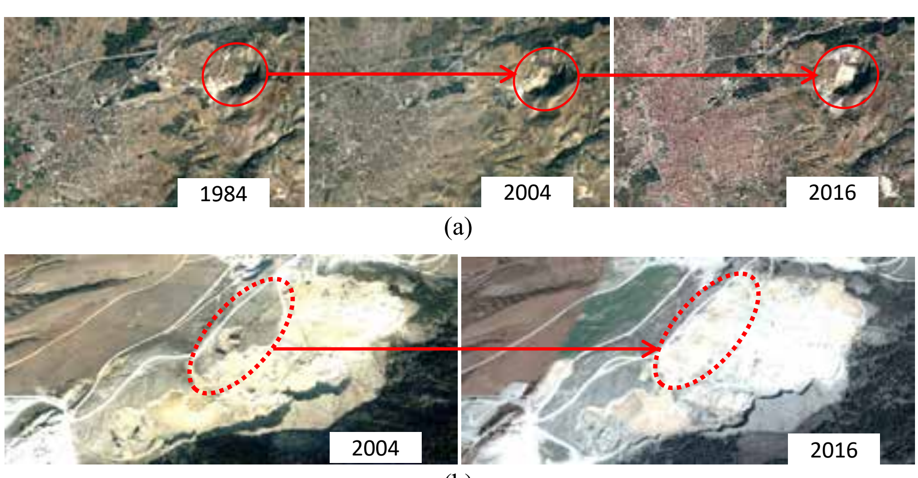

Fig. 1. Environmental damage over a 32-year period in Çorum, Turkey, a) Whole area destruction, b) Partial destruction

(concrete, glass, brick, etc.) have been haphazardly discarded, especially in developing countries. After the earthquake in Turkey in 1999, two million tons of waste concrete was generated in Adapazarı province alone (Gümrükçüoğlu *et al*., 2000). The improper disposal of construction wastes in the environment can cause several problems (floods, the proliferation of vectors harmful to human health and the degradation of urban landscapes etc.). Therefore, waste management should be prioritized for reasons of environmental protection and human health. A lot of research has been done on the use of wastes such as ceramic, brick, glass, or marble in concrete. Puertas *et al.* (2008) evaluated the usability of ceramic waste as a raw material in cement production. They milled ceramic wastes and separated them into three groups (<45µm, 45-90µm, and >90 µm). They clinkerized a raw cement mix that contained limestone, clay, sand, and Fe_2O_3. Then the authors designed new raw mixes by partially replacing clay content with ceramic wastes. They achieved favorable results in terms of reactivity and burnability with new raw mixes. Naceri & Hamina (2009) used waste brick by replacing with clinker in various amounts. It was found that waste brick cements up to a 10% replacement ratio showed comparable compressive strength results at 90 days. Aliabdo *et al.* (2016) used grinded waste glass powder for producing glass powder blended cement. Improved performances (i.e. compressive strength, tensile strength, absorption, voids ratio and density) were obtained by a 10% glass powder replacement with cement. Singh *et al.* (2017) prepared concretes by replacing cement with marble slurry. The results showed that mechanical properties increased up to a certain replacement level by taking water to cement ratio into consideration. It must be noted that most of the wastes used in most studies are production wastes obtained from factories during manufacturing processes. Batayneh *et al.* (2007) remarked that 20% of construction wastes consist of glass, plastic, and concrete. A majority of recent studies that evaluate concrete wastes focus on using wastes as recycled aggregates in concrete production (Khoshkenari *et al*., 2014; Manzi *et al*., 2013; Andreu & Miren, 2014; Medina *et al*., 2014). The purpose of using these materials for cement or concrete production is to reduce environmental impact. With this motivation, this study also investigates the use of concrete wastes in CEM II B-L type cement production. Experimental studies were especially carried out for their use in limestone-additive cement production. For this purpose, waste concrete samples obtained after the compression tests were milled. For cement production, milled concrete wastes were used instead of a limestone additive. Their chemical, physical, and fresh state (specific weights, setting times, water demands) properties, and mechanical performances (flexural and compressive strengths) at 2, 7 and 28 days were evaluated.

2. Materials and methods

Six different limestone additive cements (reference cement and five waste concrete cements) were produced. In the reference cement (RC) production, clinkers of type I ordinary Portland cement (CEM I 42.5 R), limestone, trass, and gypsum were milled in laboratory type millers (Figure 2). In the production of waste concrete cements (W), laboratory wastes of 15 cm cube concrete specimens with an average compressive strength of 65 MPa. The specimens were taken from the concrete used in the construction of the Hitit University campus. They were used after the completion of compressive tests. Cube specimens were milled, and waste concrete powders were prepared (Figure 3). The cement type used in the laboratory waste concrete cubes was CEM I 42.5 R. The cement, aggregate and water amounts were 400, 1830 and 165 kg/m3, respectively. The plasticizer chemical admixture amount used in specimens was 1.3% of total cement weight.

Fig. 2. Clinkers and laboratory type miller.

Fig. 3. a) Waste cube specimens, b) Concrete wastes after initial milling process

Waste concretes were initially milled until they reached the size of the clinker. Then W's were produced by replacing the limestone-additive with milled waste concretes in rates of 5, 10, 15, 20 and 28% by weight of limestone. The secondary milling process was performed to produce the waste concrete cements. Mix proportions of RC and W's are presented in Table 1.

Table 1. Mix proportions of produced cements

Cement Type	Clinker (%)	Limestone (%)	Waste Concrete (%)	Trass (%)	Gypsum (%)
RC	63	28	0	5	4
W5	63	23	5	5	4
W10	63	18	10	5	4
W15	63	13	15	5	4
W20	63	8	20	5	4
W28	63	0	28	5	4

After completion of the mixing stage, chemical, physical and mechanical properties of reference cement and waste concrete cements were examined. For mechanical performance tests, cement mortars were prepared in accordance with the EN 196-1 (2016) standard. For mortar preparation, mix proportions of cement, standard sand and were 450, 1350 and 225 kg/m3, respectively. Table 2 shows the related standards that were used to obtain the chemical and physical properties of the cements and to show the fresh and mechanical performances of the mortars.

Table 2. Analyses and related standards

Analysis	Related Code
Determination of chemical compositions of cements	ASTM C114
Blaine value	ASTM C204
Specific gravity	ASTM C188-16
Consistency water demand (%)	ASTM C187-16
Setting time	EN 196-3
Volume expansion	EN 196-3
Compressive strength	ASTM C 109
Flexural strength	ASTM C348-14

3. Results and discussions

3.1. Comparison of the chemical properties of the cements

Chemical compositions of RC and Ws are given in Table 3. Al_2O_3 and Fe_2O_3 amounts of W type cements were higher than reference cement (RC). The SiO_2 amount of RC increased with waste concrete replacement at a ratio of 5%. However, increasing the replacement ratio of waste concrete with limestone gradually decreased the SiO_2 content of W type cements. No systematic changes in terms of the CaO contents of cements were observed. MgO and SO_3 contents of cements generally increased with increasing waste concrete replacement ratio when compared to RC. Insoluble residue values of cements decreased with an increased replacement ratio up to 30%. Familiar results in terms of Na_2O, K_2O, and loss in the ignition values of the cements were obtained from the chemical analysis of the cement samples.

The XRD results of cements are presented in Figure 4. It was observed that all W type cements showed almost the same XRD pattern with the reference cement. This can be assumed as relative evidence that the cements were successfully manufactured by using concrete wastes.

3.2. Comparison of the physical properties of cements

Physical properties of cements are presented in Table 4. Blaine fineness values of the cements increased with increased waste concrete replacement ratio when compared to the reference cement.

Water demands of cements for achieving the proper consistency decreased, a result which differs from previous studies. Several researchers showed that an

Table 3. Chemical compositions of cements

Chemical Composition (%)	RC	W5	W10	W15	W20	W28
SiO_2	15,99	16,26	16,12	16,09	15,86	15,84
Al_2O_3	4,35	4,39	4,42	4,39	4,41	4,46
Fe_2O_3	2,41	2,48	2,44	2,44	2,43	2,47
CaO	59,11	59,23	58,82	58,95	58,88	59,13
MgO	1,58	1,60	1,59	1,61	1,61	1,63
Na_2O	0,12	0,13	0,11	0,13	0,13	0,13
K_2O	0,46	0,48	0,46	0,47	0,45	0,46
SO_3	2,46	2,40	2,51	2,55	2,61	2,68
Insoluble Residue	3,34	3,00	3,13	3,08	2,74	2,32
Loss on Ignition (LOI)	13,66	12,73	13,48	13,36	13,64	13,41

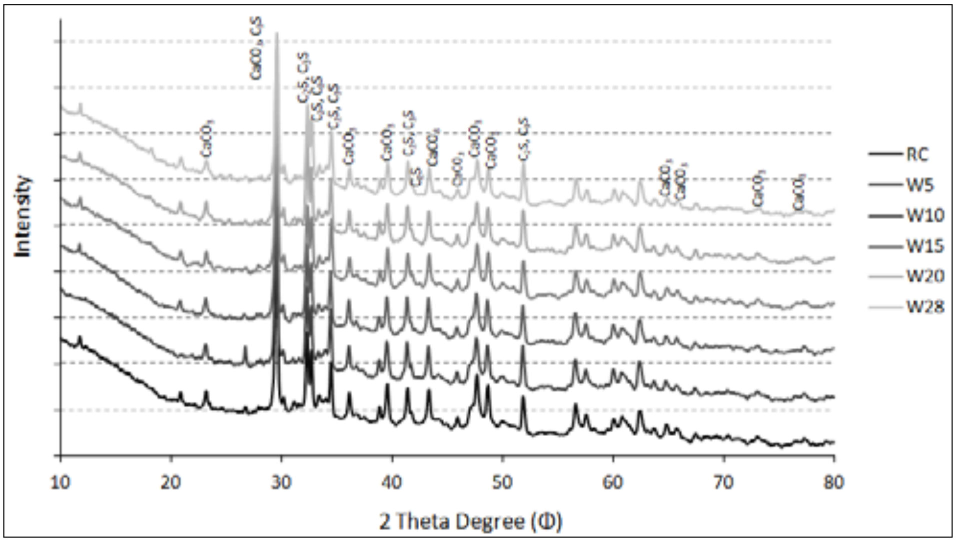

Fig. 4. XRD patterns of cements

increase in limestone content of limestone-blended cement production decreased the amount of water needed in to achieve proper consistency in some cement types. (Tsivilis *et al.*, 1999; Tsivilis *et al.*, 2002; İnan Sezer, 2007). In this study, smooth surface characteristics and lower porosity of waste concrete particles after grinding decreased the amount of water needed for good consistency. Specific weights of cements decreased when compared to RC. This was done by increasing the replacement ratio of waste concrete (except in W5). It can be explained by considering the specific weights of both limestone and waste concretes. Due to the low specific weight of waste concretes (2.40), the use of waste concrete instead of a limestone additive (2.69) decreased the specific weight of cements.

3.3. Fresh state properties of cement mortars

3.3.1. Setting properties of cement mortars

Setting times for cement mortars are presented as columns in Figure 5. Dark columns represent initiation of setting (initial setting time), and the grey columns represent the final stage of setting (final setting time). Both initial and final setting times of mortars decreased up to 10% replacement of waste concrete replacement (Figure 5). However, continuing to increase the waste concrete replacement ratio augmented the initial and the final setting times of the cement mortars (Figure

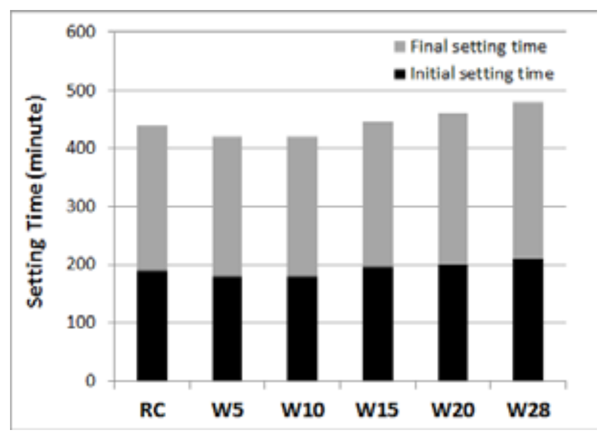

Fig. 5. Setting times of cement mortars

5). Minimum and maximum setting times were obtained from the cement mortars that containing waste concrete of 10% and 28%, respectively. A 10% replacement of waste concrete decreased the setting time by 4.5% (20 minutes) and a 28% replacement of waste concrete increased the setting time by 9% (40 minutes) when compared to the reference mortar.

3.4. Mechanical properties of cement mortars

3.4.1. Flexural performances of cement mortars

Flexural performances of cement mortars are given in Figure 6. The graph shows 2, 7 and 28 days of flexural strengths of mortars as light grey, grey and

Table 4. Chemical compositions of cements

Physical Property	RC	W5	W10	W15	W20	W28
Blaine Value (g/cm²)	4,33	4,40	4,41	4,43	4,43	4,41
Specific Gravity	3,01	3,02	2,99	2,93	2,92	2,94
Consistency Water Demand (%)	28,0	27,8	27,8	27,4	27,5	27,5
Volume Expansion	1,0	1,0	1,0	1,0	0,5	0,5

black, respectively. At 2 days of flexural tests, no systematic changes were observed. W5 mortar that was prepared with 5% waste concrete cement resulted in the highest flexural strength at 2 days. At 7 days, cement mortars prepared using waste concrete cements exhibited either equal or lower flexural strength than the reference mortar. However, all cement mortars prepared with waste concrete cements performed either the same or showed more flexural strength when compared to the reference concrete at 28 days. In terms of flexural strength, it can be concluded that the use of waste concretes up to 10% can enhance the flexural strengths at 28 days by 8%.

3.4.2.Compressive performances of cement mortars

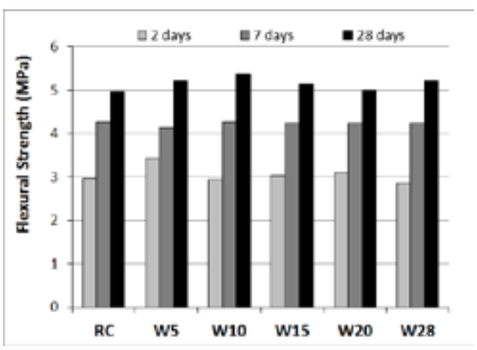

Fig. 6. Flexural performances of mortars

Compressive performances of mortars were measured with compressive strength tests at 2, 7 and 28 days. Figure 7 shows the results (see Section 3.4.1 for explanation). At 2 days, waste concrete mortars, except W5, show similar compressive strength values compared to the reference mortar. W5 mortar (mortar with a 5% replacement ratio) exhibited a higher compressive strength at 2 days. A compressive strength for the W5 mortar also increased at 7 days. For specimens W15 and W20, the compressive strengths decreased slightly compared to the reference mortar. Close performances were obtained from W10 and W28 mortars. At 28 days, no significant changes were observed in terms of compressive strengths (except W5 mortar). W5 mortar had a 9% higher compressive strength than the reference mortar.

In general, mortars exhibited similar results in terms of compressive strengths at 28 days. Also, the partial replacement with waste concretes up to 5% in cement production can improve the compressive strength of mortar at 28 days.

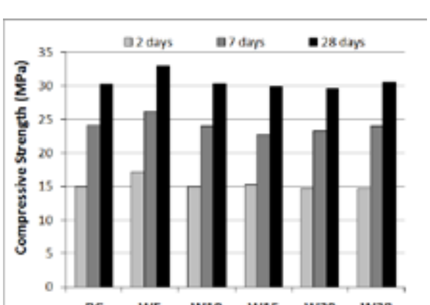

Fig. 7. Compressive strengths of mortars

4. Conclusion

Waste concretes can be successfully used instead of a limestone additive in CEM II B-L type cement production. No significant changes were achieved in terms of the chemical composition of cement. In addition, the XRD results showed that the XRD patterns of all cement were almost the same, which is relative evidence that cement can be successfully manufactured using concrete wastes. The use of waste concrete as a limestone additive with up to a 10% replacement ratio increased the flexural strength by 8%. Furthermore, the use of waste concrete up to 5% as a limestone additive increased the compressive strength by 15, 8, and 9% at 2, 7 and 28 days, respectively. A slight fluctuation was observed when the use of waste concrete ratio was from 15-28%. In the W28 series, flexural and compressive strengths were higher than that of the RC. After additional investigations, the use of higher amounts of waste concrete in CEM II B-L type cement production is possible as an environmentally-friendly alternative. When the harmful effects of cement manufacturing on nature (degradation of nature, greenhouse gas emissions, etc.) are taken into consideration, the use of waste concretes can be a sustainable alternative.

ACKNOWLEDGEMENTS

We gratefully acknowledge Votorantim Cement Company for the materials and the preparation of specimens. We also appreciate the work of Gökhan Saydam and Ali Osman Balyuz for their contribution to testing specimens.

References

Aliabdo, A.A., Elmoaty, A.E.& Aboshama, A.Y. (2016). Utilization of waste glass powder in the production of cement and concrete. Construction and Building Materials, **124**: 866-877.

Andreu, G. & Miren, E. (2014). Experimental analysis of properties of high performance recycled aggregate concrete. Construction and Building Materials, **52**: 227-235.

ASTM C109. (2016). Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens), ASTM International, West Conshohocken, PA. pp. 10.

ASTM C114. (2015). Standard Test Methods for Chemical Analysis of Hydraulic Cement, ASTM International, West Conshohocken, PA. pp. 32

ASTM C187-16. (2016). Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste, ASTM International, West Conshohocken, PA. pp. 3.

ASTM C188-16. (2016). Standard Test Method for Density of Hydraulic Cement, ASTM International, West Conshohocken, PA. pp. 3.

ASTM C204. (2016). Standard Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus, ASTM International, West Conshohocken, PA. pp. 10.

ASTM C348-14. (2014). Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars, ASTM International, West Conshohocken, PA. pp. 6.

Batayneh, M., Marie, I. & Asi, I. (2007). Use of selected waste materials in concrete mixes. Waste Management, **27**(12): 1870-1876.

Cachim, P. B., (2009). Mechanical properties of brick aggregate concrete. Construction and Building Materials, **23**(3): 1292-1297.

EN 196-1. (2016). Methods of Testing Cement–Part 1: Determination of Strength. European Committee for Standardization, pp. 38.

EN 196-3. (2016). Methods of Testing Cement. Determination of Setting Times and Soundness. European Committee for Standardization. pp. 18.

Gümrükçüoğlu, M., İleri, R., Sümer, B. & Seyfettinoğlu, M.A. (2000). Environmental impact assessment August 17 post in Adapazarı. Sakarya University, Institute of Science and Technology Magazine, **4**: 1-6.

İnan Sezer, G. (2007). Effects of limestone and clinker properties on the properties of limestone blended cement. PhD Thesis, Ege University, Institute of Applied Sciences, İzmir (in Turkish). pp. 181.

Jianzhuang, X., Wengui, L., Yuhui F. & Xiao, H. (2012). An overview of study on recycled aggregate concrete in China (1996-2011), Construction and Building Materials, **31**: 364-383.

Khoshkenari, A.G., Shafigh, P., Moghimi M. & Mahmud, H.B. (2014). The role of 0-2 mm fine recycled concrete aggregate on the compressive and splitting tensile strengths of recycled concrete aggregate concrete. Materials and Design, **64**: 345-354, 2014.

Manzi, S., Mazzotti, C. & Bignozzi, M.C. (2013). Short- and long-term behavior of structural concrete with recycled concrete aggregate. Cement and Concrete Composites, **37**(1): 312-318.

Medina, C., Zhu, W., Howind, T., de Rojas, M. I. S. & Frías, M. (2014). Influence of mixed recycled aggregate on the physical–mechanical properties of recycled concrete. Journal of Cleaner Production, **68**: 216-225.

Mehta, P.K. (2002). Greening of the concrete industry for sustainable development. Concrete International, **24**(7): 23-28.

Naceri, A. & Hamina, M.C. (2009). Use of waste brick as a partial replacement of cement in mortar. Waste Management, **29**(8): 2378-2384.

Naik, T.R. (2007). Sustainability of the cement and concrete industries. Sustainable Construction Materials and Technologies. Chun, Claisse, Naik & Ganjian (Eds), 19-25.

Puertas, F., García-Díaz, I., Barba, A., Gazulla, M.F., Palacios, M., Gómez, M.P. & Martínez-Ramírez, S. (2008). Ceramic wastes as alternative raw materials for Portland cement clinker production. Cement and Concrete Composites, **30**(9): 798-805.

Rashad, A.M. (2013). Alkali-activated metakaolin: A short guide for civil engineer–An overview. Construction and Building Materials, **41**: 751-765.

Singh, M., Srivastava, A. & Bhunia, D. (2017). An investigation on effect of partial replacement of cement by waste marble slurry. Construction and Building Materials, **134**: 471-488.

Tsivilis, S., Chaniotakis, E., Badogiannis, E., Pahoulas, G., & Ilias, A. (1999). A Study on the parameters affecting the properties of Portland limestone cements. Cement and Concrete Composites, **21**(2): 107-116,

Tsivilis, S., Chaniotakis, E., Kakali, G., & Batis, G. (2002). An analysis of properties of Portland limestone cements and concrete. Cement and Concrete Composites, **24**: 371–378.

Submitted :15/10/2017
Revised :15/01/2018
Acceptance :15/01/2018

استخدام النفايات الخرسانية كبديل للحجر الجيري في إنتاج الأسمنت الممزوج بالحجر الجيري

ايلكر بكير طوبشي[1]، حسن باياقلي[2]

جامعة أسكي شهير عثمان غازي، قسم الهندسة المدنية، إسكي شهير، تركيا [1]
جامعة هيتت، قسم تكنولوجيا البناء، كوروم، تركيا [2]

الملخص

إن الحجر الجيري المُستخدم في إنتاج الأسمنت من النوع B-L CEM II مأخوذ من الطبيعة بشكل روتيني عن طريق استنزاف موارده الطبيعية مما يؤدي إلى اختلال التوازن البيئي في المناطق بسبب تدمير الطبيعة. في هذه الدراسة، تم البحث عن استخدام النفايات الخرسانية في إنتاج الأسمنت. فقد أجريت دراسات تجريبية لاستخدامها في إنتاج الأسمنت الممزوج بالحجر الجيري على وجه الخصوص. ولهذا الغرض، تم طحن عينات خرسانية (150 × 150 × 150 مم) بقوة انضغاطية تبلغ 65 ميجا باسكال في المتوسط بعد إجراء اختبارات الضغط واستخدام النفايات الخرسانية المطحونة بدلاً من مضيفات الحجر الجيري في إنتاج الأسمنت من نوع CEM II B-L. وتم فحص خصائصها الكيميائية والفيزيائية وفقاً لمعايير الأسمنت ذات الصلة. وتم كذلك إجراء تحليل حيود الأشعة السينية على الأسمنت للمقارنة. ثم تم تقييم الأداء الميكانيكي للأسمنت في عدد 2 و 7 و 28 يوماً عن طريق إجراء اختبار الإنثناء ثلاثي النقاط واختبار الضغط. وقد أدى استخدام النفايات الخرسانية كمادة مضافة من الحجر الجيري بنسبة استبدال تصل إلى ٪10 إلى زيادة قوة الانثناء بنسبة ٪8. بالإضافة إلى ذلك، أدى استخدام النفايات الخرسانية كمادة مضافة من الحجر الجيري بنسبة استبدال تصل إلى 5% إلى زيادة قوة الانضغاط بنسبة 15 و 8 و ٪9 في عدد 2 و 7 و 28 يوماً على التوالي. وختاماً لذلك، فإنه يمكن استخدام النفايات الخرسانية بنجاح بدلاً من المادة المضافة من الحجر الجيري في إنتاج الأسمنت من نوع CEM II B-L.