32. Slovenski Kolokvij o Betonih
Ljubljana
28 May 2025

USE OF RECYCLED SAND AND EXPANSIVE AGENTS FOR THE PRODUCTION OF MORE DURABLE AND SUSTAINABLE CEMENT-BASED MATERIALS

L. Courard

University of Liège
Urban and Environmental Engineering, GeMME Building Materials
Allée de la découverte, 9 – 4000 Liège, Belgium
e-mail: Luc.Courard@uliege.be
web page: www.uee.uliege.be

B. Bissonnette

Université Laval
Département de génie civil et de génie des eaux
1065, avenue de la Médecine, Québec (Québec), Canada G1V 0A6
e-mail: benoit.bissonnette@gci.ulaval.ca

Abstract

The availability of resources for the construction industry is becoming increasingly uncertain, while at the same time the amount of construction and demolition waste is growing. Reconciling needs and secondary resources as well as contributing to reuse is a useful and motivating scientific challenge. Legal and regulatory barriers have to be overcome in order to allow a real circular economy in the construction industry. Working locally and developing an appropriate treatment of Construction and Demolition Wastes is favouring upcycling and valorization of secondary materials for prefabricated, 3D printed concrete or repair materials. It is becoming increasingly difficult to ensure the availability of good quality sand for the production of concrete. Recycled concrete sand, when properly produced, can be a serious alternative for low- to medium-range mortars and concretes. Technical properties of recycled sands are analysed, and proposals are made for increasing the rate of incorporation into mortars. In the same time, minimum requirements are proposed for using recycled sand in 3D mortars. Final properties are compared with classical materials and durability of end products is analysed. Accelerated carbonation process seems to increase recycled sands properties (before and/or after manufacturing concrete). Expansive agents may also help to manage the various types of shrinkage, which can be exacerbated in mixtures with recycled sands. But a broader and more systematic use of recycled materials calls for adapted regulations and specifications: this is essential for lowering the environmental impact of the construction industry.

Keywords: concrete, recycling, coarse aggregates, fine particles, recycled sand, mortar, shrinkage, expansive agent

1 INTRODUCTION

Sand and aggregates extraction, sourcing, use, and management remain largely ungoverned in many regions of the world, leading to numerous environmental and social consequences that have been largely overlooked [1,2]. In 2019, the 4th United Nations Environment Assembly (UNEA-4) adopted UNEA resolution 4/19 on Mineral Resource Governance, which specifically included sand as a topic of concern. At UNEA-5 in 2022, Member States requested for more information on sustainable practices related to, amongst others, sand as a mineral, as acknowledged in the UNEA resolution 5/12 on minerals and metals management [3]. Aggregate and sand materials are in high demand globally for construction purposes, with an annual growth rate of around 5% while the availability of sand is decreasing. Figure 1 shows the clear increase in sand demands over the previous and coming years. The United States of America and China show overall the highest yearly demand of sand.

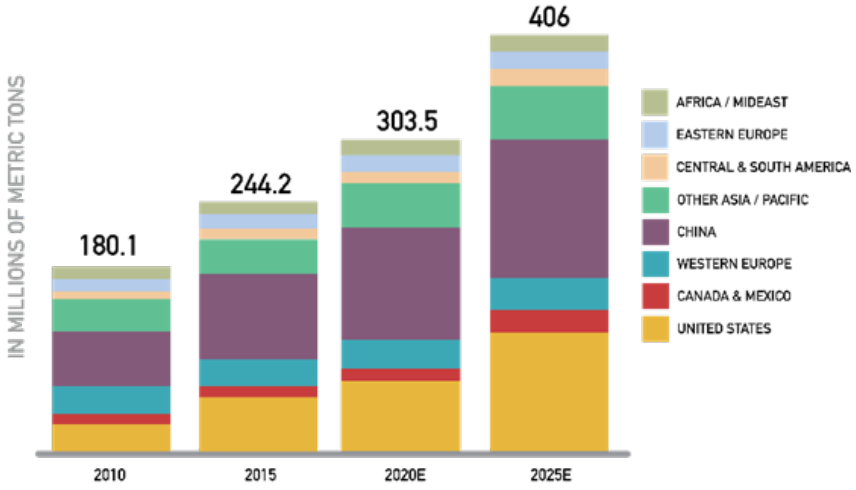

Figure 1. World sand demands in millions of metric tons (https://iveybusinessreview.ca/6580/lafargeholcim-the-plastic-solution-to-the-global-sand-wars/graphic-2-world-sand-demand/).

The global consumption of construction aggregates is expected to reach 62.9 billion metric tons by the end of 2024, up from 43.3 billion metric tons in 2016 [4]. Within Europe, EU27+UK+EFTA aggregate demand reached 2.7 billion tons annually in 2015, generating an estimated annual turnover of €15 billion. This European (EU27+UK+EFTA) demand represents approximately 10% of the global demand for aggregates, equating to 6 tons per capita per year [5].

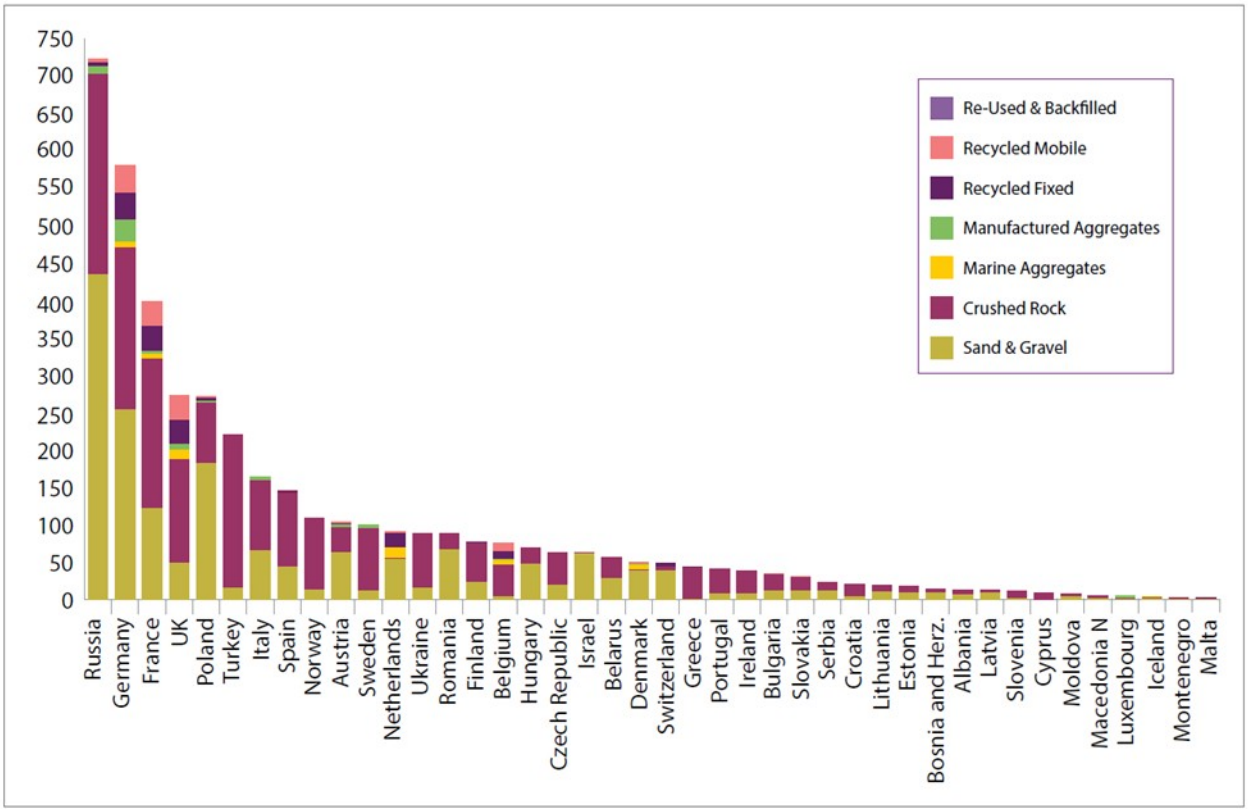

Figure 2: 2019 aggregates production in Europe [5]

Figure 2 provides a synopsis of the 2019 national production tonnages categorized by country and aggregate type. Germany emerged as the leading producer, surpassing 500 million tons, followed by Russia, Turkey, France, the UK, and Poland. In contrast, smaller nations such as Malta, Montenegro, Iceland, Luxembourg, and Cyprus exhibited production levels below 5 million tons. National tonnages depend not only on economic strength, but also on geological availability of and access to deposits, national ambient climate, ruggedness of the terrain and local building traditions.

The composition of aggregate types (Figure 3) in the EU27+UK+EFTA countries in 2019 revealed that crushed stone accounted for 46.9% of all production, while sand and gravel constituted 39.7%. Aggregate production from recycled and reused materials contributed 9.3%, with marine and manufactured aggregates comprising the remaining 4%.

Figure 3: Aggregate type percentages

Figure 4 delineates production trends from 2006 to 2020 within the EU27+UK+EFTA countries. After seven years of decline from 2007 to 2013, production went back up and stabilized around 3 billion metric tons until the Covid 19 pandemic affected production.

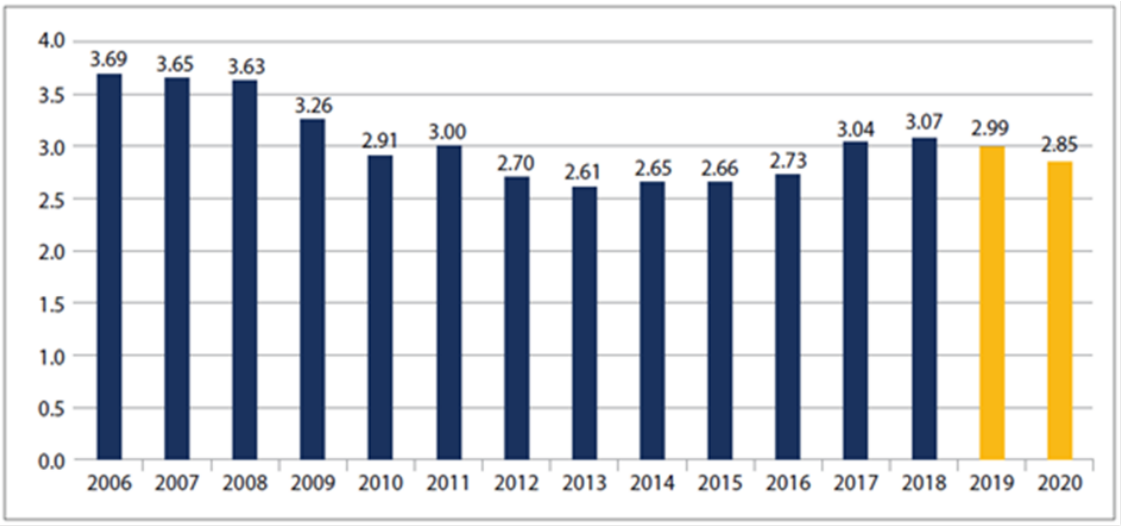

Figure 4: EU+UK+EFTA Trend in Production in Billions of Total Tons [5]

The global sand market is constantly affected by unbalances in import and export over the world. Figure 5 shows the top 10 countries with the highest export in fine aggregates between 2010 and 2014.

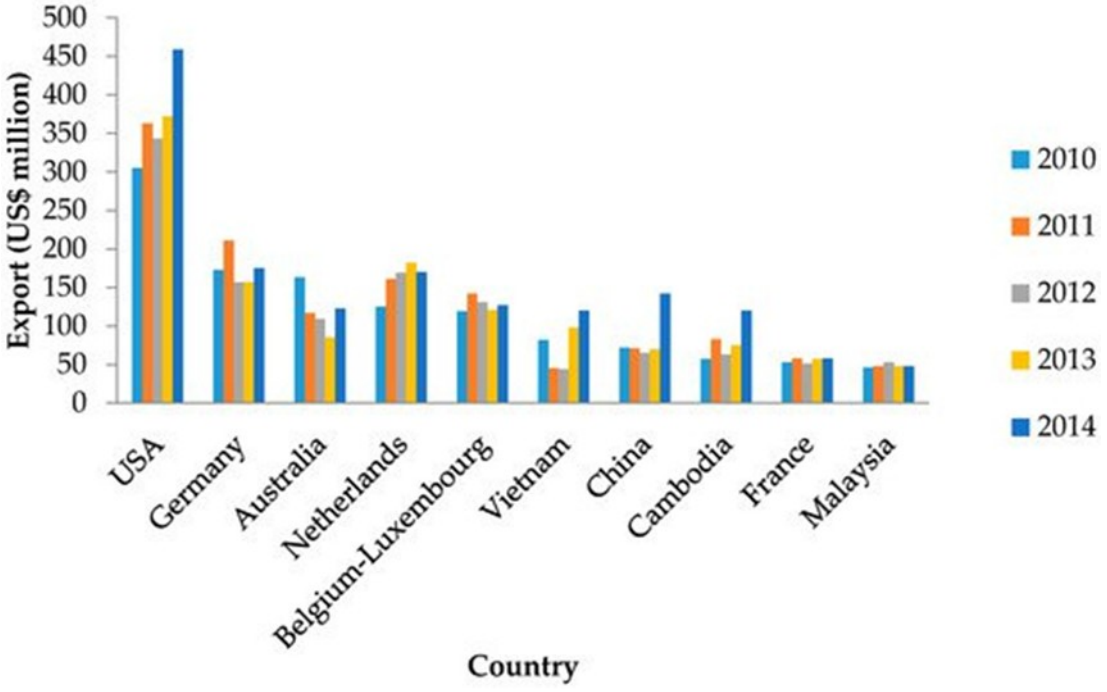

Figure 5: Top 10 of sand exporting countries over the world between 2010 and 2014 [6]

Recycling initiatives in the European aggregates industry exhibit notable variation across countries. Five European nations – Belgium, UK, the Netherlands, Germany, and France - spearhead the production of recycled aggregates, contributing to around 90% of all recycled aggregates (RA) within the EU. This production substantially reduces the demand for primary aggregates, fostering sustainability [7]. Table 1 shows an evaluation of the percentage of recycled aggregates vs total production of aggregates for the considered countries, including Slovenia.

Table 1 Estimation of recycled aggregates production [8]

	Total production (millions of tons)	Recycled aggregates (RA) production (millions of tons)	Percentage of RA vs total production (%)
Belgium	74	21.9	29.6
France	383	65.9	17.2
Germany	577	80	13.9

Netherlands	90	23.5	26.1
U.K.	272	66.6	24.5
Slovenia	0	14	0
EU27+UK+EFTA	**3023**	**303**	**10**

Recycled sand is, however, a material with specific properties that make it difficult to be used for concrete production [9,10]. In 2023, during 30th Slovenian Colloquium on Concrete [11], 3D printed applications were presented with 100% of recycled sand. They proved to be efficient, and no discriminant loss of performances was observed. However, this very specific application remains exceptional and probably not yet widespread.

2 RECYCLED SANDS FOR THE PRODUCTION OF MORTARS: PHYSICAL AND MECHANICAL PROPERTIES

The physical and chemical properties of recycled sand play a key role in its suitability for concrete applications. Unlike natural sands, which are generally fairly homogeneous, recycled sands have more variable characteristics depending on their origin and the origin and recycling processes. This variability of properties is one of the main obstacles to more widespread use of recycled sands [12].
The density of recycled sand is generally lower than that of natural sand. Recycled fine and coarse aggregates have densities between 1970 and 2140 kg/m³, and between 2120 and 2430 kg/m³ respectively [13]. This density depends on the composition of the material present in the recycled product: a mixed recycled sand is likely to have a lower density due to the large amount of ceramic particles or clay brick particles.
In addition, the increased porosity of recycled sands results in significantly higher water absorption, with values typically between 3% and 10%, depending on the quality and origin of the material [14]. The diameter of the recycled aggregate is also very important: the lower the grade, the higher the porosity [15]. The water absorption of natural sand is typically between 0.2% and 2%.
In the case of recycled concrete aggregates, this porosity is due to the presence of hardened cement paste and mortar. It has also been observed that the water absorption coefficient of aggregates increases as coarse particle size decreases (Figure 6). However, it should be noted that exact determination of the absorption coefficient is made very complex for recycled sands. Indeed, current standards for determining this coefficient, such as the standard (NBN EN 1097-6, 2022), are adapted to natural aggregates and do not take into account the specific characteristics of recycled aggregates.

The mechanical performance of recycled sands is an essential aspect for their integration in the construction sector. It has been observed that the incorporation of recycled fine aggregates of less than 20% of the aggregate share results in no significant change in concrete performance [16].

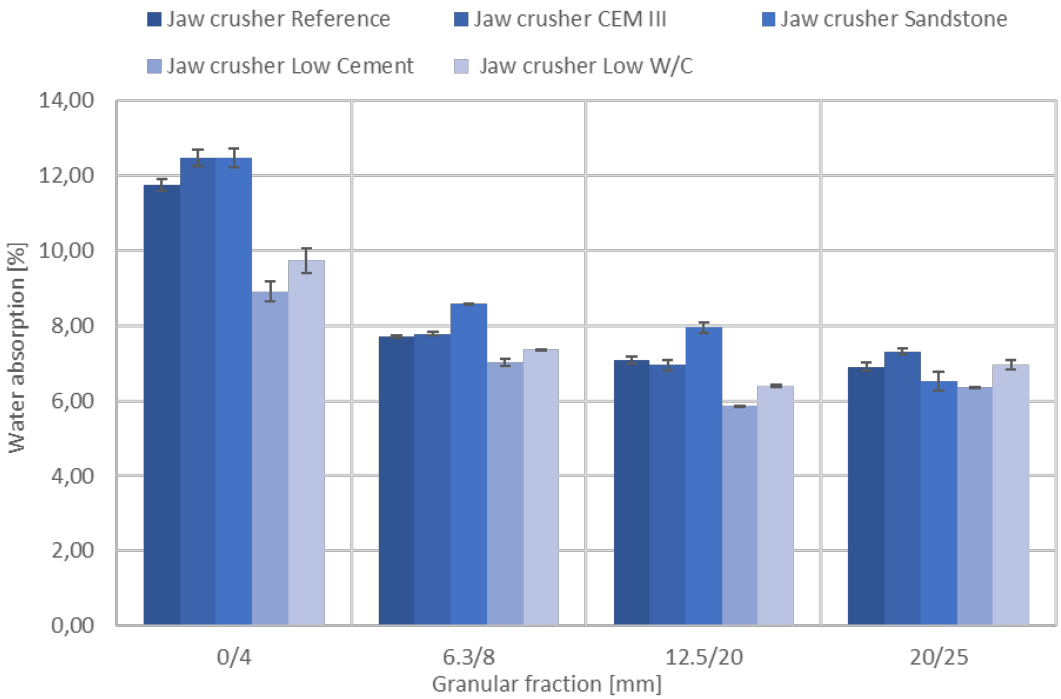

Figure 6: Water absorption for the recycled aggregates produced with the jaw crusher [15]

However, above this threshold, a significant reduction in strength is often observed. With the same amount of water and cement, concrete made with 100% recycled aggregates shows mechanical strengths reduced by 10 to 20% compared with conventional concrete [17]. This reduction is notably linked to the high porosity of recycled sand. In terms of durability, it is observed that up to a recycled fine aggregate content of 30%, the carbonation and capillary absorption tests on concretes containing recycled aggregates remained rather similar to those with natural sand [18]. This suggests that, in moderate proportions, recycled sands can induce durable performances comparable to those of natural sands. Finally, although their use is limited by challenges such as material heterogeneity of the materials and their difficult-to-quantify water absorption, recycled sands have interesting properties that can be exploited to encourage their widespread adoption.

A recent research project showed that washing may increase the quality of the materials [19]. Four different batches went through the same sorting and crushing process but to assess the effect of the washing and log washer treatment on the properties of the RCA, washed and unwashed materials have been considered:

- unwashed recycled concrete aggregates (U-RCA);
- washed recycled concrete aggregates (W-RCA);
- unwashed recycled mixed aggregates (U-RMA);
- washed mixed aggregates (W-RMA);

The water absorption of the washed RCA significantly decreases following washing. The water absorption of recycled concrete aggregates decreases from 6.5% to 5% between U-RCA and W-RCA and from 7.9% to 7.2% between U-RMA and W-RMA.

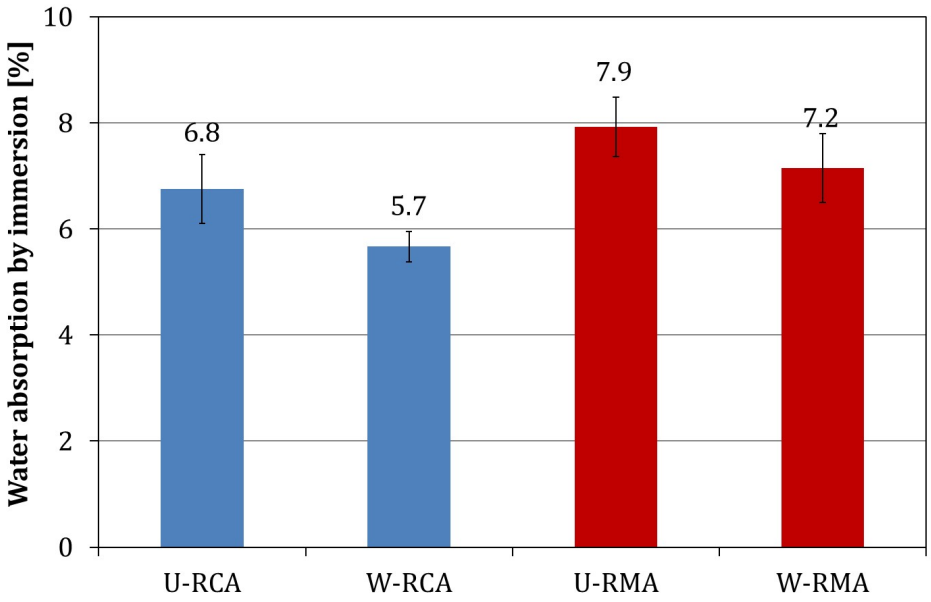

Figure 1 : Water absorption for the investigated aggregates after vacuum saturation [19]

The decrease in water absorption of the RCA is attributed to both a decrease in fine content and in cement paste content while the decrease of the RMA is only attributed to the fine particle removal. This interpretation comes from the comparison of the water absorption and the particle density. The water absorption of the RMA drops while their particle density remains constant (or even slightly decreases) which indicates that the cement paste content doesn't significantly vary.

3 USE OF SHRINKAGE COMPENSATING AGENT FOR MORTARS

……

4 CONCLUSIONS

The use of Recycled Fine Aggregates (RFA) in concrete is a direct contribution towards the circular economy. Measures to promote the use of Recycled Aggregate Concrete (RAC) are fully in line with strategic goals of the European Union (EU). Differences exist with natural sand and have to be taken into account in the desgn of mortars and concrete:

- recycled sand quality is hardly depending on the quality of the original concrete and the way it is produced,
- the density of recycled sand is generally lower than that of natural sand,
- the increased porosity of recycled sands results in significantly higher water absorption, with values typically between 3% and 10%: the lower the grade, the higher the porosity.

……

ACKNOWLEDGMENT

The authors are grateful to Wallonia Brussels International and Québec government for supporting scientific cooperation between Université de Liège and Université Laval through MORE² -

Développement de MOrtiers à REtrait compensé avec des sables de REcyclage (*Developement of self compensating shrinkage mortars with recycled sand*) (2025-2027). They want to thank MITACS organization for helping student Exchange.

REFERENCES

1. Peduzzi, P. (2014). Sand, rarer than one thinks. Environmental Development 11, 208-218. https://doi.org/10.1016/j.envdev.2014.04.001
2. UNEP 2019 (https://www.unep.org/resources/unep-annual-report-2019)
3. UNEP 2022 (https://www.unep.org/resources/unep-annual-report-2022)
4. Wiedenhofer, D., Steinberger, J.K., Eisenmenger, N. and Haas, W. (2015), Maintenance and Expansion: Modeling Material Stocks and Flows for Residential Buildings and Transportation Networks in the EU25. Journal of Industrial Ecology, 19: 538-551. https://doi.org/10.1111/jiec.12216
5. UEPG, 2021. European Aggregates Association – Annual Review 2020-2021, Brussels, 30 p.
6. Gavriletea, M.D. (2017) Environmental Impacts of Sand Exploitation. Analysis of Sand Market. Sustainability 9(7), 1118. https://doi.org/10.3390/su9071118
7. Deloitte, 2015. Screening template for Construction and Demolition Waste management in France. Version 2, September 2015, 55 p.
8. UEPG 2025 (https://www.aggregates-europe.eu/facts-figures/figures/)
9. Colman, C., Bulteel, D., Rémond, S., Zhao, Z., Courard, L. (2020) Valorization of fine recycled aggregates contaminated with gypsum residues: characterization and evaluation of the risk for secondary ettringite formation. Materials (ed. MDPI) 13, 4866 (12p.) (http://dx.doi.org/10.3390/ma13214866) (http://hdl.handle.net/2268/252190).
10. Courard, L., Rondeux, M., Zhao, Z., Michel, F. (2020) Use of recycled fine aggregates from C&DW for unbound road sub-base. Materials 2020 (ed. MDPI) 13(13) 2994, 26p. (http://dx.doi.org/10.3390/ma13132994) (http://hdl.handle.net/2268/249723).
11. Courard, L., Grigoletto, S., Muy, Y., Michel, F., Hubert, J. New developments in the recycling of construction and demolition wastes for the concrete industry. 30. Slovenski Kolokvij o Betonih, Ljubljana (7 November 2023). (https://hdl.handle.net/2268/308562)
12. Tam, V.W.Y., Soomro, M., Evangelista, A.C.J. (2018). A review of recycled aggregate in concrete applications (2000–2017). Construction and Building Materials,172, 272-292, (https://doi.org/10.1016/j.conbuildmat.2018.03.240)
13. Etxeberria, M., Gonzalez, A., Valero, I. (2012). Application of low grade recycled aggregates for non-structural concrete production in the city of Barcelona. Third international conference on sustainable construction materials and technologies, Kyoto, Japan.
14. Kosmatka, S.H., Panarese, W.C., Kerkhoff, B. (2002). Design and control of concrete mixtures. Portland Cement Association.
15. Hubert, J., Zhao, Z., Michel, F., Courard, L. (2023). Effects of crushing method on the properties of produced recycled concrete aggregates. Buildings 13(9), 2217 (https://doi.org//10.3390/buildings13092217).
16. Yaprak H., Aruntas, H.Y., Demir, I., Simsek, O., Durmus, G. (2011). Effects of the fine recycled concrete aggregates on the concrete properties. International Journal of the Physical Sciences 6(10), 2455-2461. (https://doi.org//10.5897/IJPS11.253)
17. Silva, R.V., de Brito, J., Dhir, R. (2014). Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. Construction and building materials 65, 201-217. (http://dx.doi.org/10.1016/j.conbuildmat.2014.04.117)
18. Hubert, J., Muy, Y., Courard, L. Use of recycled fine aggregates in high added value applications. International Conference on Advances in Engineering and Technology for Sustainable Development. Hanoi University of Civil Engineering, Hanoi, Vietnam, Nov 2-3, 2023 (https://hdl.handle.net/2268/308792)

19. Washing process for enhancing performances of coarse recycled aggregates. L. Courard, S. Delvoie, Z. Zhao, F. Michel, J. Hubert. Journal of Materials in Civil Engineering (*under revision*).
20. ……..