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Towards the Application of Recycled Coarse Aggregate Sourced from Large Panel System Buildings in the Manufacturing of Self-Compacting Concrete

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Today, endless discourses about Large Panel System (LPS) buildings take place to ask whether the residents should be concerned about their flats being demolished. Taking into account: turning from the "machine for housing" created by Le Corbusier to modern construction, sudden disasters like gas explosion, progressive collapse, planned demolitions, the trend can result in the creation of huge amounts of waste. LPS buildings are usually located in areas of dense urban development. Recycling of these wastes is very problematic. Because concrete load bearing panels seem to be in good condition, there is urgent need to evaluate the possibility of recycling them, e.g. as coarse aggregate in a new concrete mix. Self-Compacting Concrete (SCC) seems promising with its practical feature that it does not have to be vibrated during concreting, which in turn leads to a reduction in noise, making it a perfect material for investments in areas of dense urban development. Such solution would allow to eliminate the transport of waste, and at the same time to reduce it. The aim of the research is to preliminary evaluate the properties of Recycled Coarse Aggregate (RCA), acquired from the Construction and Demolition Waste (C&DW) of LPS residential building. The results of the sieve analysis in the products of 4-8 mm showed little irregular grains content, amounted to 5.9 % of the selected representative sample. Because no study before analysed RCA from LPS, there is a need of further research focusing on properties of acquired aggregate and concrete. The novelty of the manuscript lies in conducting preliminary research towards the recycling LPS for new SCC.

1. Introduction

For the sake of the environment, there is a trend of recycling and reusing Construction and Demolition Waste (C&DW), (Mah et al., 2018). An interesting issue of possible recycling is Large Panel System (LPS) technology, built in the second half of the twentieth century. Nowadays, endless discourses regarding LPS buildings take place on whether the residents should be concerned about their flats being demolished. Taking into account sudden disasters like gas explosion, progressive collapse, planned demolitions, the trend can result in the creation of huge amounts of waste. As LPS are usually located in city centers, the significant costs of transporting demolished concrete should also be taken into account. Ostrowski et al (2020) pointed out that coarse aggregate constitutes about 70 % of the volume of concrete. Therefore, replacing natural aggregate with recycled would make a real difference in reducing demolition waste. Because concrete load bearing panels seem to be in good condition, there is urgent need to evaluate the possibility of recycling them, e.g. as coarse aggregate in a new concrete mix. Self-compacting concrete (SCC) was assumed as the best fit. SCC is characterized by good fluidity, stability, and the ability to flow around reinforcement. It allows structures with a significant degree of reinforcement and atypical forms to be concreted and is highly resistant to

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environmental conditions. Its practical feature is the fact that it does not have to be vibrated during concreting, which in turn leads to a reduction in noise, making it a perfect material for investments in city centers (where LPS are usually located). It would be possible to eliminate the transport of waste and, at the same time, reduce it.

Although LPS is making a comeback in the market (Abakumov et al., 2020), this article examines in particular old LPS technology, from the second half of the twentieth century. All descriptions and definitions are related to old systems that are not being built anymore.

So far, huge numbers of analysed residential blocks have been more or less unskilled renovated (Laban and Milanko (2008). Nowakowski (2019) paid attention to lack of knowledge in the retrofitting process. Moreover, these actions cannot fully stop the end of service life. Despite the renovation strategy and constant maintenance, some of the LPSs will still have to be demolished. In case of unforeseen events like gas explosion, progressive collapse, or planned demolitions, this can result in the creation of huge amount of waste. Kabirifar et al. (2020) estimated that an overall 35 % of C&DW is landfilled globally, despite considering many strategies for C&DW management. The US example shows that methods for collection, treatment, and disposal of concrete residuals are not always specified. Agencies sometimes rely on contractors for suggestions and proposed plans (Tymvios et al., 2019). Therefore, a new and well-developed strategy is needed.

Huuhka (2015) analysed the possibility that panels could make up detached houses. However, Kibert and Chini (2000) proved before that the majority of LPS were not designed to dismantle them. Additionally, in case of random catastrophes, concrete panels can be broken, damaged, or even crushed. The oldest structures in western Europe have already been demolished due to the poor quality of the construction joints, with the concrete still in a fairly good condition. Jasiczak and Girus (2017) examined the external layer of the external wall of the edifice completed in 1986 with R-76, version of Rataje closed variant LPS technology in Poznan, Poland. Girus (2019) evaluated the external layer of the external wall of the edifice completed in 1988 with SL-85, version of S-Sz closed variant LPS technology in Poznan, Poland. In both cases, according to the documentation, the expanded clay concrete C12/15 was designed as the external layer. The results of the compressive strength prove not only the correctness of the design, but also that in few cases the concrete used was stronger than expected. Knyziak (2016) analysed the durability of 95 apartment buildings in Warsaw, Poland, of which 62 were in LPS technology. He examined a number of elements from foundations to roofs, describing the technical state. The results show that concrete load-bearing elements, including walls and ceilings are mostly in *good* condition. Knyziak et al. (2017) noted that the thickness of concrete in the façade layers often exceeded the design values. Due to the fact that concrete in LPS has very good strength parameters, it can be reused as a recycled aggregate in new concrete mixes. Niewiadomski (2015) noticed that even nanoparticles can have a huge impact on the physical and mechanical properties of concrete. Unfortunately, no one has examined RCA from LPS before and there is no information how RCA from such source can affect concrete.

Silva et al. (2021) highlight the potential for substitution of recycled aggregates, without significant loss of performance. Although RCA (even on a small scale) generally lowers properties of SCC, authors found out that for old precast elements such as beams and columns (Fiol et al., 2018), concrete pieces from precast concrete rejections (Salesa et al., 2018), present better results in terms of compressive strength, compared to natural aggregate. The authors found no research on LPS with RCA in the Scopus database (date of search – February 2022). Therefore, own initial research has been prepared.

Experimental studies proved that the morphology of the coarse aggregate affects the properties of SCC. Ostrowski et al. (2018) concluded that sharp edges of irregular aggregates can induce more pronounced stress concentrations, which leads to improved compressive strength. The morphology of the grain aggregate affects the rheological parameters, air voids, and aggregate distribution. Ostrowski et al. (2019) proved that with an increase of regular grains, slump flow also increases. This is due to the different areas of RCA and other geometrical characteristics of these grains, compared to the natural aggregate. One can conclude that the initial preparation of grains plays the key role in preparing concrete mix with desirable parameters (Gawenda, 2021). The focus on the production of regular grains results in better flow of the mixture, while irregular grains impact e.g. shaping the top layer of some surfaces, ensuring greater friction.

Conducting comprehensive basic research in the area of the use of RCA from the dismantling of LPS for the purpose of designing SCC could have significant benefits for the next generation of researchers and engineers. The novelty of the manuscript lies in conducting preliminary research towards the recycling LPS for new SCC, which is shown in Figure 1.

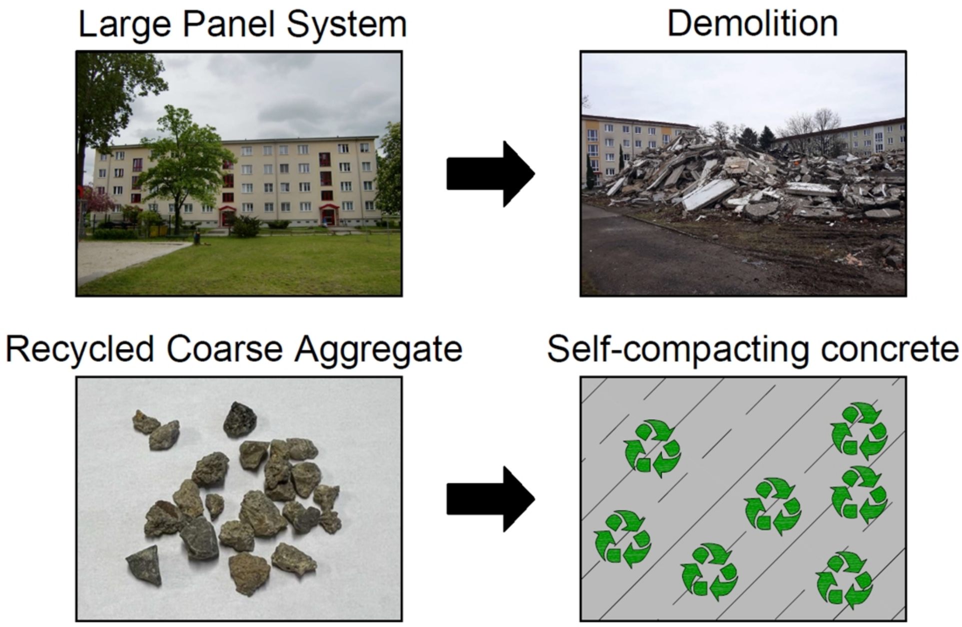

Figure 1: The idea behind the research

2. Materials and methods

3.1. Materials used

To verify the potential of RCA from LPS, pieces of concrete panels were acquired from the demolition of a 4-story residential building. The subject was Wohngebaude Typ P1, built in LPS technology (german Plattenbauweise) around 1960, located in Hoyerswerda, Germany. Wastes were obtained thanks to Wohnungsgesellschaft mbH Hoyerswerda company. According to documentation, panels were prepared with concrete class C 12/15.

3.2. Recycled coarse aggregate treatment

Panels were split into smaller pieces size 40-150 mm and then subjected to the comminution in a two-stage comminution processing system of first classification. In the first stage, the feed was fragmented in an L44.41 Makrum jaw crusher operating at a 20 mm outlet gap. The received material 0-45 mm was screened on a three-deck vibrating screen, which separated the aggregate into 4 fractions: 0-2 mm, 2-4 mm, 4-8 mm and 8-45 mm. Next, the 8-45 mm oversized product was fragmented in an Eko-Lab jaw crusher (6 mm outlet gap) in the second stage, which was operated in recirculation with a screen. Such a two-stage technological system enabled the production of aggregate in the 4-8 mm fraction in a selective manner in order not to crush the aggregate too much, to obtain as much output of the fraction as possible, and to increase the cubic form of the grains. The use of multi-stage comminution and screening systems, along with the return of materials and small degrees of comminution, favours an increase in the content of regular grains in the obtained products. The 4-8 mm final product was subjected to a sieve analysis to determine the particle size distribution and the content of irregular grains. The content of non-formed grains was measured using slotted sieves according to the PN-EN 933-3: 2012 standard (flakiness index FI).

3. Results and discussion

As a result, 41 % final 4-8 mm fraction and 59 % of the remaining fractions were obtained (intended for other studies beyond the scope of this article). The results of the sieve analysis allowed us to distinguish the content of irregular grains (Table 1). The content was relatively low (5.9 %) compared to crushed aggregates obtained from natural rock raw materials. The shares of irregular grains in the products of 4-8 mm grinding reach 20 % in typical technological systems (Gawenda, 2021). The particle size distribution is shown in Figure 3a. Based on the previous experience of the authors, the study examines the grain size φ 4–8 mm as it allows to obtain the SCC, even high-performance, (Ostrowski et al., 2018). The regularity of the grains presented depends on the relation between the narrow particle fraction range and the size of the slot in the sieve. The selected sieve was determined to be half of the maximum size of the particle of a certain fraction (dmax / 2). The results were compared with the research that analysed coarse granite aggregate to create SCC. Additionally, existing studies of applying RCA in SCC were examined. Their particle size distribution for RCA is shown in Figure 3b.

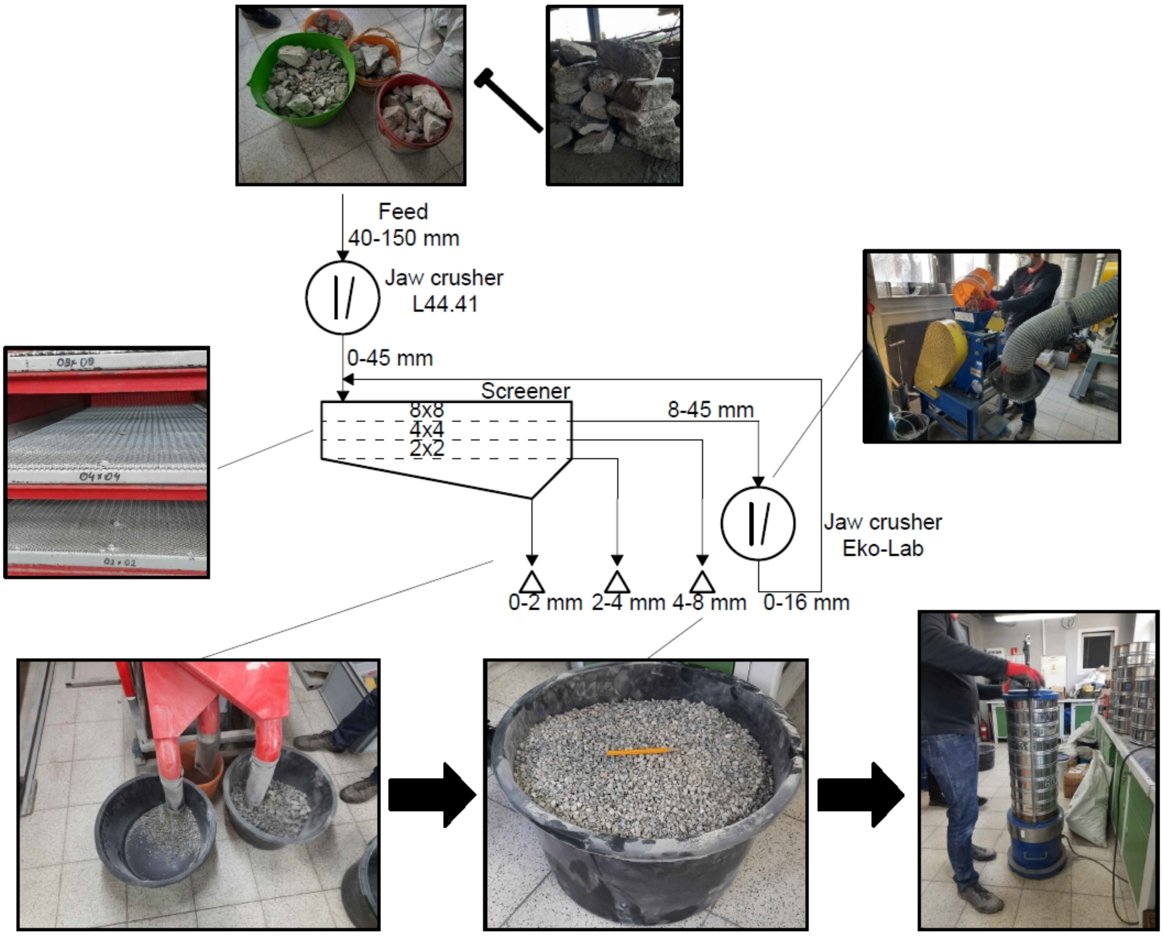

Figure 2: Technological scheme of aggregate production performed

From the literature survey presented in the Introduction, it seems that old concrete panels, due to their satisfactory condition, could be recycled as coarse aggregate in new SCC mixes. However, current state of knowledge does not yet provide any information on the use of RCA in SCC, especially acquired from LPS technology. In order to verify this theory, the initial research was conducted by preparing RCA from LPS. Sieve analysis of grains with diameters of 4-8 mm (Table 1) showed a very high cubic form of grains. Only about 5.90 % of the 1,707 g selected representative sample had irregular size, and there was no need for further processing of RCA.

Table 1. Sieve analysis of a representative sample

Size class [mm]	Mass of grains [g]	Slotted sieve size [mm]	Mass of irregular grains [g]	Percentage of irregular grains [%]
4 - 5	383	2.50	35	9.10
5 - 6.3	636	3.15	36	5.70
6.3 - 8	688	4.00	30	4.40
Total	1707		Mean	5.90

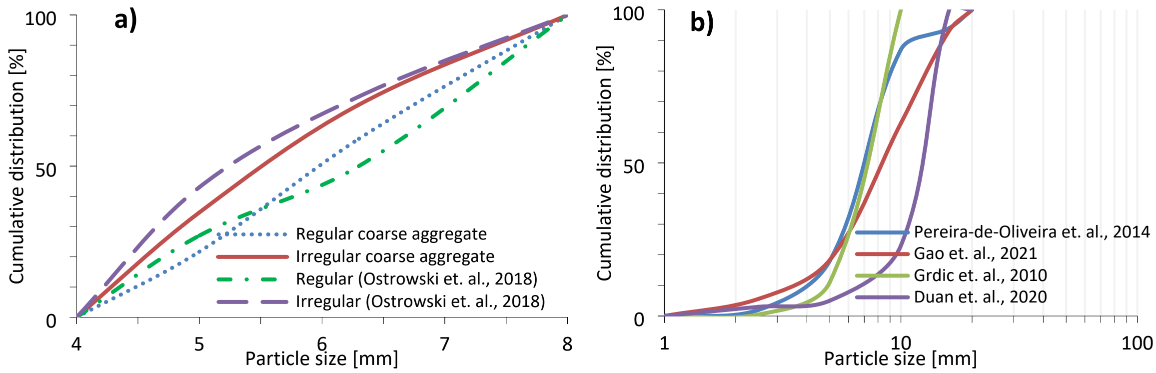

Figure 3: Particle size distribution of: a) prepared RCA with comparison to coarse aggregate 4-8 mm of other research b) other existing studies using RCA in SCC

4. Conclusions

The authors analysed the current state of knowledge on Recycled Aggregate from C&DW in SCC and proposed LPS technology as an innovative and unexplored source of acquisition of RCA. Conclusions of the research are as follows:

- Theoretically C&DW from old LPS buildings (built in the second half of the twentieth century) presents an interesting application as Recycled Aggregate. Although it is only one source of material, especially in Eastern Europe, LPS are a huge part of national stock.
- No study on RCA from LPS was found, there is a need to develop research focusing on LPS, the possibility of demolition, the properties of aggregate and concrete.
- Although concrete panels are being analysed, one has to remember that acquired waste may be heterogenous. Insulation system, plaster etc. should be removed first that the residues of the attached elements have marginal influence on the properties of aggregate and concrete.
- The panels acquired from demolition present a very high cubic form of grains. According to the literature survey, this can impact concrete properties such as compressive strength, rheological parameters, and slump flow.
- Studies, in which recycled aggregates are applied in concrete, in general do not focus on the source of recycled aggregate but rather check the fresh and hardened properties of SCC. Two cases founded with precast elements show an increase in compressive strength, suggesting that they were built with good quality concrete. There is a possibility that such wastes are beneficial for eco-concrete properties.

The authors do agree that this case requires further and detailed research. The ongoing study will focus on experimental studies of SCC with LPS RCA with the influence of aggregate morphology on concrete properties.

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