FINAL REPORT ABOUT THE TEST SERIES "CONCRETE RECYCLING IN DEEP FOUNDATION WORK"

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ABSTRACT

The company PST Spezialtiefbau Süd GmbH wants to use concrete with 100% recycled aggregate in its future deep foundation projects. The objective is not only to use concrete with recycled aggregate, but also to do all required processes on site to save valuable resources and reduce emissions. To use concrete with 100% recycled aggregate in Germany you need approval, on an individual case basis from the respective ministry of buildings, because the concrete is not produced according to the requirements of the standards. A test series conducted in November 2021 proved that concrete with 100% recycled aggregate meets the requirements of a conventional concrete and can be used for the production of bored piles. The test series and their results are described in more detail below.

INTRODUCTION

After dismantling an existing building, the waste is either recovered, disposed of or recycled. In the case of recycling, building waste has so far been used primarily in road construction and earthwork. The company Ettengruber GmbH Recycling und Verwertung started developing various concrete formulations using recycled aggregate, which consists entirely of processed building waste. This concrete was already successfully used for a test building at the Bayernkaserne barracks in Munich.
Many years of close commercial relationships between PST Spezialtiefbau Süd GmbH and Ettengruber gave rise to the question of whether concrete with 100% recycled aggregate can be used in deep foundation work as concrete in deep foundations is subject to different requirements to that used in construction. The objective was not only to use concrete with recycled aggregate, but also to do all required processes on site. That is, after dismantling a building, the waste should be processed into recycled aggregate with a mobile processing plant on site and the concrete should be produced with a mobile mixing plant on site as well. The major advantage of this recycling process is the reduction of transport to landfill and avoiding concrete deliveries to the site.
Through a test series in November 2021, the companies PST Spezialtiefbau Süd GmbH and Ettengruber wanted to check if concrete with 100% recycled aggregate can be produced and used without any disadvantages, in comparison to conventional concrete, in deep foundation projects. The project development company Neuplan GmbH supported them in these tests and provided a site in Munich where the tests could be conducted. For further reduction of emissions on site, the test series included the use of a Liebherr LB 16 unplugged — a battery-electric drilling rig that releases almost no emissions (Scope 1) on site.

THE TEST SERIES

The test series examined if the concrete with 100% recycled aggregate meets the required properties of a conventional concrete for the production of bored piles. The following points were examined to answer this question:

- Processability and pumpability (visual observation)
- Consistency (slump flow tests)
- Compressive strength (cube testing)
- Structure of the hardened concrete (extracting drill cores)
- Overcut and surface quality of the secant pile wall (excavation of the pile wall)

Production of the recycled aggregate

The recycled aggregate was completely made up of building waste. During the dismantling of the building by a demolition excavator, the waste, including concrete and bricks, was presorted and if need be, separated from the reinforcement. Afterward the material was fed into the mobile processing plant, which removed any remaining iron and steel by an overbelt magnet and crushed the material to the required size. The processed material was recycled aggregate with a particle size distribution of 0/16 mm.

Ettengruber developed concrete formulations for the test series with the following special properties:

Concrete with 100% concrete recycled aggregate

- required strength C30/37
- consistency F5
- particle size distribution 0/16 mm

Concrete with 100% mixed recycled aggregate

- required strength C20/25
- consistency F5
- particle size distribution 0/16 mm

The main difference between the two types of recycled aggregate is their composition. The DIN 1045-2 divides the recycled aggregate into different types according to the European standard EN 12620. Type 1 is concrete recycled aggregate and consists mainly of concrete, solid rock, gravel, etc., see Fig.1 (right). Type 2 is mixed recycled aggregate that contains, in addition to concrete, solid rock, gravel, etc., as well as a higher amounts of bricks, etc., see Fig. 1 (left). According to the DIN 1045-2, up to 45% of natural aggregate can be replaced by recycled aggregate with a particle size d > 2 mm depending on the type of recycled aggregate and the exposure class and moisture class. So, as mentioned already in the abstract, the concrete used for this test series does not meet the standard, because the used aggregate is 100% recycled and the particle size distribution is 0/16 mm.

Fig.1: Mixed recycled aggregate (left) and concrete recycled aggregate (right)

Production of the concrete

The formulations were prepared in a mobile mixing plant, see Fig. 2. The aggregates were poured into the supply container. The binding agent and water were added in the forced mixing drum, along with special superplasticizers and retarders to optimise the concrete properties. After the specified mixing time, the fresh concrete was transported by a conveyor belt, see Fig. 2.

Fig. 2: Mobile mixing plant with a conveyor belt

Production of drilled piles

The production of the test piles was conducted with the Liebherr LB 16 unplugged drilling rig using the Kelly drilling and the double rotary drilling methods. In the following figures, just the double rotary drilling method is demonstrated. After the drilling template was built, see Fig. 3, the drilling process was started. In the double rotary drilling method, the drill casing, including the continuous flight auger, is drilled down to the required depth, see Fig. 4. Once the final depth has been reached, see Fig. 5, the casing and the auger are extracted. During the extraction, concrete is pumped via a concrete pump through the hollow auger and a concrete pile is created.

Fig. 3: Drilling template

Fig. 4: Positioning at the drilling point and starting drilling process

Fig. 5: Reaching the final depth and starting concreting

After concreting, the excess drilled material is removed and, if applicable, the reinforcement cage installed, see Fig. 6 and Fig. 7.

Fig. 6: Removing the drilled material

Fig. 7: Installing the reinforcement cage

Examination of the concrete

During the concreting process no difference could be detected in the processability and pumpability of the concrete with 100% recycled aggregate (both formulations). The reinforcement cage could be installed without any problems. After the production, no settling water was detected. The consistency was examined by a slump flow test. The slump flow of about 600 mm met the requirements for a consistency F5, see Fig. 8. For further proof, that concrete with 100% recycled aggregate can be used in deep foundation work, concrete cubes were produced on site, see Fig. 9, as required by concrete monitoring classes 1 or 2 in accordance with the applicable standard.

Fig. 8: Examination of the slump flow

Fig. 9: Production of concrete cubes

The concrete cubes were examined in the test laboratory at the Munich University of Applied Sciences. The samples were tested for compressive strength after 2, 7, 28 and 56 days. The samples achieved the required compressive strength at the respective point in time. The individual values are shown in the diagram below, see Fig. 10.

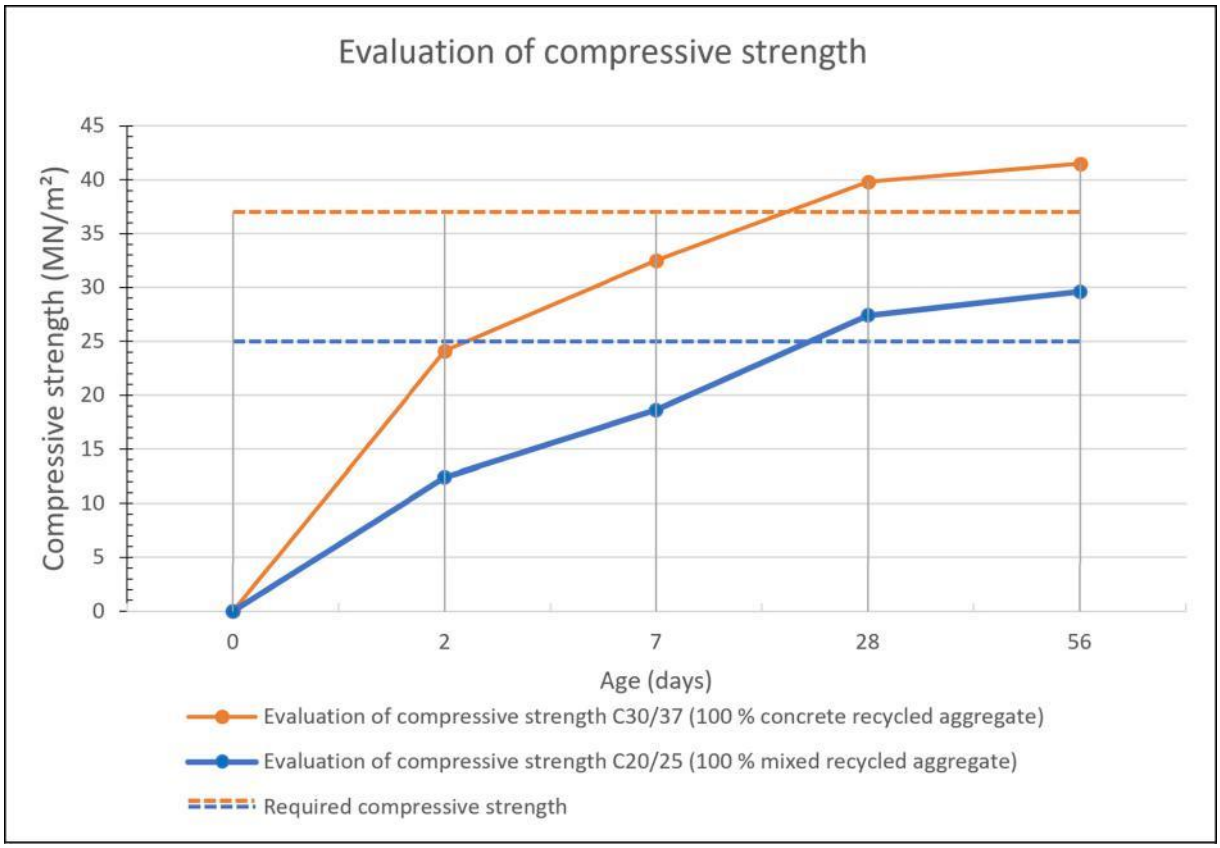

Fig. 10: Evaluation of compressive strength of concrete C30/37 with 100% concrete recycled aggregate and C20/25 with 100 % mixed recycled aggregate

For checking the structure of the concrete after hardening, concrete cores were extracted by way of core drilling after a hardening time of 28 days, see Fig. 11. Drilling was performed to a pile depth of approx. 4 m (13 ft) to 7 m (23 ft). The drill cores showed no signs of abnormalities with respect to the monolithic structure. Neither air pockets nor "gravel pockets" were detected. A distinct difference can be seen between the two formulations with respect to colouring, see Fig. 12 and Fig. 13. The recycled concrete with mixed recycled aggregate has a distinctly reddish colour. The recycled concrete with concrete recycled aggregate shows no difference to conventional concrete.

Fig. 11: Core Drilling

Fig. 12: Drill core with concrete recycled aggregate

Fig. 13: Drill core with mixed recycled aggregate

After the concrete had hardened, the secant pile wall was cleared to allow the overcut and the surface quality to be examined. Due to the lower compressive strength at the beginning of the concrete C20/25 with mixed recycled aggregate, see Fig. 10, the assumption came up that through the drilling of the secondary piles the overcut between the primary and secondary pile could not have been properly produced. But no abnormalities were detected at the secant pile wall, see Fig. 14. The overcut of the piles showed no sign of abnormality, e.g., breakouts or similar. The surface of the secant pile wall was as it would be expected in gravelly soil.

Fig. 14: Secant pile wall

CONCLUSION

The test series has successfully demonstrated that concrete with 100% recycled aggregate meets all requirements and can be used for the production of bored piles like conventional concrete.

Further benefits of using recycled concrete are of course the reduction of emissions and the preservation of valuable resources.
Just as an example, if you require 4000 m^3 concrete and you process the building waste of the dismantled building to recycled aggregate and produce concrete on site, there is no need for concrete deliveries to the site. If you assume that one truck mixer transports on average 7.5 m^3 concrete, you would need about 530 truck mixers to travel to the site. Through the production of the concrete on site, up to 500 transports can be avoided. Furthermore, transport to landfill can be essentially reduced through using waste from the existing building on site for the production of recycled concrete.
Another important advantage is that concrete can be produced in the required amount available within the required timeframe. There are no waiting times for concrete deliveries due to the traffic rush hours in crowded cities, as is often the case in Munich.

OUTLOOK

Due to this successful test series producing a secant pile wall using concrete with 100 % recycled aggregate, PST Spezialtiefbau Süd GmbH is using concrete with recycled aggregate at a current construction project in Munich.

ACKNOWLEDGEMENT

Thank you to the companies Ettengruber, Neuplan and Liebherr, who made the test series possible!
We achieved great results and got one step further to implementing sustainability in deep foundation engineering.

REFERENCES

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