Goumans/Senden/van der Sloot, Editors
Waste Materials in Construction: Putting Theory into Practice

A study of the potential of utilising electric arc furnace slag as filling material in concrete

Catharina Bäverman and Francisca Aran Aran[1]
Department of Chemical Engineering and Technology
Royal Institute of Technology
Stockholm, Sweden

Abstract

Sand in concrete has been substituted by steel slag from an electric arc furnace. The physical properties investigated were break load and compressive strength. The two materials showed similar results. The leaching properties of the materials were also investigated to study whether the steel slag concrete could be acceptable from an environmental point of view. The leaching properties of both materials showed similar results, except for chromium leaching. The release rate of chromium has been calculated, and the results show that the chromium leaching should be no problem.

Introduction and background

Large quantities of waste material are produced annually in the steel industry. The use of these secondary materials in civil engineering applications is of great interest nowadays, both to decrease the amounts landfilled and to replace natural aggregates like sand and gravel. The utilisation of these materials is only interesting if there are no environmental effects caused by the substitution. Recycled scrap iron generates a slag with a high metal content. The slag used in this study comes from a scrap-metal-based steel industry, and is an electric arc furnace (EAF) slag. EAF slag is presumed not to have any binding properties useful in concrete production, and can, therefore, be used to replace natural aggregate in concrete.

The aim of the study was to investigate whether steel slag can be used in concrete as filling material to substitute sand. The influence of steel slag in concrete was investigated and compared to normal concrete. The steel slag concrete was also compared to steel slag to study the influence on leaching of cement in contact with the slag.

Material and Methods

The slag used in this study was an EAF slag from Fundia Steel AB, Sweden. The slag was crushed and sieved to give a particle size distribution similar to that of natural sand.Two types of concrete were prepared: a normal concrete with natural sand as aggregate, and a steel slag concrete with steel slag as aggregate. The preparation technique was the standard technique for preparing concrete specimens. The specimens were kept in a moisture chamber at 100% humidity for 7 days, the first day in the mould, and at 50% humidity for 21 days.

Physical properties

The physical properties investigated were compressive strength and breaking load in order to investigate whether steel slag concrete could make a good product. The steel slag concrete had a higher density than the normal concrete. The compressive strengths and breaking loads of the two different types of concrete were similar, and they can both be considered as medium strength concrete. The steel slag concrete was, however, more brittle than the normal concrete.

Leaching tests

The leaching properties of the steel slag concrete were studied to see whether the material is acceptable from an environmental point of view. Batch leaching tests were performed on crushed material with a particle size less than 0.16 mm, at constant pH, 9.5, 10.5, 11.5, 12.5 and 13.5, at liquid-to-solid ratio of 5 and at pH 9.5, 11.5 and 13.5 at a L/S ratio of 100. Samples were taken after one and seven days. A second series of experiments performed on the steel slag concrete and on the normal concrete involved batch leaching tests using slabs. This test can be used to study the diffusion, from deeper portions of the sample. Similar tests have earlier been used for diffusion measurements in granite(1). Concrete slabs, 6*40*40 mm, were made. Ten slabs were put in a Teflon holder and placed in a vessel, see figure 1. A volume of 300 ml of water was added to the vessel. The leachate pH was kept at 9.5, 11.5 or 13.5 by

---

[1] Resident in Barcelona, Spain.

the addition of nitric acid or sodium hydroxide. The vessels were closed and samples were taken after 1, 2, 4, 8, 16 and 32 days.

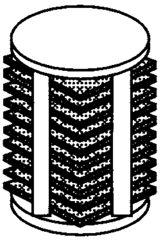

Figure 1. Ten slabs of concrete were put in a Teflon holder and placed in a vessel.

Analyses

The samples were analysed with ion chromatography. The ion chromatography system consists of a Dionex model DX-300, with both suppressed conductivity detection and post-column reaction with UV/VIS-detection. The content of Ca, K, Mg, Mn, S, Co, Cr, Cu, Zn, Cl, Pb, Ni were determined.

Results and discussion

Crushed sample

The natural pH of the leach water in contact with the samples was the same for the two concrete samples, whereas it was one pH unit lower for pure steel slag. This shows that the final pH of the leachate is controlled by the cement and that the substitution did not considerably affect the final pH. As the pH in our experiments was manually adjusted by the addition of acid, we observed that it was difficult to keep a constant pH, due to the high pH buffering capacity of the materials. This problem did not occur when the pH was kept at a higher pH than the initial pH. The buffering reactions are probably the dissolution of oxides, mainly lime (CaO). This effect was the same for both steel slag concrete and normal concrete.

Chromium was the only element of those analysed for which the leach pattern differed significantly between steel slag concrete and normal concrete. The chromium concentration in the batch experiments is shown versus pH in figure 2. The results show that the chromium leaching from the steel slag concrete follows the leach pattern for steel slag at high pH, above 12, but that at a pH below 12 the leaching from the steel slag concrete is higher than that from both the steel slag and the normal concrete. The minimum chromium leaching from the steel slag concrete was observed at the natural pH of the material. The concentration at this pH is in the same range as that of the maximum level for Swedish drinking water, which is 0.9 µM(2).

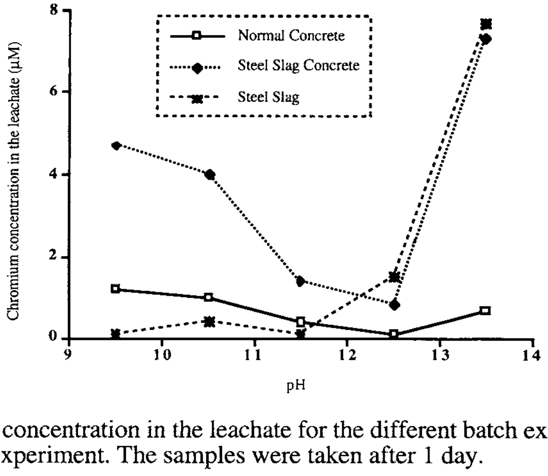

Figure 2. Chromium concentration in the leachate for the different batch experiments versus pH of the experiment. The samples were taken after 1 day.

Slabs

In the experiments with concrete slabs, the concentrations in the leachate from the normal concrete were similar to the concentrations in the experiments with crushed material at the corresponding pH. There were no significant differences between the samples taken at various times. In the leachate from the steel slag concrete, the chromium concentration for the experiments at pH 9.5 and 11.5 was constant at about 0.5 μM, independent of the time at which the samples were taken, whereas at pH 13.5 the chromium concentration showed a strong time-dependence, shown in figure 3. The release rate was $1*10^{-6}$ mol/(m^2*day). It would take about 50 years to dissolve all the chromium in this material if the release rate is constant. The solubility of chromium at this pH is of the order of 10^{-2} mol/dm^3(3), and it is thus far from saturation.

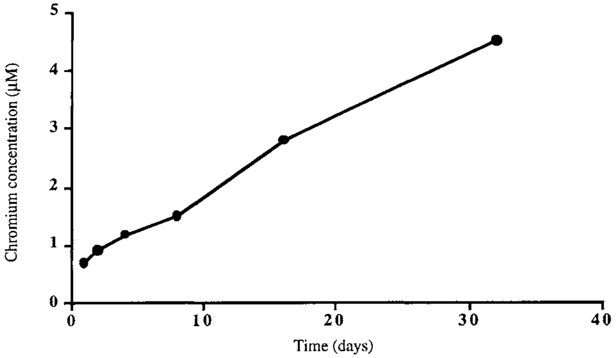

Figure 3. The concentration in the leach water in the leaching test at a pH of 13.5. The release of chromium was time dependent at this pH.

Leaching mechanisms

The time dependence of the chromium release is shown in figure 3. After the initial quick rise, the leaching rate is constant. The pore diffusion does not limit the leaching in this case. The leaching rate found experimentally is typical of a case where the dissolution or reaction rate is the controlling factor.

A comparison of the surface area exposed to leaching in the two experiments showed that the fine-grained particles had a specific surface area at least 86 times larger[2] than the slabs (outer surface). The leached amount was, however, only 14 times larger (in g/kg concrete) from the ground material than from the slabs, after 7 days of leaching. Assuming that the surface area of the particles is 86 times larger than that of the slabs and that the dissolution rate is the same for slabs and fine particles, when the solution is far from equilibrium, these results show that the outer exposed surface of the slabs contributes 16% of the leaching and that the exposed inner surface must be 5 times larger than the outer surface. This is the same as though the outer 0.8 mm depth of the concrete slabs contributes to the leaching as if it is fully available for leaching.

General discussion

The main variable controlling the leaching of heavy metals is the final pH of the solution(4). This was not affected by the addition of steel slag instead of sand to the concrete. The leaching of most elements was not affected, with the exception of chromium, as the leaching was similar for both concrete types. The greater leaching of chromium from steel slag concrete compared to that from normal concrete may not be an environmental problem as the leaching at the normal pH (about 12.5) is very close to the drinking water limit and cannot, therefore, be considered to be a problem. The release rate, even under extreme conditions (pH 13.5 shown in figure 3) is very low.

---

[2] The surface area, in this discussion, is calculated assuming that all particles are cubes with a 0.16 mm side. The smaller particles contributes with a larger surface area. There is, therefore, reason to believe that the specific surface area is larger than has been assumed.

If the steel slag concrete were used to make a swimming pool (25m*12m*2m) and the walls were not coated, it would take more than three years with no change of water, and no cleaning either, to exceed the drinking water limit for chromium, assuming a constant release rate and that the release rate is similar in neutral water as at pH 13.5. This is, of course, not true, but it is improbable that the release rate is larger at neutral pH, or that the rate increases with time. It is, therefore, probable that it would take much longer than three years in a real situation to exceed the drinking water limit.

Conclusions

In this study, steel slag was used to replace sand as an aggregate in concrete. The compressive strength and break load were the same for both materials but the steel slag concrete broke into much smaller pieces.

The leaching from the steel slag concrete and from regular concrete are similar for all metals except chromium. The release rate is, however, low for chromium so it should not be an environmental problem. The release is lowest at the pH that is natural for the concrete, i.e. about 12.5.

The results of both the physical study and the leaching tests show that this steel slag can well be used as a substitution for sand in medium strength concrete. There are, as far as we can see, no environmental risks associated with the utilisation. The benefits are that virgin material is saved and that the steel slag does not have to be deposited in landfills.

Acknowledgements

The authors thanks Gunnar Klingstedt and Lennart Magnusson at the Cement and Concrete Institute in Stockholm for help in the preparation of the concrete samples and in the measurement of physical properties of the specimens. They have also contributed to the work in valuable discussions. We also thank Dr Luis Moreno and Professor Ivars Neretnieks at the department of Chemical Engineering and Technology at the Royal Institute of Technology for their contributions to this work. This work was financed by the Swedish Environmental Protection Agency/AFR.

References

1. Skagius, A-C.K. Diffusion of dissolved species in the matrix of some Swedish crystalline rocks, PhD thesis, Department of Chemical Engineering, Royal Institute of Technology, Stockholm, Sweden, 1986.
2. SLV FS 1989:30, Statens livsmedelsverks kungörelse om dricksvatten, ISSN 0346-119X, 1989.
3. Stumm, W. and J.J. Morgan, Aquatic Chemistry, Chemical Equilibria and Rates in Natural Waters, Third Edition, John Wiley & Sons, ISBN 0-471-51185-4, 1996.
4. Chandler, A.J., T.T. Eighmy, J. Hartlén, O. Hjelmar, D.S. Kosson, S.E. Sawell, H.A. van der Sloot, J. Vehlow, International ash working group, International perspective on characterisation and management of residues from municipal solid waste incineration, summary report, December 1994.