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# Use of gasification residues in compacted concrete paving blocks

Erika Holt [a,*], Paula Raivio [b]

[a] VTT Building and Transport, The Technical Research Centre of Finland, Box 1800, 02044 Espoo, Finland
[b] Contesta Oy, Box 23, 01601 Vantaa, Finland

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**Abstract**

Research was done to determine the possible uses of fine-grained solid gasification residues in concrete products. Due to the residues' chemical composition, compacted concrete paving blocks were studied as one viable non-structural application of adding the residue. Six different residues were tested in the laboratory at up to 25% replacement by dry weight of either cement or aggregate. After these preliminary laboratory tests, one residue was used in full-scale field tests at the Lakan Betoni factory where 10 and 15% of straw-derived residue was used as a cement replacement. Tensile strength, compressive strength, resistance to freezing–thawing cycles, absorption and leaching were evaluated. The addition of the residue improved the workability of the concrete, provided a beneficial dark coloring and did not adversely affect most properties. The freeze–thaw resistance should be improved by reducing the factory compaction effort to ensure sufficient void space.


*Keywords:* Mixture proportioning (A); Admixtures (D); Ash (D); Gasification

## 1. Introduction

Environmental concerns make it more important to find suitable methods for disposal of by-products. With the introduction in Finland of new production plants to gasify waste and generate energy, there will be more by-products (or wastes), which need proper disposal. In recent years the concrete industry has accepted certain by-products such as silica fume and fly ash as components in their products. In some cases the by-product is beneficial to the concrete properties, while in other cases the by-product is merely a replacement of more expensive materials like cement or filler, and the by-product is used in the concrete primarily to save disposal costs. This project aimed to find a use for gasification residues within the concrete industry.

The types of concrete products that can accept gasification residues are highly dependent on the by-products' chemical composition and grain size distribution. Before a by-product can be used, these chemical and physical properties need to be verified.

By-products can be added to the concrete either as a replacement for the fine aggregate or for the cement. Replacing cement is the more economic choice of the two since cement is the most expensive ingredient in concrete. Some precautions must be taken when adding by-products to concrete products due to their chemical reactivity, for example, by-products containing chlorides are avoided in concrete which contains steel (re-bar).

Another concern is that as electric utilities are upgraded to low-$NO_x$ burners the by-product residue often has a higher carbon content. The higher carbon ash can affect concrete products as, amongst other things, it adheres to air-entraining admixtures, causing a decrease in the volume of entrained air [1].

In this study, concrete applications for the by-product substitutions were selected which would not be affected by the chemical composition of the residue. For this reason, paving blocks were chosen which are manufactured by compacting dry-concrete into a mould, similar to roller compacted concrete. Dry-concrete means the concrete has a low paste content, usually with a lower binder content than traditional concrete. With a lower paste and water content the concrete cannot be self-consolidated by vibration and therefore requires alternative compaction methods.

The by-products used in this study were from the gasification process, which was designed to dispose bio- and recycled-fuels that are difficult to burn with conventional techniques due to harmful compounds. Gasification occurs at around 900 °C in a reducing environment. Residues in the product gas are collected by cyclone and filters and the purified

* Corresponding author. Tel.: +358 20 722 4567; fax: +358 9 461 665.
*E-mail address:* erika.holt@vtt.fi (E. Holt).

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Table 1
Residue properties

| Residue | Gasifier fuel | Density ($g/cm^3$) | Specific surface ($m^2/kg$) | Mineral composition |
|---|---|---|---|---|
| Cement | – | 3.12 | 440 | – |
| FW-BA | Straw | 2.59 | 510 | Quartz, pyroxene, feldspar, amorphous |
| FW-CD | Straw | 2.28 | 680 | Sylvite (KCl), lime, calcite, amorphous |
| SK FD | Wood | 2.44 | 640 | Periclase (MgO), calcite, amorphous |
| ENE 99/21-FD | Waste pellet | 2.32 | 2130 | Calcite, lime |
| ENE 99/24-FD | Waste pellet | 2.54 | 1310 | Calcite, lime, sylvite, halite (NaCl), metallic aluminium |
| ENE 99/24-CD | Wood | 2.68 | 630 | Lime, metallic aluminium, calcite, quartz |

BA = bottom ash. CD = cyclone dust. FD = filter dust.

gas is burned together with coal, oil or natural gas. Development of gasification techniques has been carried out since the late 1970s at VTT Energy in Finland [2]. One of the goals during the development work has been to find utilization areas for the residues in the building industry and to avoid landfill disposal.

The composition of the gasification cyclone and filter dusts is highly dependent on the gasified fuel and other process additives. It was noted that the dusts showed pozzolanic reactivity. This led to the idea of utilizing the gasification residue in the manufacture of various concrete products. The dusts also included abundant amounts of chlorine that is harmful for moulds and re-bar of some concrete. The purpose of these tests was to determine if the gasification residues could be incorporated to compacted concrete for a savings in material costs. Preliminary laboratory tests were done prior to full-scale factory tests to evaluate how the compacted concrete products were affected by the gasification residue addition.

## 2. Materials

Six gasification residue samples from various pilot gasifications plants were provided for this investigation, as shown in Table 1, with their gasifier fuel density, specific surface area and mineral compositions compared to cement. The residues' chemical composition was evaluated using XRF and AAS analyses, with the main results given in Tables 2 and 3, respectively. The particle size distributions of the six residues and the reference cement, as measured by a Sedigraph 5100 machine, are shown in Fig. 1. The first residue, FW-BA, has a grain size more similar to fine aggregate while the other residues have size fractions resembling cement grains. Note that 99.5% of FW-BA residue was retained on the 63 μm sieve or greater, so Fig. 1 only shows the size distribution of the finer particles. From the grain size distribution we see that most of the residues are slightly finer than the Rapid cement and therefore contribute to tighter particle packing when used in the concrete products.

None of these residues can be considered for use in the cement manufacturing process or in reinforced concrete because of their high chlorine content: excess chlorine would accelerate the corrosion of steel reinforcement bars that are often placed in structural concrete applications. For this reason compacted concrete paving blocks, which do not contain any steel reinforcement, were selected as a possible application.

The residues do have some pozzolanic reaction, though they are not as strong of a binder as cement alone. This is demonstrated in Fig. 2, where the compressive strength was tested when 25% of the cement was replaced by the gasification residues. These reactivity tests were done using tests similar to the EN 450 test standard [3] for testing fly ash reactivity. The mortar mixtures had a water/cement ratio of 0.5, containing 75% CEN standard sand and 25% cement by dry weight. The expectation was that the strength would only be reduced by about 25% compared to the reference, which held true for some of the residues but not all.

In all concrete tests described in the next sections, the cement used was rapid hardening cement (CEM II A 42.5 R) from Finnsementti Oy in Finland. Aggregates consisted of clean natural granite, with a maximum size of 10 mm with the gradation given in Table 4. Clean cool tap water was used for mixing and no admixtures were used.

## 3. Experimental program

The test program included laboratory tests to establish the amount of residue which could be added to the compacted concrete, followed by multiple property tests on selected

Table 2
Calculated element composition of residues, measured by XRF and carbon analyses

| | FW-BA | FW CD | ENE 99/21 FD | ENE 99/24 CD | ENE 99/24 FD | SK 2FD |
|---|---|---|---|---|---|---|
| C | 1.35 | 27.2 | 43.8 | 9.17 | 13.1 | 47.1 |
| Si | 32.2 | 8.69 | 1.23 | 11.2 | 6.72 | 1.48 |
| Ca | 5.53 | 14.8 | 20.6 | 22.7 | 24.4 | 9.15 |
| Al | 5.07 | 0.401 | 0.54 | 11.11 | 6.24 | 0.387 |
| K | 5.77 | 13.3 | 1.93 | 1.17 | 1.88 | 1.95 |
| Na | 1.11 | 0.5 | 0.226 | 2.06 | 2.07 | 0.082 |
| Mg | 0.65 | 0.62 | 1.3 | 1.56 | 1.42 | 16.82 |
| Cl | 0.224 | 5.47 | 1.02 | 1.91 | 9.73 | 0.268 |
| Fe | 1.07 | 0.275 | 0.768 | 1.89 | 1.68 | 0.937 |
| P | 0.195 | 0.339 | 0.617 | 0.411 | 0.41 | 0.357 |
| Si | 0.406 | 0.848 | 0.217 | 0.263 | 0.508 | 0.071 |
| Ti | 0.103 | 0.023 | 0.051 | 1.04 | 1.69 | 0.019 |
| Fe | 0.026 | 0.034 | 0.024 | 0.096 | 0.191 | 0.054 |
| Mn | 0.027 | 0.012 | 0.81 | 0.085 | 0.079 | 0.33 |
| Sr | 0.029 | 0.025 | 0.049 | 0.029 | 0.027 | 0.025 |
| Zr | 0.009 | 0.001 | 0.001 | 0.017 | 0.015 | 0.001 |
| Nb | 0 | 0 | 0.001 | 0.001 | 0 | 0.001 |
| Sn | 0 | 0 | 0 | 0.01 | 0.019 | 0 |
| Ba | 0.049 | 0.033 | 0.151 | 0.167 | 0.156 | 0.08 |
| La | 0.003 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 |
| Ce | 0.002 | 0.001 | 0.001 | 0.004 | 0.003 | 0.002 |
| Ta | 0 | 0 | 0 | 0 | 0 | 0 |
| Th | 0 | 0.001 | 0 | 0.001 | 0 | 0.001 |
| U | 0 | 0.001 | 0.005 | 0 | 0.001 | 0.002 |