Short Communication

The Mechanical Properties of Coal Gasification Slag as a Component of Concrete and Binding Mixtures

Radosław Pomykała*

AGH University of Science and Technology, Faculty of Mining and Geoengineering,
Department of Environmental Engineering and Mineral Processing, Poland

Received: 20 June 2013
Accepted: 28 February 2014

Abstract

Gasification in entrained flow reactors is now one of the most dynamically developed technologies of thermal conversion of coal. The basic, solid by-product of this process is slag, and in some cases also fly ash. In Poland, so far there have been no examples of industrial application of coal gasification. However, the high popularity of such systems in the world indicates the possibility of the appearance in Poland in the future, along with by-products of gasification. To pre-determine the possible future directions of management of this type of material, slag from coal gasification in foreign installation was obtained and tested.

This article discusses the possibility of using slag from gasification of coal as a component of concrete and binding mixtures. The mechanical properties of such composites were tested because of the different content of the slag, the type of cement used, and the seasoning time.

Keywords: slag, coal gasification, aggregate, concrete, binder mixture

Introduction

Gasification of coal is one of the most dynamically developing clean coal technologies. This process enables the production of liquid fuels, electricity, and heat while achieving high rigor in the environment, in particular reducing emissions. Gasification plants currently under construction are based primarily on one of the three types of reactors: fixed bed, fluidized bed, and entrained flow. The most of them, up to 2016 will be based on the last one [1].

So far Poland has not yet constructed an industrial coal gasification plant. However, the rapid development of this technology in other countries suggests that it may take place in the near future. The start of the operation of an industrial coal gasification plant will bring with it a new byproduct that will require new methods of management. Depending on the technology used and on the temperature during the process, by-products of gasification are created in the form of fly ash, agglomerated ash, or slag.

This paper presents the results of mechanical tests of samples of concrete and binder mixtures prepared with the participation of slag from coal gasification, formed in an entrained flow "slagging" reactor in a foreign installation. This type of reactor has a high operating temperature that exceeds the melting point of the mineral matter in the fuel. During gasification, liquid mineral material slag runs down the walls of the reactor until a collection point, where it is rapidly cooled. In this way, the primary product of this process is an amorphous slag. Fly ash captured in the purification of exhaust gas may be a separate product, and also be recycled to the reactor [2-4].

Research on the management of gasification by-products, including slags, are normally conducted by research centres located close to the gasification plant. In literature

*e-mail: rpomyk@agh.edu.pl

outside Poland you can find examples of research on the possibilities of by-products of gasification. Most of the research concerns the possibility of using such materials as aggregates for building and road construction [3, 5]. They were also useful in the ceramics industry [6-8].

Possibilities of using by-products from thermal coal conversion depend on the local needs and available technology logistics as well as the properties and the suitability of such materials. Taking into account national and international experience on the use of combustion by-products, we can distinguish several major directions in which by-products of gasification could be used. In Polish conditions, recipients of such materials can be primarily mining, the building industry, road construction, and the cement industry.

In Poland, so far we've seen a number of studies to define the properties of gasification by-products from plants based on entrained flow reactors and fluidized bed reactors [9], and an analysis of possibilities of utilizing these first in mining technologies [10].

This paper considers the subject of the application of slag from gasification of coal components of concrete and binding mixture. Present result tests of mechanical properties include compressive and flexural strength of such composites.

Materials and Testing Methods

For testing was used slag from coal gasification originating in a foreign installation based on the entrained flow reactor. First, the basic properties of the material were determined, such as the density and particle size distribution (Fig. 1).

In the first part of the study concrete samples were prepared in the proportions: cement 0.5, aggregate 3, water 1 (0.5/3/1). As a binder component was used Portland cement CEM I 42.5. In the reference samples quartz sand was used as an aggregate. Subsequently, in the samples of concrete, sand was replaced with slag from coal gasification, up to 100% of the share. All samples were made in the form of concrete beams with dimensions: 40×40×160 mm. The samples after 24 hours from preparation were placed in water and seasoned there until the 90th day, and then they were seasoned in air-dry conditions at 20-23ºC and 50% humidity.

Realized research focused on the mechanical properties: flexural strength (Rf) and uniaxial compression strength of 40×40 mm cubic samples. Samples were tested after 28 days (and marked with an index of "28"), after 90 days (index "90"), and after one year of aging (index "Y").

The second, parallel run phase of the study was to determine the applicability of gasification by-products as components of binder mixtures. Due to the fact that the material is characterized up to 3 mm grain size, some of the slag has been milled to a grain size typical for fly ash. Milled gasification slag was used to prepare samples of binder mixtures, with the same water-to-solid ratio (w/s = 0.5), but with different contents of cement. Cement grout was used as a reference samples (with 100% cement as solids), and in the subsequent series cement was partially (30, 50, and 70%) replaced by the milled slag. For testing was used Portland cement CEM I 42.5 and metallurgical cement CEM III 32.5. Prepared samples had the shape of beam size

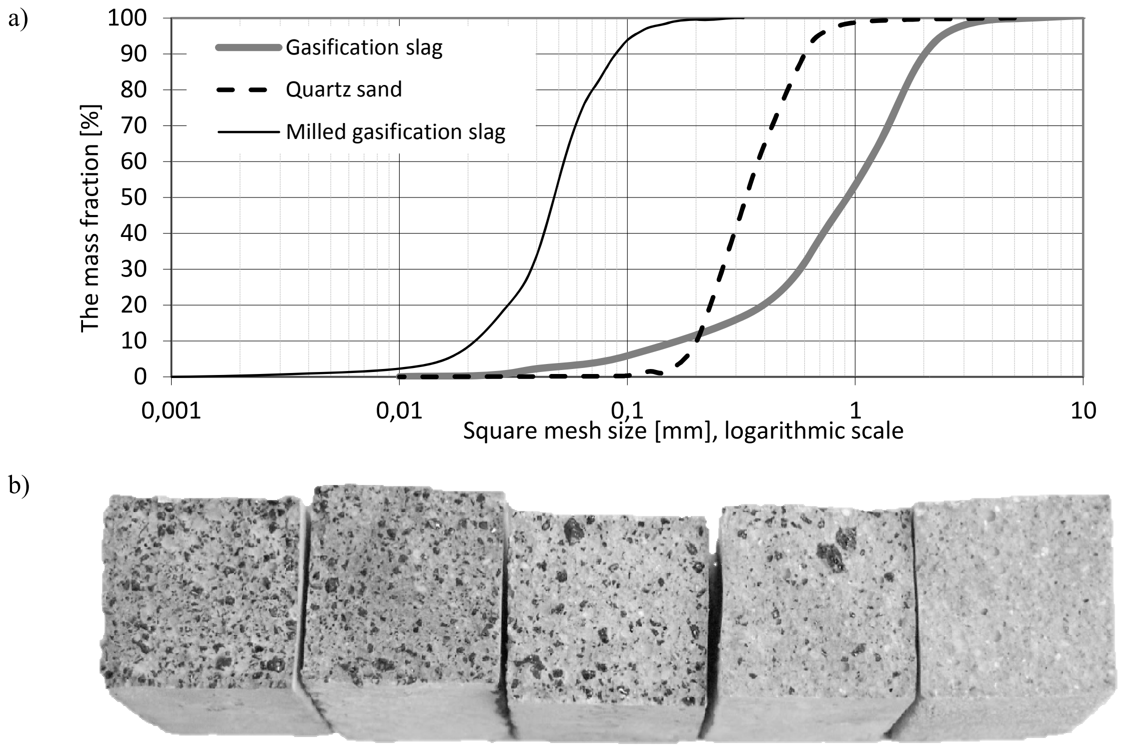

Fig. 1. Tested materials: a) granulation; b) distribution of particles of slag in concrete samples (after bending test), from the left: 100% of slag in aggregate, 75%, 50%, 25%, and 0%.

40×40×160 mm (similar to concrete samples). The samples were seasoned after preparation at 22ºC at relative humidity of 100%. Strength tests (Rc and Rf, such as concrete samples) were performed after 60 days of preparation.

Tests Results

The results of particle size distribution of the materials used are summarized in Fig. 1a. Grading milled slag is close to the particle size of fly ash from coal combustion. Specific density of the slag is 2.63 Mg/m^3, and the sand 2.54 Mg/m^3.

Fig. 1b shows pictures of concrete specimens with different shares of slag as aggregate, after the bending test. Even the arrangement of grains shows that some of the slag grains were destroyed, which was not observed for the grains of sand.

The strength parameters of concrete involving the slag as aggregate were tested in three test periods: after 28 days, after 90 days, and one year after preparation. The results are shown in Figs. 2c and 2d. As expected, the strength of the samples increased with seasoning time. Between the first series of measurements (after 28 days) and the final (after year) growth Rc is from 10 to 20%. Much larger differences

a)

b)

c)

d)

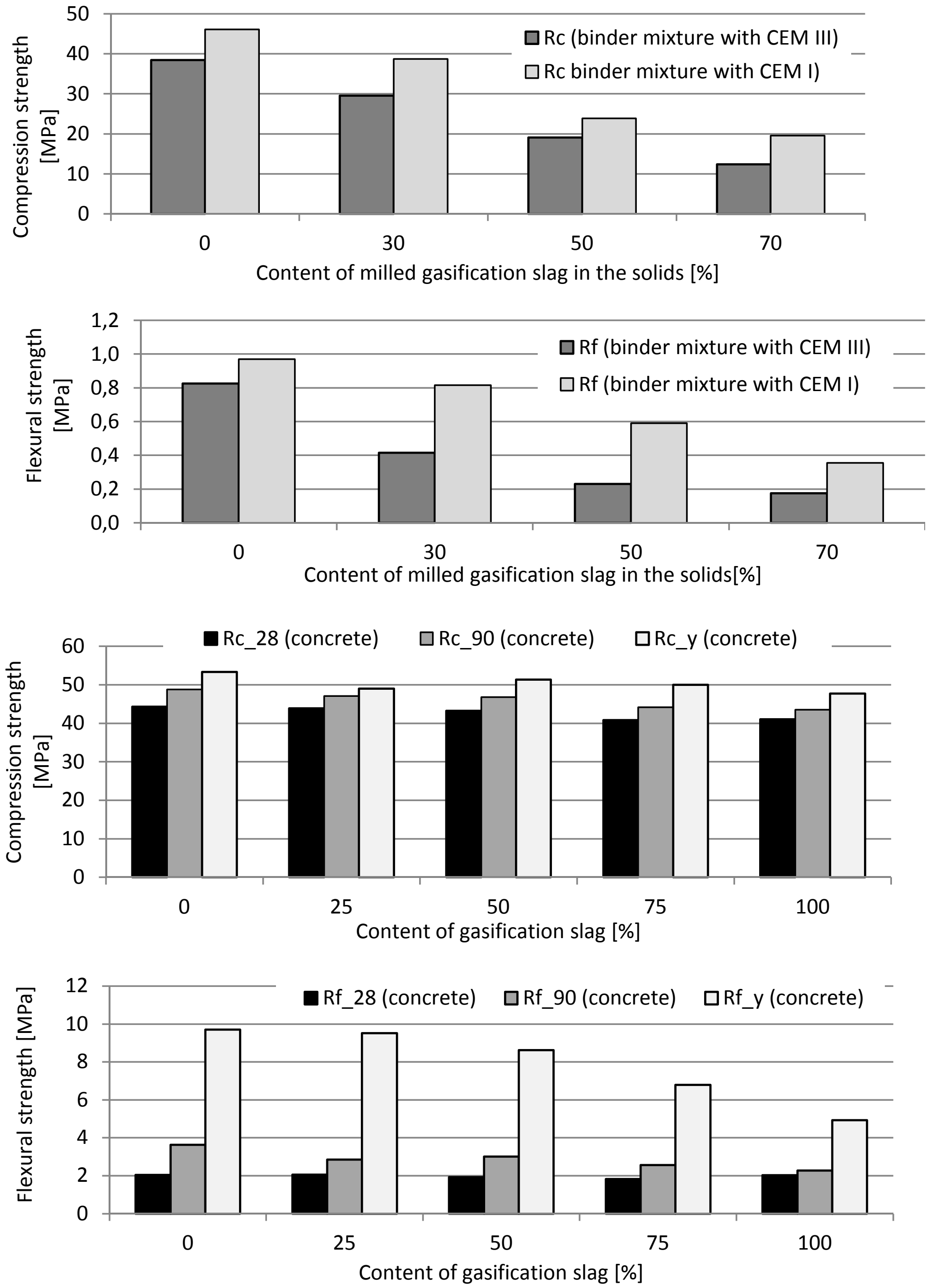

Fig. 2. Mechanical properties of samples with content of gasification slag: a) compression strength of bonded mixtures, b) flexural strength of bonded mixtures, c) compression strength of concrete, d) flexural strength of concrete.

were observed in the case of flexural strength. For some samples Rf increased more than fourfold after one year.

Larger content of slag in the aggregate resulted, generally lowering both the compressive strength and flexural. Nevertheless, reducing Rc of samples containing slag did not exceed 10% compared to standard samples (with sand as aggregates).

Different was the case for the bending test: after 28 days, the results for all samples were very similar to each other. However, the passage of time increased the difference between the Rf of samples with bigger slag content in aggregate (75 and 100%), and the bigger Rf of the other samples. Lower flexural strength of samples with the highest content of the slag is also confirmed by macroscopic observation. After the bending tests, on fracture surface cracking cases of larger grains of slag was observed. Such a phenomenon did not take place for the samples based on the sand aggregate

The strength test results of binding mixtures are shown in Figs. 2a and 2b. Strength sample mixtures decrease with increasing shares of milled slag faster in samples based on metallurgical cement. In mixtures in which the proportion of slag in solids of 70%, Rc of samples reaches 32% of the value Rc of the cement grout, and the Rf only 21%. For mixtures prepared from Portland cement, loss of strength is smaller. For samples containing 70% of milled slag in the solid parts (and 30% of Portland cement), Rc value reached 42%, and Rf 32% of the strength of cement grouts.

Conclusions

The purpose of realized studies was to preliminary determine the suitability of slag originating from coal gasification in an entrained flow reactor, as a component of concrete and binding mixtures, because of the mechanical properties.

Studies have shown the possibility of replacing all or part of the natural aggregate (sand) by the slag from the gasification of coal in concrete samples. Dependence between increasing slag content and a drop of strength were observed. The drop in the case of Rc was low – not more than 10%, even when the only slag was as aggregate. More important proved to be the effect of slag aggregate on flexural strength. Because of the Rf it would be advisable to use mixtures of slag with sand or other comparable aggregate.

Milled slag from coal gasification can also be used as a filler component for the preparation of binder mixtures. Especially in mixtures of Portland cement, high strength properties were obtained, even with 70% share of the milled slag. Binders with comparable parameters are now available on the market and used in engineering works, road building, mining engineering, etc.

The studies performed are of preliminary nature. It is only byproducts of gasification studies available on the domestic market (coming from the gasification of coal in the local indigenous plants) that will allow for a precise definition of their management capabilities.

Acknowledgements

The researches in this paper have been developed in the framework of the research project of the Ministry of Science and Higher Education No. N N524 361038: Research slags from high temperature coal gasification installations in terms of their use in the mining technologies.

References

1. CHMIELNIAK T., TOMASZEWICZ G. Gasification of solid fuels – the actual state and expected directions of development. Karbo **3**, 191, **2012** [In Polish].
2. Clean energy, chemicals and fuels from coal – evaluation of the development potential. Edited by T. BOROWIECKI, J. KIJEŃSKI, J. MACHNIKOWSKI, M. ŚCIĄŻKO. Institute for Chemical Processing of Coal, Zabrze, **2008** [In Polish].
3. HIGMAN CH., VAN DER BURGT M. Gasification. GPP Elsevier. **2008**.
4. POMYKAŁA R., MAZURKIEWICZ M. The coal gasification process in the light of properties of arising wastes. Przegląd Górniczy **7-8**, 183, **2011** [In Polish].
5. AINETO M., ACOSTA A., RINCÒN J.M., ROMERO M. Production of lightweight aggregates from coal gasification fly ash and slag. World of Coal Ash (WOCA), Lexington, USA, 2005. www.flyash.info, **2005**.
6. ACOSTA A., IGLESIAS I., AINETO M., ROMERO M., RINCÓN J.MA. Utilisation of IGCC slag and clay steriles in soft mud bricks (by pressing) for use in building bricks manufacturing. Waste Manage. **22**, 887, **2002**.
7. AINETO M., ACOSTA A., IGLESIAS I. The role of a coal gasification fly ash as clay additive in building ceramic. J Eur. Ceram. Soc, **26**, 3783, **2006**.
8. CHEN L-M., CHOU M-I.M., CHOU S-F. J., STUCKI J.W. Production fired bricks using coal slag from gasification plant in Indiana. World of Coal Ash (WOCA) Conference, Lexington, **2009**.
9. POMYKAŁA R., MAZURKIEWICZ M. Selected properties of the waste from coal gasification. Przegląd Górniczy **1/2**, 100, **2011** [In Polish].
10. POMYKAŁA R.: Properties of waste from coal gasification in entrained flow reactors in the aspect of their use in mining technology. Arch. Min. Sci., **58**, (2), **2013**.