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Influence of type and maximum aggregate size on some properties of high-strength concrete made of pozzolana cement in respect of binder and carbon dioxide intensity indexes

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HIGHLIGHTS

- Influence of type and size of aggregate and pozzolana cement on HSC was determined.
- 0/8 mm aggregate with cement at 700 instead of 600 kg/m^3 improved strength by 8.5%.
- In case of 0/16 mm aggregate there was no need to increase cement amount to 700 kg/m^3.
- Basalt or granite of 0/16 mm size and 600 kg/m^3 of cement curbed HSC carbon footprint.

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ABSTRACT

In compliance with up-to-date concrete technology requirements combining technological and ecological aspects, the paper describes the effect of the type and maximum aggregate size and cement content on some properties of high strength concrete. The following kinds of coarse aggregate were used to produce concrete: natural mineral (gravel) and crushed (granite and basalt) aggregates and pozzolana cement – ingredient classified as ecological binder. The concretes contained a highly effective superplasticiser and microsilica. Air content in concrete mixes, water absorption and concrete compressive strength after various periods of hardening were examined. Certain calculations (based on compressive strength results) on values of intensity indexes of cement used and carbon dioxide, treating them as a key for evaluation of eco-efficiency of concrete, were performed. Using pozzolana cement with simultaneous use of a highly effective superplasticiser and microsilica made it possible to obtain high strength concrete, made of mineral natural and crushed aggregates. More encouraging strength tests results were achieved for concrete of crushed aggregates, particularly granite. It was discovered that using aggregate with a maximum particle size less than 8 mm instead of aggregate with particles measuring up to 16 mm with a simultaneous increase in the cement content led to a greater rise in concrete strength. The smallest indexes of binder and carbon dioxide intensity were obtained as a result of use of granite and basalt aggregate, with a maximum particle size up to 16 mm.

1. Introduction

A growing intensity of extreme weather conditions brought about by climate changes has become a serious social and economic problem of XXI century. Natural changes of the climate are particularly connected with solar activity, occurrence of *Milankovitch cycles* (variations in eccentricity, axial tilt, and precession), volcanic activity and ENSO (*El Niño–Southern Oscillation*) phenomenon. However, the increasingly higher and higher ratio of carbon dioxide concentration in the atmosphere, which has been observed for last 150 years, undoubtedly, is becoming increasingly significant. In 2013, for the first time, the CO_2 content in the atmosphere exceeded 400 ppm (http://climate.nasa.gov/news/916/) [1].

C.D. Keeling has been conducting researches on carbon dioxide content in the atmosphere since the fifties of last century. Although they do not constitute a direct evidence for anthropogenic reasons for the intensity of climate changes, today, in light of the other evidence, it is difficult to find more rational interpretation. According to measurements conducted by R.F. Keeling (C.D. Keeling's son) in

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9 observatories in the world [2,3], rise in CO_2 content is associated with a simultaneous lowering of oxygen to nitrogen proportion which is presented in the upper part of Fig. 1. The only plausible explanation of this phenomenon is the use up of oxygen in the processes of combustion of fossil fuels. It is more difficult to agree with one of most recognised alternative hypothesis, according to which the increase in CO_2 content in the atmosphere is a result of rise in the temperature of the oceans and seas, brought about by increased solar activity. Had this hypothesis been true, the proportion of oxygen to nitrogen would not have changed. It is only the carbon dioxide content in the atmosphere that would have changed. In fact, there is an observed, on the one hand, correction between the drop in the proportion of oxygen to nitrogen [2,3] with a commonly known C.D. Keeling curve (lower part of Fig. 1) illustrating the increase in the carbon dioxide concentration in the atmosphere and, on the other hand, the lower activity of the sun in the last 11-year cycles (http://solarscience.msfc.nasa.gov/predict.shtml) [4].

Concrete technology is one of the areas of human activity involved in increase in CO_2 emission, in particular cement production, key constituent of concrete. In addition, high demand for energy, demand for water, erection of buildings and its demolition are the reasons why concrete is not considered to be particularly environmentally friendly or compatible with the demands of sustainable development [5]. Hence, in the opinion of not only the environmentalists' expectations but also the average users' of the environment, concrete construction sector is obliged to undertake immediate action aimed at reducing its environmental impacts, including reduction of CO_2.

The regard for the environment has led to appearance of such notions as: green building, green concrete, green cement, biocement, eco-cement [5–8], which define industrial materials and processes that are environmentally friendly, but at the same time are economically viable and thus meet the expectations of concrete technology. Aïtcin's [9] opinion, according to which "the concrete of tomorrow will be green, green, and green", seems to be the best summary of the significance of this aspect.

The principles of sustainable development regarding construction and concrete industry have also begun to be a concern of not only environmentalists, but also governments on local, state, and national levels. Slowly by slowly, owners and developers have consequently begun to implement "going green" principles, for political reasons as a source of impalpable benefits and promotion. Still, they also find it as a way to improve the quality of the environment, where they live. They have realised that such aspects as reduced energy consumption and reduced life-cycle costs [5] are truly worth it.

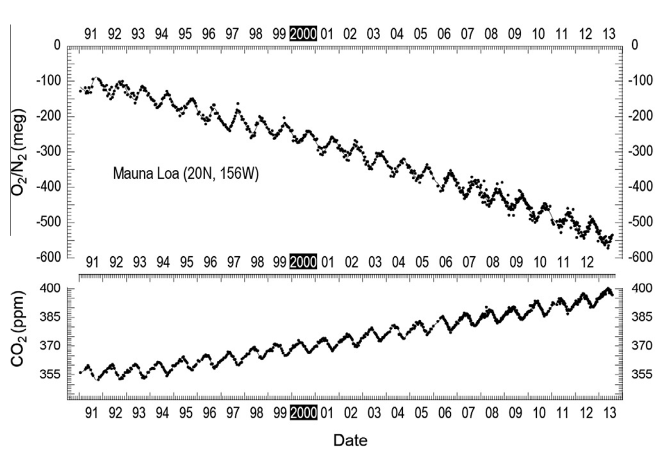

Fig. 1. Correlation between carbon dioxide quantity and oxygen to nitrogen ratio in the atmosphere based on Mauna Loa observations [3].

The aim of the present day technologists' is to produce increasingly sophisticated concrete, in terms of technical parameters, that is absolutely environmentally friendly. The potential tools and strategies needed to meet the environmental challenges in the construction and concrete industry could be achieved in different ways. They are as follows:

- replacement, as much as possible, of Portland cement by supplementary cementitious materials, especially by-products of industrial processes, such as fly ash, ground granulated blast furnace slag and silica fume [5,10–13],
- using eco-cements [7,14,15],
- using recycled materials, including recycled concrete aggregate, in place of natural resources [5,16–20],
- improvement of durability and service life of structures and as a result reducing the amount of materials needed for their replacement [12,16,21,22],
- improvement of concrete mechanical and other properties, which can also reduce the amount of materials needed [5,23],
- reusing wash water [5].

One of the criteria that can be a measure of sustainable development in the cement and concrete industry are Damineli's et al. [24] propositions on binder intensity index and carbon dioxide intensity index (b_i and c_i, respectively). The first one describes the cement mass per 1 m^3 of concrete necessary to achieve 1 MPa strength. The second presents the mass of carbon dioxide emitted in the production process of such a volume of cement that make it possible to attain the concrete strength of 1 MPa. Hence, the b_i index makes it possible to estimate the efficiency of a given cement binder in the process of obtaining the durable concrete. The c_i index means a unitary contribution of the binder into the CO_2 emission. If a complementary assessment of the eco-efficiency of cement is to be achieved, it is essential to use both indexes simultaneously.

As in all processes of concrete production, most of the carbon dioxide emission comes from the production of cement, the data can be treated as nearly estimating this emission for the needs of concrete production with specified parameters. Obviously, estimations should be carried out individually, since emissivity of CO_2 varies from cement plant to cement plant and different raw materials needed to produce clinker are used, and since selected concrete components vary in terms of quality and quantity.

More precise estimations could be achieved by including the volume of CO_2 emitted in the cause of transport of raw materials and cement as a final product, and emitted from technological operations connected with execution of concrete structure (production, transport and compaction of concrete).

In the light of concept of indexes [24], use of cements with mineral additives results in lower value of the c_i index compared to the value of c_i for Portland cements without mineral additives. On the basis of local and international data, Damineli et al. [24] estimated that CO_2 emission index in the production of purely clinker cements is approximately 4.3 kg/MPa and 1.5 kg/MPa in the production of cements with mineral additives [24]. The c_i index is related to the binder intensity index b_i, that for concretes with compressive strength exceeding 50 MPa is approximately equal to 5 kg/m^3/MPa, and for concretes with strength of 20 MPa is even 13 kg/m^3/MPa. Hence there are two ways of reducing CO_2 emission, i.e. selecting cements with mineral additives and producing concretes of high strength, more durable by nature, which can bring a meaningful effect when low proportion of Portland clinker cements are used for the production of high-strength concretes (HSC).

Reports on high-strength concretes in a "green" option refer to replacing a part of cement binder in the concrete with mineral