CONCRETE PRODUCTION IN THE ASPECT OF SUSTAINABLE DEVELOPMENT PRINCIPLES

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1. INTRODUCTION

It is expected, that construction industry in XXI century will satisfy of the society requirements for healthy and durable building works. However, from different reasons concrete structures can be considered as incompatible with the principles of sustainable development. In concrete production a large amounts of valuable, natural raw materials are used, and during cement production gas emission to the atmosphere takes place, contributing to the global greenhouse effect and in consequence – to the climatic changes [1].

2. CONCRETE PRODUCTION INCLUDING ENVIRONMENTAL PROTECTION ASPECTS

Three issues are widely discussed with regard to sustainable development: ecological production, changes of climate and reduction of natural resources.

The “clean production” is among elements of sustainable development strategy in the field of construction industry. It is defined as permanent protection of natural environment individual elements against consequences of production processes and against pollutions caused by products.

Clean Production Strategy assumes [2]:

- economical management of materials used in production process,
- energy economy,
- excluding of materials and products, which are harmful for environment and health of people,
- prevention measures against generation of waste materials.

In many parts of our globe the changes of climate took place. To the scientists [3] this phenomenon in mainly concerned with high degree of gas emission to the environment, in the
range of 280-370 ppm. Emission of greenhouse gases, mainly CO\textsubscript{2}, and its concentration in the environment is mainly associated with industrial transport and cement production. According to statistic data, cement production provides about 7\% of the world CO\textsubscript{2} emission [3,4].

The third aspect is the reduction of natural resources. Concrete industry consumes a large amounts of raw materials like sand, gravel, crushed aggregates and water. For production of portland cement and multi-component cement, 1 billion tons of materials is used every year. In addition, cement production uses a large amount of limestone and clay, with the involvement of high energy-consumption.

When technical conditions of building deteriorate or when building no longer perform the functions, before the assumed working life expired, then such big utilization of natural resources and energy can be considered as wastage.

There are the cases when nowadays built structures need repairs during guarantee period. It specially concerns bridges, parkings, garages and marine-structures [5].

Mostly, the concrete structures are designed for the intended use of at least 50 years. From the time when HPC production has started, there is a chance that these structures would last about 100 years. The progress in reduction of using of natural raw materials by extending of building materials durability is rather long-time solution.

In the opinion of many persons, systematic actions to develop of ecological production in a large scale – is the solution of the new strategy. Similarly, water which is recover from the cement industry, may be substitute for water used in concrete mixes, after assessment of fitness for use [6].

The production of multi-component cements, which incorporate waste materials such as fly ash, slag and silica fume, are examples for ecological industrialization. In this way, cement industry provided the excellent materials and reduced the onerous effect on the environment.

In Polish construction industry, the concrete mixes incorporating 15-20\% of fly ash have been used for many years. The amount of fly ash utilized for this purpose is estimated as 700,000 tons yearly.

3. THE CURRENT STATE OF MANAGEMENT OF WASTES COMING FROM CONSTRUCTION INDUSTRY IN POLAND

The Act concerning waste, dated of 27.04.2001, imposed the obligation for waste management planning, which is the basis for preparation of plans in a lower levels. According to GUS data, as much as 139,340,000 tons of wastes have been produced in 2000 in Poland. According to waste catalogue given in Decree of Ministry of Environment of 27.09.2001, construction wastes are qualified to the 17th group. They are defined as wastes coming from construction sites, repairs and demolition of building works and road infrastructure. The amount of such wastes in 2000 was estimated as about 218,600 tons [8], it means about 1.8\% of total wastes.

Such wastes are derived from many scattered companies in the field of construction and repairs, in road and industry building, what makes the precise estimation very difficult. Above mentioned data include the group of large enterprises, producing more than 1000 tons of waste yearly.

The amount and type of wastes coming from small and medium firms were not the subject of investigation and they are not covered by statistic data. From the fragmentary information it may be concluded, that the amount of the latter wastes are estimated as 2-8\% of a total wastes generated in Poland.

Building wastes are formed both on the construction stage and during planned or emergency repairs and demolition works. Depending on the source, the qualitative characteristic of these
waste is very diversified. Wastes coming from building works, repairs and demolition works in industrial construction may be polluted by: heavy metals, petroleum products and impregnating substances. Wastes coming from railway building may be polluted by impregnating substances (sleepers), oil, grease, other dangerous substances, heavy metals (broken stone), as well as by soil and stones. Depending on assortment and pollutions, including dangerous substances (asbestos), the wastes have been divided on the subgroups and marked by codes e.g. concrete wastes and concrete debris from demolition and repair are marked: 17 01 01.

3.1 Industrial production of aggregates from construction wastes

According to data for 2003 [9], 15 firms is involved in the recycling of construction wastes. Production of recycling aggregates includes the following stages:
1. Initial selection and segregation of road and construction debris,
2. Initial sieving and separation of oversize elements,
3. Shattering oversize elements,
4. Crushing and separation of material

4. HIGH PERFORMANCE CONCRETE (HPC)

There are many definitions for HPC [10]. ACI defines it as special engineering concrete, with one or more specific properties, which is improved by selected materials and by appropriate component proportions. This definition may not be adequate in relation to concrete, for which specific requirements was determined, such as good workability, high early compressive strength and high resistance to exposure conditions. Generally, the majority of critical opinions, with regard to ACI definition of HPC, did not accept this view, that durability is not obligatory but only optional parameter [1]. Statement, that combination of high strength and durability of concrete is unsuitable, resulted probably from many cases of cracks and premature deterioration of HPC in structures [11, 12]. But generally, the incorrect mix proportions, which were used to production of high strength concrete were the reason. Typical HPC mixes contain in 1 m$^3$ 400-500 kg of portland cement or mixed cement, small amount of silica fume, fly ash or slag and they are designed with low w/c ratio. The superplasticizers and air entraining admixtures are used, when frost resistance of concrete is required.

Research works and practice indicated, that HPCs with high strength were mainly produced. On the other hand, the massive structures are still executed with a large portland cement content, what results in a big shrinkage. Therefore, Aitcin [13] has proposed to complete HPC
definition in this way: **HPC is the concrete with low w/c ratio and stabilized shrinkage, which receives adequate water to the shrinkage self-control.**

The research works carried out by Ho and Sheinna [14] have shown, that certain amount of cement in HPC may be replaced by other materials e.g. granite dust (by-product formed during granite aggregate production) which may be applied in new generation of SCC, instead of limestone powder. Replacement of certain amount of cement by dust not only decreases of cement consumption, but also reduces the energy needed for concrete vibration. Another example: to the very high performance concrete fly ash, slag and silica fume were used individually and in several combinations with cement. As high strength as 200 MPa was obtained together with w/c = 0,16, high density and high fluidity of mixes [15].

In concrete technology in Poland, as additions to concrete silica fume, slag and fly ash are used. In 1992 silica fume was applied in the first supervised by ITB structure, which was viaduct in Warsaw (fig.3).

![Fig. 3 Viaduct on Hynka street in Warsaw – supervised by ITB (Concrete Department).](image)

Above considerations, with regard to research works and practical applications of HPC, attract the attention to this type of concrete and answer the question: weather HPC is or it is not the choice satisfying the principles of sustainable development. The majority of conventional concretes may not be qualified as materials satisfying these principles, because they are not durable, contain a large amount of cement and small quantities of cement replacement materials.

### 5. HIGH VOLUME FLY ASH CONCRETE (HVFAC)

Fly ash - the main by-product of coal combustion may be used as compound of multi-component portland cement and also as pozzolanic addition to concrete. In common practice, fly ash is used in the amount of 15-20 % in relation to the cement mass. Normally, this quantity gives sufficient advantages in concrete workability an price, but in may be insufficient to improve durability of concrete to sulfate attack, alkali expansion and thermal cracking. For these reasons, the bigger quantities of fly ash – up to 35 % m.c. are used, but such composition still can not be qualified as HVFA system.

According to Malhotra and Mehta [16], the amount of fly ash in HVFA should be at least 50 % m.c.

From theoretical point of view, and on the basis of practical experience, the authors settled, that concrete incorporated 50 % of fly ash is possible to be produced in compliance with the assumptions of sustainable development. Such concrete mixes are characterized by high workability, high strength and durability.
The mechanism of cement hydration in the presence of pozzolanic materials is commonly known and described in bibliography. Improvement of concrete properties, as a result of their application, is connected with the ability of reactive SiO$_2$ to the reaction with Ca(OH)$_2$, and formation of C-S-H phase [17]. The only disadvantage of this system is too slow strength development, but workability of concrete mix is its virtue.

Several advantages, due to application of large quantity of fly ash in concrete are presented below [1]:

1. very good flow properties, better pumpability and better compactibility,
2. better finishing surface, quicker execution, without additional energy,
3. longer setting time, allowing to carry out the additional technological operations e.g. joining of the next layers.

### 6. OWN EXPERIENCE

ITB technical supervision on the building site of Warsaw`s tunnel takes into account of the investor requirements: economic effectiveness and maintenance of proper state of construction after execution of works. Typical technical specification was completed by several specific material, technological and logistic requirements, for various conditions of tunnel construction.

According to the regulations at that time, the decision regarding fly ash application has to be taken by the Minister.

In actual state of the art, when environmental conditions of future construction are properly defined, the technology of concrete execution and choice of materials may be precisely specified. To prevent asking the questions during implementation of this difficult construction, the rule has been adopted: to determine all potential hazards before the construction has started, and then to determine the procedures for specific situations.

The innovations in specification are given below:

1. essential components (concrete materials) were covered by the procedure of permanent delivery monitoring, according to European standards,
2. conformity procedures were defined and the Quality Plan was established,
3. the calculation of structure durability was determined on the basis of initial tests of concrete resistance to simulated deterioration, during ageing tests carried out in the conditions of simulated aggression,
4. according to ISO 9001, the procedure on the contact among investor, supervising body, management of construction and subcontractors has been determined,
5. the specific procedure in the range of quality has been applied for concrete suppliers.

According to the requirements the following materials were used: cement CEM I 42,5, aggregates in grit form and natural sand. Silicate fly ash was admitted by special, formal procedure. For such cement-fly ash combination, the appropriate chemical admixture (on the basis of polycarboxyethers) were selected.

All materials satisfied the requirements of specifications and standards, and their deliveries were controlled and supervised according to the principles of ISO 9001.

The various concrete mix proportions were used, including fly ash variations. The fly ash/cement ratio was in the limits from 0,15 to 0,42. Applying bigger quantities of fly ash and keeping the same mix consistence, the amount of water and w/c ratio was reduced. Concrete 1 was characterized by w/s = 0,39, and concrete 2 – w/s=0,32. Concretes were frost resistant and watertight. The results obtained on samples taken from 5 randomly chosen concrete
batches fulfilled the requirements of PN-88/B-06250 for concrete F150 and W8. According to EN 206-1 these concretes have been qualified to exposure class XF4. During the structure execution, about 300 mix proportions have been made, since the concrete composition was verified before every concrete placing, and it took into account all technological aspects: type of structure, the way of moulding, curing, weather conditions etc. Fig.4 presents the results of strength for 210 concretes.

**Fig.4 Statistic analysis of 210 series of 28-days compressive strength results of concrete built in the tunnel construction, \( R_{\text{mean}} \) value = 50.3 MPa.**

After 2 years curing of randomly chosen samples of concretes in the climatic chamber, the compressive strength was tested and compared with 28-days results. On fig.5 and 6 the results of strength are presented.

**Fig.5 Statistic analysis of 28-days compressive strength of concrete built in the tunnel structure, \( R_{\text{mean}} \) value = 47.4 MPa.**
Fig. 6 Statistic analysis of 28-days compressive strength of concrete built in the tunnel structure, $R_{\text{mean}}$ value = 72.8 MPa.

Fig. 7 Compressive strength of concrete after 28-days and 2 years. (maximal p/c ratio permissible by EN 206-1 is 0.33).

Fig. 7 indicated, that the concrete strength is on the increase with the increase of fly ash content in binder. Independent on p/c proportion in binder, after 2 years, about 50% increase of strength is observed.

Two concrete compositions, with the extreme fly ash quantities, marked as concrete 1 and 2 are given in table 1.
### Table 1. Mix proportions

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<th>Composition of concrete (1) p/c</th>
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<tr>
<td></td>
<td>Cement kg/m^3</td>
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<td>300</td>
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<td>Composition of concrete (2) p/c</td>
<td>240</td>
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*Fig.8 Compressive strength of concrete 1 and 2, after 28 days and 2 years hardening.*

### 7. SUMMARY

In last decades, the development and the range of HPC application in Europe gradually increased. The application of HPC was so far limited mainly to the buildings and bridge structures such as: elements subjected to high compressive loads, walls, pavements, and beams with the small cross-section (slim structures) etc. Obtained results and practical experience should be formulated in the form of rules.

Present practical experience on the application of HPC, based on many research works can be transferred also to the underground construction and can be effective in development of a new technologies, specific for this type of structures. The specific requirements concerning underground construction force also certain conventional technologies to the further development.

The costs of removal of waste materials are increased all over the world. At the same time it was recognize, that fly ash is the cheap and easy available by-product, which can be applied in concrete industry.

HVFA system, to a large extent, allows to overcome the problems of thermal cracks, alkaline expansion or sulfate aggression. As an effect of w/c reduction and taking the advantage of fluidization due to superplasticizers, as well as by reasonable dosage of aggregate, concrete which is properly cured, indicates homogenous microstructure and high strength without cracks.
Summing up- in respect of the increase of requirements in relation to future concrete, HVFA technology provide the optimal, sustainable solution. It reduces the production costs and contributes to decreasing of wastes materials, which are created by two large industrial branches – cement industry and coal mining. In that situation, the link between low production costs and environmental protection seems to be suitable solution and development of HFVA may be recognized as conforming to the principles of Sustainable Development. Application of such high fly ash content is difficult for acceptance, because of slow development of concrete durability in the early stage of hardening. The results of own research works presented here certify the chance for safe application of fly ash in the proportion p/c = 0.42.

8. REFERENCES

8. Monitor Polski Nr 11, z dnia 28 lutego 2003r.