POBOLJŠANJE ODRŽIVOSTI KONSTRUKCIJSKIH BETONA PRIMENOM KREČNJAČKOG FILERA

IMPROVING SUSTAINABILITY OF STRUCTURAL CONCRETE BY APPLICATION OF LIMESTONE FILLER

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Savremeno društvo ima moralnu obavezu da pametno upravlja energijom, kako bi se očuvala životna sredina za buduće generacije. Potreba za cementom podrazumeva izuzetno visoku upotrebu relativno skupe energije, evidentnu u svim segmentima proizvodnje i primene. Upotreba fosilnih goriva tokom proizvodnje cementa glavni je problem za stvaranje efekata staklene bašte i klimatske promene. Do kraja tekuće decenije, oko 10% ukupnih emisija CO_2 *antropogenog porekla biće posledica proizvodnje cementa. Da bi se sačuvala konkurentnost betona kao najkorišćenijeg građevinskog materijala, potrebno je preduzeti odgovarajuće mere u cilju promocije održivog razvoja. U tom smislu, zamena cementa jeftinijim i čistijim materijalima – filerima, može imati značajan globalni doprinos. Sprovedene analize prikazane u ovom radu nesumnjivo ukazuju na veliki potencijal zelenih betona sa niskim sadržajem cementa i visokim sadržajem filera u konstrukcijama.*

Ključne reči: *filer, zeleni beton, održivi razvoj*

Modern society has the moral obligation to manage energy wisely, in order to preserve the environment for future generations. The need for cement implies the extremely high use of relatively expensive energy, evident in all segments of production and application. The use of fossil fuels during cement production is the main problem for creating the greenhouse effect and climate change. Until the end of this decade, about 10% of total CO2 emissions of anthropogenic origin will be a consequence of cement production. In order to preserve the competitiveness of concrete as the most widely used building material, it is necessary to take appropriate actions to promote sustainable development. In that way, a cement replacement with a cheaper and cleaner product – filler could have a significant global contribution. The conducted analyses shown in this paper undoubtedly provide the great potential of green concretes with low cement and high filler content in structures.

Key words: *filler; green concrete; sustainable development*

1 Introduction

Construction, as an industry with a significant impact on the environment, is changing, among other things, in accordance with the attitudes that define the so-called sustainable development - such progress of the society that allows the satisfaction of its needs, and at the same time does not endanger the possibility of satisfying the own needs of the generations to come. In that sense, all aspects of construction (planning, design, realization, serviceability, duration or lifespan, etc.) are critically considered, reviewed and, if feasible, optimized from the aspect of sustainable development. Sustainable use of resources, energy efficiency, and durability of buildings, with respect to the possibility of recycling materials and minimizing waste materials and environmental impact, are the basic aspects of the evident commitment to sustainable development in construction today [1].

Within construction, one of the most important challenges in terms of sustainable development is the production and use of cement. Namely, the cement industry affects the environment within each of the stages of the cement production process, from quarry to final use. Unfortunately, this was not given much importance, but the companys' attention was predominantly focused on profit, Figure 1

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(left). In the last 30 years, due to public pressure on the cement industry, the issue of sustainability has become increasingly important, Figure 1 (right).

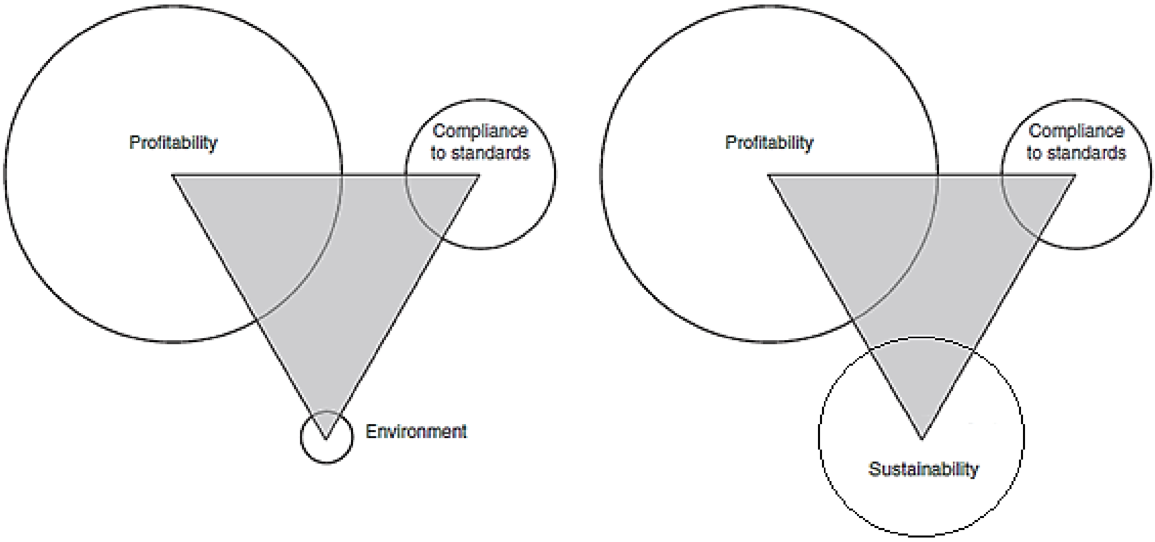

Figure 1: Schematic presentation of the preoccupations of the cement industry during the twentieth (left) and twenty-first century (right) [2]

The use of fossil fuels during cement production is a major problem for creating greenhouse effects and climate change. During the production of 1 t of pure portland cement clinker, about 4 GJ of energy is consumed, and approximately 1 t of CO_2 is emitted into the atmosphere. Moreover, due to the burning of fossil fuels and cement production, the world emits over 36 billion tons of CO_2 annually [3], which compared to the period of 20 years ago represents an increase of 45%, Figure 2. Additionally, according to the National Oceanic and Atmospheric Administration (NOAA) [4] the average global land temperature for the last 20 years has increased by about 0.9˚C, while the sea temperature in the same period has increased by about 0.4˚C compared to the average temperature from the twentieth century.

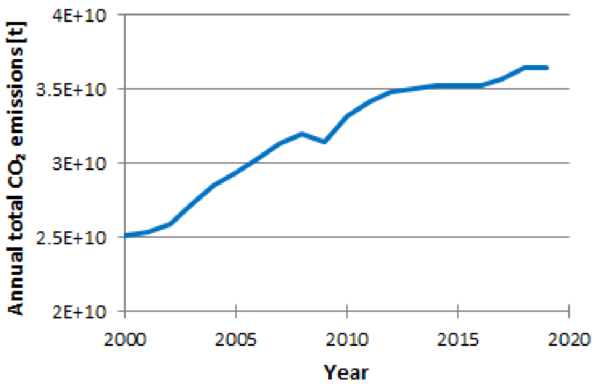

Figure 2: The amount of CO_2 emitted due to the burning of fossil fuels and the production of cement on an annual basis in the world [3]

Due to increased demand for cement, by the end of the current decade as much as 10% of total carbon dioxide (CO_2) of anthropogenic origin will be a consequence of cement production [5]. There are numerous ways to neutralize or at least reduce this impact, and some research in this field is being conducted on a global scale.

In the context of reducing the amount of cement in concrete, there is a certain positive effect of using fillers. There is no universal definition of filler. It can be said that these are mainly inert or weakly reactive fine powder materials, which can be of different origins and mineral compositions. [6]. Fillers of limestone origin - limestone powder, are the most widespread and most used [5,6], but also the only one whose application in concrete is regulated by standards. It is mainly a fine micronized powder, of different granulometric compositions, obtained by grinding high-purity calcium carbonate. The paper analyzes the influence of the application of different green concretes with low cement content and high filler content in reinforced concrete structural elements. The conducted analyzes undoubtedly indicate the great potential of these concretes in all structures, and thus in concrete structures of renewable energy sources.

2 The implementation of taxes

In order to reduce pollution, a large number of countries are introducing some kind of so-called environmental taxes, on the principle of "polluter pays". In Serbia, this fee is currently regulated by the Regulation ("Official Gazette of RS", No. 86/2019 and 89/2019) [7], Article 1: "By this Regulation Detailed criteria for determining activities that affect the environment according to the degree of negative impact on the environment that arises from the performance of activities are determined, the amounts of fees for protection and improvement of the environment". According to the mentioned Decree, concrete production belongs to activities that have a great impact on the environment (Manufacturing, sector C 23.61-69) for which an annual fee in the amount of 20,000 RSD to 2,000,000 RSD is envisaged, depending on the size of the legal entity. However, at the beginning of the current year, the Law on Climate Change was also adopted in Serbia ("Official Gazette of RS", no. 26/2021) [8]. This law regulates the system for limiting greenhouse gasses emissions and it practically performs the harmonization of national regulations in this area with EU regulations [9,10]. In the countries of the European Union, for many years now, companies have been obliged to obtain a permit for the emission of a certain amount of greenhouse gases (GHG) and to pay an appropriate fee for that. This led to the formation of the EU ETS (European Union Emissions Trading System), which operates on a "cap and trade" system. The current value of GHG emissions on the stock exchange is around 60 € / 1t CO_2-eq, with a further tendency to grow [10,11].

The EU also plans to introduce additional taxes on CO_2 in the coming years for imported products from other countries (so-called transboundary carbon equalization mechanism). These taxes should prevent producers who may want to avoid paying existing taxes from relocating their production to countries where they are not yet paid, unfair competition and to put additional pressure on other countries to introduce GHG emissions charges as soon as possible.

3 The use of filler in concrete

There are three cement factories in Serbia, LafargeHolcim, Moravacem and Titan, with a total annual capacity of over 3 million tons. In addition to cements produced within the mentioned cement factories, to a certain extent there is also cement from other producers on the market, originating from the surrounding countries (e.g. Nexxe, Dalmacija cement, etc.). Along with the evident efforts of these companies to improve their business and reduce the negative impact on the environment, the amount of cement used needs to be reduced by alternative approaches. Scientific research has shown that by replacing a certain amount of cement with limestone powder, structural concretes with similar mechanical properties as comparable cement concretes without fillers can be obtained [12]. The percentage of cement replacement, quantity and granulometric composition of limestone powder, as well as water-cement ratio significantly affect the physical and mechanical properties of concrete with low cement content and high content of limestone powder.

Mineral additives, according to the standard SRPS EN 206 [13], are defined as fine or finely ground materials of mineral (inorganic) origin, which are used in concrete to achieve and/or to improve certain properties. There are two types of these additives, namely inert and semi-inert (almost inert) additives (Type I) and pozzolanic or latent hydraulic additives (Type II). Type II mineral supplements are also called pozzolans. Limestone powder is the most commonly used type I mineral additive in concrete. In special concrete that is compacted only under the influence of its own weight (Self-Compacting Concrete - SCC), the use of limestone powder increases the shear stress limit, but does not imply a notable effect on plastic viscosity and spreading [14].

The influence of filler on the properties of fresh concrete is a function of its origin, type and properties. Generally speaking, a finer and less porous filler with a spherical grain shape has a positive effect on the workability of concrete. This is especially pronounced in SCC concretes, since they can be divided into three types (powder, combined and viscous) based on the amount of filler used, where the powder component with the present superplasticizer contributes to the high degree of fluidity of the mixture in the fresh state. In the hardened state, there is an increase in compactness, and thus an improvement in physical and mechanical characteristics, primarily compressive strength.

As an illustration of this effect, Figure 2 shows a comparative representation of SCC and normally vibrated concrete (NVC, made without fillers), used in real constructions. In NVC, it can be noticed that the transition zone between the aggregate grain and the cement matrix is larger, and thus higher porosity in the vicinity of the aggregate grain (visible in the figure as darker fields), as well as uneven structure of cement stone, as a consequence of uneven water-cement ratio (significant color differences can be seen in the figure) in NVC [15]. From the aspect of durability, an improvement is expected in the case of concrete made with fillers, since the structure of the transition zone is more compact and less porous. However, research has shown that concretes made with fillers (primarily limestone powder) are more susceptible to carbonation, have less resistance to freeze thaw actions (with or without de-icing agents) frost and salt and sulphate resistance, which is most often attributed to chemical reactions inside concrete with less cement and more fillers. [16].

In the context of rheology, research shows some advantages of using fillers as a less deformable component compared to a cement matrix, which generally results in lower values of shrinkage and creep of concrete [17].

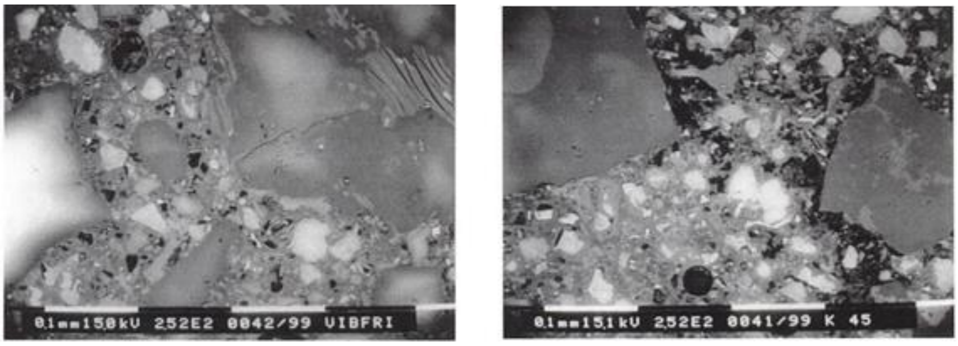

Figure 2: Comparative view of the SCC and NVC structure [15]

4 Comparative assessment of concretes with different amounts of filler

The structural application of concretes with different compositions is dominantly determined by their physical and mechanical properties, along with rheological and the aspects of durability. For the sake of illustration, several types of concrete are presented in table 1, showing a wide range of concrete types with respect to their composition.

Table 1: Composition of different types of concrete

Concrete type	Normal	Self-compacting	Optimized 1	Optimized 2
Cement (kg/m^3)	330	380	230	180
Limestone filler (kg/m^3)	-	220	150	200
Aggregate (kg/m^3)	1830	1700	1830	1830
Water (kg/m^3)	169	183	139	120
Superplasticizer (kg/m^3)	2.3	7.6	5.7	7.6
Compressive strength (MPa)	49.5	55.8	51.1	51.5

In comparison with the normally produced concrete, the self-compacting concrete has a similar or higher amount of cement, but the filler provides better workability, along with superior properties in hardened state. Nevertheless, the ecological and economic aspects are substantially improved when the concrete is structurally optimized, providing simultaneous reduction in cement, improvement of microstructure and preservation of workability and hardened state properties.

Comparative results of conducted analyzes for 1 m^3 ready-mix concrete (transport excluded), are shown in Figure 3. From this Figure, it is obvious that compared to normal concrete, the price of optimized concrete did not decrease significantly, only by 2-4%. Considering the large amount of concrete produced, even a small reduction in the unit price can result in a large economic profit. However, if the savings in possible taxes (36-66%) that will be introduced in the near future are taken into account, then the economic benefit will be significantly higher.

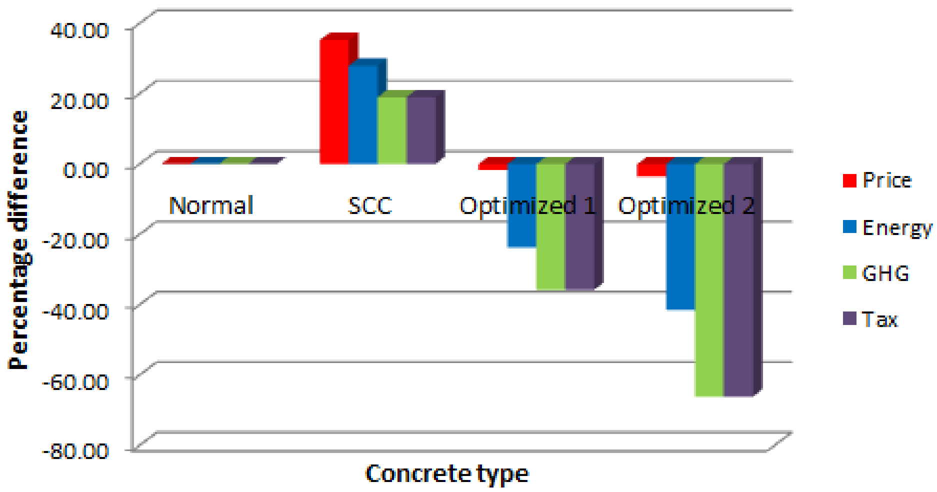

Figure 3: Benefits of green concrete use

It should be noted that the initial price of SCC concrete is significantly higher in some cases, jumping to as much as 35% compared to normal concrete. In addition, the monetary expenditures necessary to regulate the tax increased by about 19%. And the environmental potential of these concretes is declining, as energy demands increase by 28%, resulting in an increase in GHG emissions by as much as 19%. In this sense, the use can be justified only in the case of setting certain specific requirements in terms of workability that ordinary concrete can not meet.

On the other hand, the great environmental benefit of optimized mixtures is evident. GHG emissions can be reduced by an incredible 66%, and energy demands about 42%.

Based on the above, it is clear that the modern conceptual approach in construction implies multi-criteria optimization in every sense. For example, from the aspect of application of materials in construction, the approach in which a material has favorable or acceptable physical-mechanical characteristics in that light must be considered insufficient, because there are a large number of parameters related to its application, which must be considered in each case. In order to raise the confidence of the entire construction industry and enable the wider practical application of these innovative concretes, it is necessary to continue with further research in this area.

5 Conclusions

Modern society has the moral obligation to manage energy wisely, in order to preserve the environment for future generations. The substantial incline towards the renewable sources of electrical energy is a good example of this commitment, and it is ever more followed by the same trends implemented in the construction sector, providing structures for this application. The need for cement implies the extremely high use of relatively expensive energy, evident in all segments of production and application, and the viable way of reducing the quantity of cement used in concrete, in order to improve the economic and ecological aspects of contemporary concrete, is presented in this paper.

The possibility of reduction of cement up to 45% with the limestone filler offers reduction in environmental impact of the concrete and the equivalent carbon footprint of 66%, according to the green house gasses emission. Due to the fact that these types of structural concrete are applicable in the wide range of structures, their applications in the concrete elements of the structures used in the field of renewable sources of electrical energy harvesting are widely justified: as foundations and columns of wind towers, foundations and pillars of solar panels, biomass storage and management facilities, hydropower and geothermal energy structural elements.

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