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Ecological Aspects of Concrete Production

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ABSTRACT

Concrete industry is now the largest consumer of natural resources and one of the largest producers of waste. Only in Europe, the annual production of concrete is over 750 million m^3 which is around 4 tonnes of concrete per capita. Although concrete itself as finished material does not have harmful effect on the environment, production of concrete components has influence on the environment. In the process of production and use of cement, aggregate and water in concrete, ecological aspects should be considered.

Different aspects of making concrete production more environmentally friendly are analysed in the paper. Possibilities of using blended cements, new types of binders, recycled aggregates and treated waste water have been shown. Ecological aspects in concrete industry are: lowering CO_2 emission, conservation of natural resources, and construction of more durable concrete structures.

INTRODUCTION

Environmental protection and energy savings are becoming essential world problems in all fields of technology. Today, the need for a comprehensive thinking on sustainable development is also recognized in civil engineering. Sustainable construction engineering begins with decision to build a construction that will be sustainable. This does not mean only to use the construction material that is environmentally friendly. Looking at the entire life cycle of construction, it is important to see how much energy is needed for heating, lighting, cooling, quantity of carbon dioxide that is going to be produced, level of noise that affects environment, etc. and to consider all of these aspects. In order to preserve clean environment, there is a need for improvement of existing technologies by transforming them into sustainable and environmentally friendly. Concrete industry is now the largest consumer of natural resources and one of the largest producers of waste. Basis for sustainable concrete industry lies in these three aspects: reducing CO_2 emissions by using by-products of other industries (slag, fly ash, silica fume) for cement production, conservation of natural resources by replacing part of the aggregate with recycled construction waste and part of the water with recycled water in concrete production and construction of durable concrete structures. The problem of durability of construction materials is emphasized in recent years because it has been proven in practice that the materials, which have been traditionally considered durable, under the influence of aggressive environment degrade very quickly and cause enormous costs for rehabilitation. This problem finally manifests as problem of construction and demolition (C&D) waste disposal. In addition, demands for structure life cycle of 70, 100 and more years have been increased and thereby demands for improving the properties of materials incorporated in the construction process have been increased as well.

Only in Europe, over 750 million m^3 of concrete is produced annually, which rounds up to 4 tonnes of concrete per capita. Although concrete itself as finished material does not have harmful effect on the environment, production of concrete components has. Particularly, annual world consumption of Portland cement is about 1.5 billion tonnes and it is expected that this number will increase in the future. Only in Asia, consumption of cement was doubled in the period of 11 years (from 1994. 0.68 billion tonnes to 2005. around 1 billion tonnes). For production of 1 t of Portland cement clinker, around 850 kg of CO_2 is emitted in the environment. Studies show that just cement industry is responsible for 7% world emission of CO_2. It is well-known that CO_2 emission is the main reason for the basic ecological problem – global warming. Besides energy consumption and emission of CO_2 during production of cement, major problem of concrete structures is durability i.e. early damaging. This problem finally manifests as problem of construction and demolition waste disposal. Annually is produced more than 1 billion tonnes of C&D waste which is disposed on the landfills all over the world.

Basis for sustainability in concrete industry lies in three primary aspects as demonstrated with Figure 1.

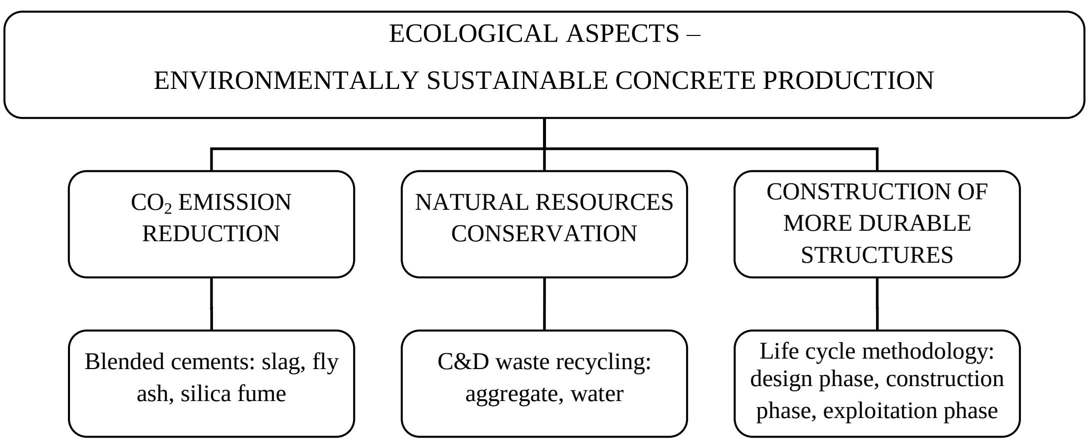


Fig. 1. Ecological Aspects of Concrete Production

In this paper, all three aspects of sustainable concrete production will be described with special stress on the situation in Croatia. Examples of sustainable concrete technology, such as ideas that are being researched and those already implemented in practice, will be presented.

CO_2 EMISSION REDUCTION

In Croatia there is still a growth trend of CO_2 emission. In year 2006 direct CO_2 emission from cement industry was around 2.5 million tonnes, which is compared to year 1990 growth of 51 %. In year 2006 specific CO_2 emission was estimated to be 850 kg CO_2/t of clinker or

700 kg CO_2/t of cement. That means that in Croatia cement industry causes around 8-9 % of total CO_2 emission. [EKONERG 2007]

Blended cements

With the aim of lowering atmosphere pollution, there are initiatives for the use of blended cements, i.e. cements produced by substituting part of cement with by-products of other industries, such as slag, fly ash and silica fume. These substituting materials are considered waste materials during technological processes of other industries and are in that way ecologically harmful [Roskovic and Bjegovic 2005]. The use of these blended cements has four main advantages:

- lowering CO_2 emission;
- enabling a way to deposit waste materials from other industries (such as metallurgic and heat);
- conservation of natural resources;
- lowering the price of cement (cement produced with by-products is significantly cheaper than Portland cement).

All these advantages make cement produced with by-products appealing to end consumers and concurrent to traditionally used Portland cement. But besides these known advantages, newer research in this field show that concrete prepared with blended cement has even better durability properties than concrete prepared with Portland cement without compensation of mechanical strength.

The main reasons for the positive effect the addition of mineral admixtures has on durability of concrete are the fact that some of the mineral admixtures such as fly ash, silica fume and slag have pozzolan reactivity and that they fill up volume of pores (silica fume and limestone). By pozzolan reaction with consumption of $Ca(OH)_2$ more C-S-H phase emerges in transition zone resulting in the decrease of capillary porosity [Roskovic 2007]. Past testing of blended cements point to the fact that cements with mineral admixtures ensure satisfactory durability to cement through higher strength and higher resistance to penetration of fluids [Sarkar and Ghosh 1993].

In order to demonstrate this hypothesis detailed analysis of concrete mixes prepared with blended cements was performed. The idea was to perform testing on known concrete mixture, already used for construction and on two mixtures that had different substitutions of cement with by-products (slag and fly ash) and crashed limestone. Three concrete mixtures were prepared and tested: concrete mixture (C100) was prepared with the same chemical admixtures and properties as concrete used during the construction of a reinforced concrete bridge at the Croatian Adriatic sea coast; second (C65S12FA18L5) and third (C45S18FA32L5) mixture were similar to the first one, but with the significant replacement of the cement with slag, fly ash and crashed limestone. Designed concrete class for all three mixtures was C30/37. The content of specific binder in blended cement was chosen based on the previous experience and results [Stipanovic et al. 2007; Roskovic 2007]. In all three concrete mixtures cement CEM II/A – S 42,5R (6 – 20% slag) and the same chemical admixtures were used: 0.02 % of air-entraining admixture; 1.85 % of superplasticizer and 0.2 % of retarding agent. Chemical admixtures were added to achieve required concrete properties in fresh and hardened state. Three mix designs used in this research are shown in Figure 2.

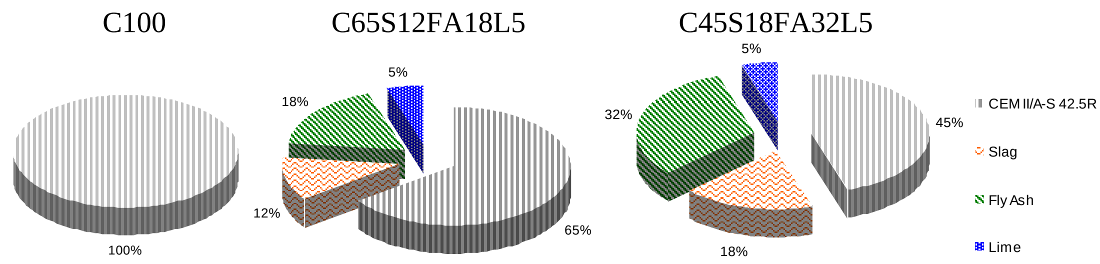


Fig. 2. Schematic Overview of Cement Substitution in Three Mixtures

In order to investigate the effect of blended cements on properties of concrete, following tests were performed: compressive strength (according to EN 12390-3), water permeability (according to EN 12390-8), capillary absorption (according to national standard HRN. U-M8.300.), chloride diffusion (according to NT BUILD 492), freeze and thaw resistance (according to CEN/TS 12390-9) and shrinkage and creep deformation (according to national standard HRN U.M1.029 and HRN U.M1.27) [Stipanovic et al. 2007]. Some of the results are presented in Figure 3.

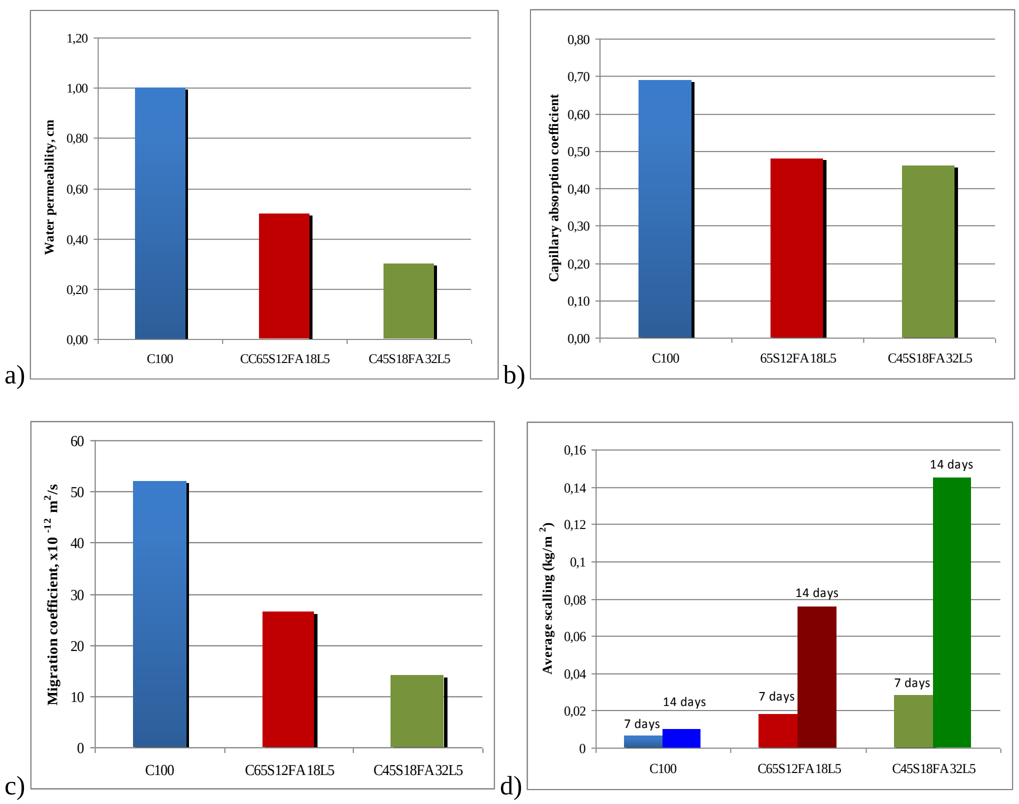


Fig. 3. Results of Testing Ecologically Friendly Concrete: A) Water Permeability; B) Capillary Absorption; C) Chloride migration Coefficient; D) Freeze/Thaw Resistance

Results from performed research show that ecologically friendly concrete has better permeability properties (capillary absorption, water permeability and chloride diffusion) than normal concrete. Furthermore, all mixtures have met requirements for designed class of concrete C30/37. Utilization of blended cement concrete in environments where excessive freezing and thawing is expected should be designed with special attention.

NATURAL RESOURCES CONSERVATION

Ordinary concrete consists of 12 % of cement, 8 % of water and 80 % of aggregate. Therefore, if for the production of concrete 1.5 billion tonnes of cement per year is used, at the same time 900 million l of water and 9 billion tonnes of sand and stone are used [Mehta 2002]. Estimated value of C&D waste produced in the Republic of Croatia, based on the data collected in the frame of CONWAS project (2006-2008), is approximately 2.5 million tonnes per year. This leads to the number of approximately 600 kg of C&D waste per capita. These numbers show the necessity of substituting some of the natural resources in the technological processes, such as aggregate and water, with recycled materials.

Construction and demolition waste - recycling

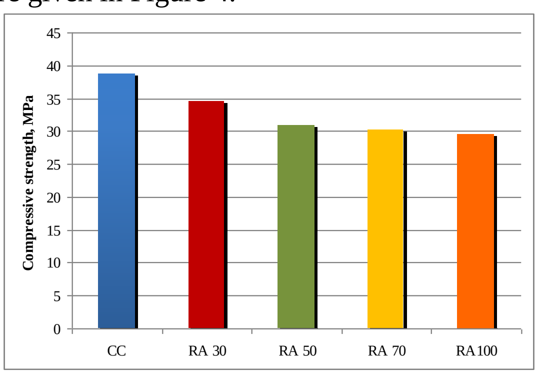
Construction and demolition (C&D) waste is type of material that is produced from construction and demolition works, renovation or reconstruction, either on the surface or under ground. C&D waste has considerable financial value and technologies for separation and recycling are accepted, easy accessible and usually cheap. The most important fact is that there is a market for recycled aggregate, since this material can be applied in different areas of civil engineering - as material for roads bearing layer as well as an addition for various concrete and asphalt mixtures. Inspection performed during 1998 showed that from 9 million tonnes of waste that is being produced in Croatia, around 2.5 million tonnes is construction waste, which means that every citizen of Croatia yearly produces around 600 kg of construction waste [Bjegovic et al. 2009].

The problem of using recycled aggregates in the past was mainly related to the lack of standards regarding the production and application of such aggregates. Because of this lack, potential users of aggregates had no guarantees about the influence of aggregates on the properties of concrete. On the other hand, advantages of recycled aggregates are:

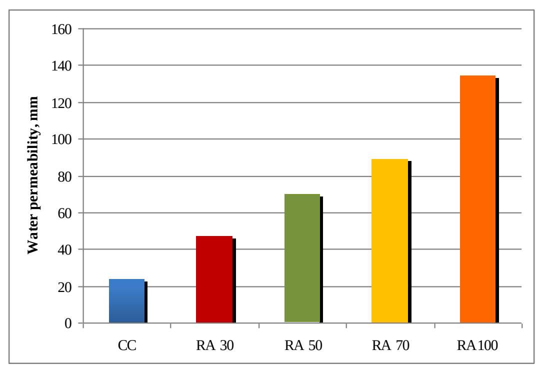
- environmental contribution - approximately 40% of demolition material is disposed in nature; the use of recycled aggregates reduces the exploitation of natural resources that are limited;
- energy efficiency - recycled aggregate can be produced on site using mobile crushers and thus reduces power consumption when transporting materials to the plant for processing waste from demolition;
- the reduction of CO_2 emission - no emissions during transport of materials to the facility; the same material can be used in the construction process;
- price - recycled aggregate is economically acceptable if the recycling process is well organized; contractors can also reduce costs for transport and disposal because they do not have to pay the fee for waste disposal;
- new job opportunities - working places in the facilities for recycling of aggregates, as well as institutes and institutions whose task is to test and improve the properties of recycled aggregates; larger use of recycled aggregate increases the need for better-educated personnel;
- the global markets - recycled aggregate can be used in the production of prefabricated concrete elements such as pavement, blocks for the repair of the landslide, construction elements for bridges and non-constructive elements of buildings [Nelson Shing 2004].

The project LIFE05 TCY/CRO/00014 CONWAS – "Development of sustainable construction and demolition waste management system for Croatia" was primarily proposed with the aim to provide relevant authorities (primarily the Ministry of Environmental Protection, Physical Planning and Construction) thorough overview of the present state and data necessary for the decision about the best possible construction and demolition waste management system for Croatia. The project started officially on February 1, 2006. The expected duration of the project was set for 24 months and the project was completed in the planned time frame. In order to obtain relevant data on C&D waste, a pilot project in the region of the City of Zagreb and Zagreb County has been elaborated. The pilot project has been consisted of the following activities: monitoring the C&D waste separation at waste origin or at sorting plants, keeping records of C&D waste at the entrance, processing waste material in the recycling facility and reporting on all the relevant data including C&D waste types and quantities. In accordance with data collected during the project, quantities of C&D waste in each Croatian county were estimated as well as the total quantity of 2.345.000 tones per year for the Republic of Croatia.

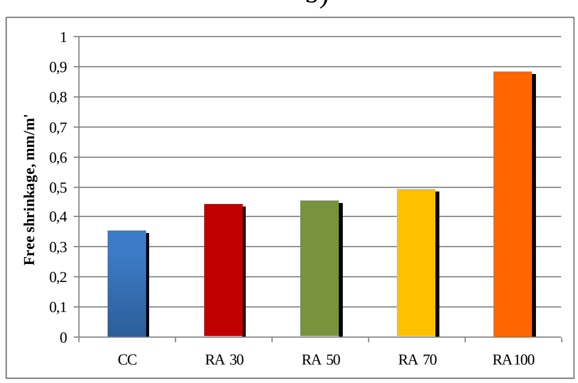
For the purpose of the experimental study of concrete prepared with recycled aggregate, 6 different concrete mixtures were prepared: CC (control concrete made with natural aggregate) and 4 concrete mixtures with different percentage of recycled aggregate - 30, 50, 70 and 100 % (RA30, RA50, RA70, RA100) [Kovac 2008]. Fresh and hardened concrete properties as compressive strength, shrinkage and water permeability for control concrete and for concrete with different percentage of recycled concrete aggregate in concrete composition are given in Figure 4.



a)



b)



c)

Fig. 4. Results of Testing Recycled Aggregate Concrete

Considering the obtained results, it is recommended to use maximum of 30 % recycled aggregate in concrete mixtures because, up to that amount, properties of concrete regarding the compressive strength, free shrinkage and water permeability would be satisfactory, or very near to the control concrete properties. In the case of higher amount of recycled aggregate in concrete, for example more than 50 %, chemical admixtures should be used to improve concrete properties.

Water – reuse

Water quality, which is used for making concrete or mortar, is essential to their properties in hardened state. For the fresh tap water it is not necessary to test suitability for the preparation of concrete or mortar. Water that is not drinkable may also be suitable for preparation of concrete, but that should be tested. These water types can be wastewater from the concrete industry, water from underground sources, natural surface water and industrial wastewater. Possibility of using these water types for preparation of concrete must be tested and compared with the results of testing specimens prepared with distilled or deionised water. Figure 5 shows the treatment of the water that remains after washing concrete mixers for making new concrete mixtures in precast concrete plant Beton Lucko, Croatia. Water is separated in the pool in which the aggregate and cement particles sediment on the bottom. It is recommended to use maximum 20 % of treated water in the total water amount for making new concrete mixtures without influencing on relevant concrete properties.

Fig. 5. Treatment of Waste Water For Production of New Concrete Mixtures, Beton Lucko, Croatia

DURABILITY

Durability of a structure is defined as its ability to preserve functionality, stability and aesthetic properties under expected environmental influences without larger maintenance and repair costs during designed service life. Designing, constructing and maintaining more durable structures is one of the key postulates of sustainable development, since degradation of structures causes need for premature demolition, which consequently causes generation of significant amount of C&D waste, consumption of energy and pollution. Research have shown that if concrete structures would be build with service life of 250 rather than 50 years, usability of natural resources would increase 5 times [Mehta 2002]. Premature loss in durability of structures is mainly caused by: poor quality of construction, wrong selection of building materials, poor design and non regular or absence of maintenance. All these are consequences of inadequate approach towards durability design. Durability design of concrete structures requires sustainable methodology in all three phases of life cycle: design phase, construction phase and exploitation phase. For each of the phases the prescriptive measures should be given.

Design phase

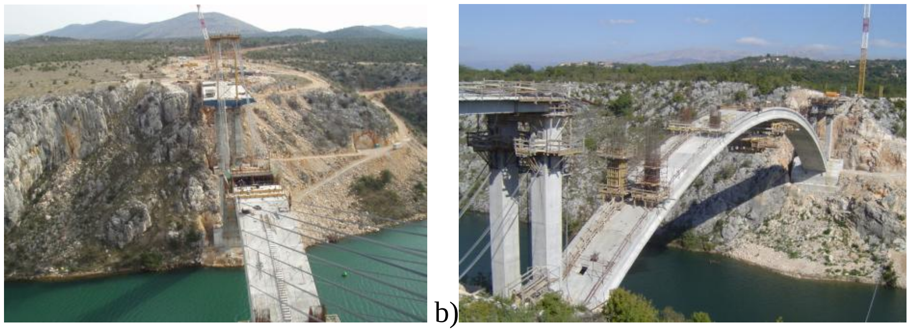
Numerous examples of early deterioration of reinforced concrete structures have shown that design methods and approaches used in the last 30 years were not adequate. Durability design procedures for reinforced concrete structures in aggressive environment were and for a large extent still are empirical. They are based on deem-to-satisfy rules (e.g. minimum cover, maximum water/cement ratio) and the assumption that if these rules are met, the structure will achieve an acceptably long but unspecified service life. Nowadays, engineers worldwide tend to use performance-based approach when designing civil engineering structure with targeted service life of seventy, one hundred or more years. Performance-based approach to the durability design of reinforced concrete structures means that it is based on durability indicators like materials parameters measured in laboratory and on site and geometrical characteristic of cross section of reinforced concrete element. These durability parameters (chloride diffusion coefficient, gas permeability, water permeability, capillary absorption coefficient, porosity) and geometrical characteristic of cross section (concrete cover) are some of the parameters which are defined in design phase for a specific environmental class of exposure [Stipanovic Oslakovic 2009].

Construction phase

Material parameters that are given in the performance-based specifications must be measured and checked in the construction phase, as a part of quality control. Similar procedures that apply for concrete strength control during construction, should apply for other material properties critical for a specific environmental exposure class. For example, if a structure is designed for exposure class XS, testing method and limiting values of chloride diffusion and water permeability should be prescribed in the concrete design phase. Number of specimens per amount of cast concrete, which must be tested for quality assurance, should be prescribed as well. During construction special attention should be given to concrete cover control and assurance that required concrete cover is achieved.

Exploitation phase

During exploitation of structure, one of the key issues in assuring durability and sustainability and obtaining “early warning” is performing constant monitoring. Main aim of the corrosion monitoring is to allow the owner to perform an on-time repair, before the cracking and delaminating of concrete. In almost all new large concrete bridges situated close to the Adriatic sea, which are a part of the new motorway system in Croatia, sensors for constant corrosion monitoring were embedded [Bjegovic et al. 2007]. Two of those bridges, Bridge over Krka River and Bridge over Cetina River are presented in Figure 6. Experience from corrosion monitoring on these bridges show that constant corrosion monitoring with the use of corrosion sensors embedded into structure are a good way of preventing serious degradation of concrete structures and enabling on-time repair, which is as well contribution to sustainability of concrete structures.



a) b)

Fig. 6. a) Bridge over Krka River; b) Bridge over Cetina River

CONCLUSION

Today's economic and political situation in the world shows that the current way of dealing with the environment is not sustainable. Construction materials industry is largely dependent on energy sources that can not be renewed. It is necessary to make a big step towards environmentally sustainable economy and construction sector has a large role in that process. It is necessary to adopt a series of standards and regulations that will encourage construction that uses sustainable methods. C&D waste management should be based on the experience from the countries like the Netherlands, Belgium and Denmark, that recycle more than 80% of the total generated C&D waste. The task of each community is to make a variety of restrictions, regulations, subsidies and incentives for end users, and stimulations of scientific research to bring new technologies in that area. The development of new environmental technologies will increase the economic profit using sustainable materials, while the price of non-sustainable conventional materials will rise. Such a base will allow investors, whose main goal is economic profit, to start to apply environmentally sustainable ways of construction.

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