Economic evaluation of using of geopolymer from coal fly ash in the industry

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At the present time, almost every area needs using of secondary raw material sources. This trend is most obvious in the industry, mainly in the area of materials production, when there is a possibility of economic effectiveness increasing during production. Also, the contribution of secondary raw material using is not negligible in the area of living environment protection, since it can use the waste of industrial production again. The task of this contribution is an economic evaluation of using a geopolymer from coal combustion as a possible alternative raw material. The basic input is the cost of materials for the manufacture of concrete using of Portland cement with fly ash as a substitute for cement and fly ash as an additive to concrete. Evaluation is carried out based on analysis of the possibilities to reduce the total price of material costs for the production of 1m^3 *of concrete, with possible using in the industry. The main method for economic evaluation of using geopolymer is the classical cost calculation. The results of the analysis show possible reducing of cost, which is possible through replacement of cement by fly ash more than 18 % of the material.*

Key words: *fly ash, geopolymer, economic evaluation, price of material cost, industry*

Introduction

In a world where people have a limited amount of resources, it is necessary to search for effective solutions, but also to replace limited non-renewable resources with others. On the other hand, in present time, steelworks are at a stage of permanent changes that are marked with still stronger competition pressure. Therefore, managers must solve questions about how to decrease production costs, how to overcome competition and how to survive in the world market (Antošová, et al., 2013). Simultaneously with the decrease of some rare resources, demand is increasing in the world. The consumer society is constantly expected to offer significantly exceeds demand. One of the possibilities to preserve valuable resources for future generations is recycling, which in addition to the possibility of replacing of non-renewable resources also addresses the issue of processing already unnecessary goods (Rybár and Kudelas, 2007). In the world, the amount of waste that is increasing is largely stored in landfills, and its existence does not only occupies the land, but also constitutes a potential risk for the environment (Cehlár, et al., 2013).

Geopolymers are relatively new and little-known alternative materials. Few laymen today suspect about their existence and the opportunities geopolymer bring for the industry as well as for the environment. Fly ash belongs to a group of by-products from the combustion of coal and ashes and slag, fly ash is deposited in the impoundments where its specific physical and chemical properties are degraded.

According to research, fly ash presents full raw material, which can replace not only some naturally occurring materials, but depending on the qualitative characteristics of coal, of which it is rising, it may well exceed these materials.

Geopolymer has become a common term, especially in the US, France and India, where much attention is given to it for decades. Due to their unique character, some geopolymers are replacing naturally occurring materials. One of the best examples is the use of geopolymer materials in Formula 1 vehicles just for their exceptional resistance to fire, or in the production of concrete road, which in the world are used in the construction of runways at airports. Mainly these applications suggest that the company should pay attention to the semi-products and waste because some of them can hide yet undiscovered properties that may be beneficial.

Each year, The European Union produces about one hundred million tonnes of coal fly ash as a waste of heat and electricity production. Fly ash belongs to a group of semi-products from coal, as well as ash and slag combustion. While all produced slag is consumed for a long period of time, particularly due to the needs of the construction industry, fly ash is deposited in the ponds, where its specific physical and chemical characteristics degrade. According to research, fly ash presents a full raw material, which can not only replace some naturally occurring materials, but depending on the qualitative characteristics of coal, from which it occurs, fly ash can over-exceed those materials. The most common way of fly ash using is filling of already not used

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mining areas. Another possibility is the disposal of fly ash as an application to the soil, in which the fly ash significantly improves its physical, chemical and mechanical properties.

Present state of possible geopolymer using

In 1979, Professor Joseph Davidovits introduced the concept of geopolymer to indicate inorganic binders with a structure resembling natural zeolite crystal structure (Davidovits, 2011). Twenty-five years ago, very few laboratories and institutions dealt with geopolymer. Over the last decade, the situation has changed. Some laboratories engaged in research in the field of geo increased. While the number of professional, scientific research papers published on geopolymer was close to zero in 1991, it rose to over 400 per year in 2013 (Geiger, 2011). Abroad, fly ash as a raw material is used for decades, since it presents cheap raw material, often with sufficient functional characteristics, usually without harmful effects on humans or the environment (Davidovits, 2002).

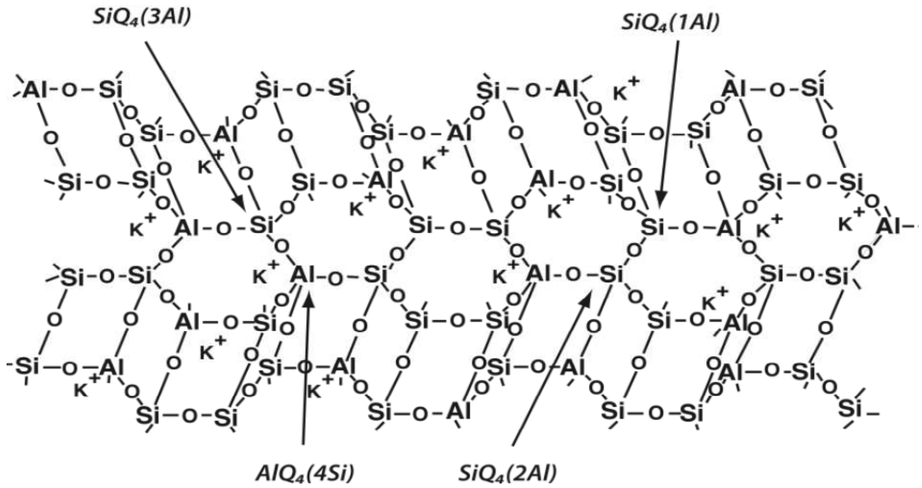

Fig. 1. Model of geopolymerization (Davidovits, 2011).

Fly ash from burning of hard coal, respectively lignite, presents an interesting source of raw materials for secondary processing. Since it is an inorganic material, based primarily on oxides of silicon, aluminium and iron, it is chemically very similar to the traditional building material - cement. Due to its chemical composition, physical parameters, and at the same time a sufficient amount, fly ash is a suitable source of raw material available for further industrial use (Sisol, 2014). In addition to various technical and technological aspects of fly ash using, which favourably affects the characteristics of the materials, their use also has substantial economic and environmental benefits (Ahmaruzzan, 2010). Not all fly ash, produced at the present time, is suitable by their properties for the use in the manufacture of building materials. In particular, fly ash derived from combustion processes of not coal raw materials, are often not suitable for the purposes mentioned above. However, there are some other non-conventional applications of fly ash that are in various stages of verification.

For example, the production of a material suitable for adsorbing of various pollutants from waste water belongs among the most perspective ways of its use. In the present time, fly ash has been used successfully with a suitable composition for the removal of toxic and heavy metals from waste water from industrial processes. Fly ash with a high content of residual coal can also serve to remove various inorganic substances (Iyer, and Scott, 2001).

Any fly ash contains also various minerals containing metal oxides in certain volume. The largest share, represented in the fly ash, is aluminium and iron, which means metals that are important for the technical materials. Therefore, fly ash can be used as an important source of bauxite instead of aluminium, or source of iron instead of iron ore.

Abroad, the fly ash is used as a raw material for decades, since it presents rather cheap raw material, often with sufficient functional characteristics, typically without harmful effects on humans or the environment (Davidovits, 2011).

Fly ash represents either cement or pozzolana component, depending on the content of CaO. Partial or complete replacement of cement by fly ash reduces overall production costs. Research of geopolymer concrete based on fly ash has shown that it has a potential use in various applications because it has similar properties and durability as traditional concrete from cement. Moreover, recent studies have shown that geopolymer concrete based on fly ash does not require such heat treatment, when there is not added a small volume of the ingredient, which is a carrier of calcium, for example a slag (Yao, 2014).

Tab. 1. Possibilities of fly ash using as a raw material in the industry (Davidovits, 2011).

Branch	Possibilities of using
Metallurgy	Steel production Preparation of dusting and thermal insulation layers, Dusting core material, Forming material during steel casting
Mining	To basis of robbed mining areas
Agriculture	upgrading of heavy soils, preparation of bio-organic mineral fertilisers, seed coating, as a source of micro and macro elements
Construction	Production of cement, aggregates, manufacture of artificial stones, concrete, brick and ceramics production, road construction

Nowadays almost everyone already recognises the need for the use of secondary raw materials (Tauš, et al., 2015). This trend is particularly noticeable in the construction industry, particularly in the field of building materials production, since it gives the opportunity to increase the economic efficiency of production. Also, the benefit of using secondary raw materials is not negligible in the field of environmental protection, as the re-use of waste from industrial activities (Špak, et al., 2012). Especially in mining companies, which often go through the crisis, implementation of new innovative production represents the way how to solve problems of mining companies. (Jurkasová, et al., 2015).

Tab. 2. Production and using of secondary products from coal burning in EU 15 in 2010 (www.ecoba.com).

	Fly ash	Ash	Slag
Produced volume	31 616 000	4 052 000	1 000 000
Consumed volume (t)	13 785 000	1 890 000	1 000 000
Consumed volume (%)	43.60	46.64	100.00
Concrete production	2 152 000	178 000	0
Mixed concrete	1 947 000	1 000	0
Additive to the concrete	4 947 000	62 000	3 000
Concrete blocks	760 000	798 000	0
Bricks / ceramics	83 000	16 000	0
Fillings	3 174 000	513 000	0
Water treatment	115 000	0	0
Temporary storage	201 000	87 000	0
Disposed in dump	2 260 000	87 000	0
Other	607 000	322 000	997 000

Methods of economical evaluation of geopolymer using

Subject of searching presents the fly ash resulting from combustion of black coal during the production of heat and electricity as a raw material, which can be without further processing used as an input material in the industry for the production of precast concrete:

1. as a complete replacement of cement in the final concrete mix for the production of precast concrete.
2. as a partial cement replacement in the final concrete mix for the production of precast concrete.

The main method for economical evaluation of geopolymer using is the standard cost calculation, processing according to the following steps:

1. Costs calculation:
   - data collection – types of used material, unit prices for individual materials,
   - calculation of assumed consumption of individual types of materials,
   - calculation of total material costs for individual types of concrete,

2. analysis of costs effectiveness,
   - defining of units, that would be compared,
   - defining of costs type that would be analysed,
   - defining of the total benefit of the analysis,
   - defining of projects that would be compared,
   - comparing of the resulting values of the projects,
   - the decision of the most convenient alternative.

The cost of the concrete production by using of geopolymer depends on the properties of individual types of concrete, which provide technical standards, as well as the requirements of the individual components. Concretes are divided into 16 basic strength classes under current Slovak technical standard norm EN 206-1. National Annex to this standard provides requirements and specifications for all types of concrete, as well as the conditions, under which the concrete can be used.

Properties of concrete depend on the quantity and quality of its components. Cement is the most active part of the concrete, and it is usually the most expensive. Its selection and proper using are essential to achieve an economic balance between the desired properties of the prepared concrete mix and the cost of its production.

The cement of the category I and II is the most popular among manufacturers of concrete since it ensures an adequate level of strength and durability. To achieve higher levels of concrete characteristics, special cements are using. When choosing a concrete, there is necessary to consider what final properties of concrete are expecting. That choice depends on how much the producer understands the issue of concrete and also the relationship between the cement and the resulting characteristics.

Re-use of materials must regard valid legal regulations of the Slovak Republic, as well as principles of sustainable environmental development (Khouri, et al., 2016). Therefore, the composition of concrete mixture with fly ash using was calculated according to the information from the Patent Application No. 70-2010, "Preparation of alkali-activated adhesives – so-called geo-polymers of fly ash from the combustion of coal in the wet bottom boilers with content over 15 % ". For the preparation of the fly ash concrete, it is necessary to use activating solution that is prepared by mixing of solid NaOH with a solution of Na_2SiO_3 (water glass). The composition of concrete mixture with fly ash using as a partial replacement of Portland cement was calculated on the basis of existing standard STN EN 206-1.

Results of analysis of geopolymer using

A geopolymer concrete based on fly ash offers some economic benefits that give it an advantage over Portland cement concrete. The costs of fly ash are negligible. Producers of heat and electric power treat with fly ash as waste; therefore it presents a problem. Stocking of such waste has its limitations, such as legislation, as well as localization and capacity.

Strategic planning with respect to dynamics and innovation necessity has a great importance during economic evaluation of industrial production (Pawliczek, et al., 2015). Nowadays, almost everyone is already aware of the need to use secondary raw materials. This trend is particularly noticeable in the industry as it provides the opportunity to increase economic efficiency. Appreciable is the benefit of secondary raw materials using in metallurgy and environmental protection, as the re-use of waste from industrial activity (Pflughoeft, et al., 2015). The cost for the production of concrete using fly ash was determined according to information of patent registration No 70-2010, Preparation of alkali-activated adhesives – so-called geopolymer from ashes, obtained during burning of coal in the wet bottom boilers containing over 15 %. For the preparation of the fly ash concrete, there is necessary to use an activating solution, which is prepared by mixing of solid NaOH with a solution of Na_2SiO_3 (water glass).

Tab. 3. Material costs of concrete production for strength class C 55/67 with fly ash using without concrete.

Element	Producer	MJ	Volume	Price per MJ	Price
Fly ash	TEKO	t	0,360	0,000	0,000
Aggregate of stone fraction 0/4 mm	EUROVIA	t	0,958	4,000	3,832
Aggregate of stone fraction 4/8 mm	ALAS Slovakia	t	0,342	5,300	1,813
Aggregate of stone fraction 8/16 mm	ALAS Slovakia	t	0,410	5,000	2,050
Water	Slovakia Average	m^3	0,037	2,032	0,075
Sodium hydroxide	PG Chem	kg	29,44	0,770	22,669
Water glass	LARO	l	123,97	0,596	73,886
Together			**104,329**		

Through the comparison of the total material cost for production of concrete with high strength class C 55/67, there has been proved that the price of the materials for the concrete without the use of Portland cement, only with fly ash using, is a few times higher than that of the traditional concrete using Portland cement. Moreover, the transport cost of mineral raw materials plays an important role in the mining process carried out in mining companies. Quantitative methods of operational analysis can help to optimise supply and decrease cost by this way (Pavlíčková, Teplická, 2014). The motivation of employees, their efficiency and the work productivity could also decrease cost and increase mining business effectiveness.

Tab. 4. Material costs for concrete production for strength class C 40/50 with fly ash and Portland concrete using.

Element	Producer	MJ	Volume	Price per MJ	Price
Fly ash	TEKO	t	0,078	0,000	0,000
Cement CEM I 42,5 R	Holcim	t	0,306	108,98	33,348
Aggregate stone fraction 0/4 mm	Eurovia	t	0,958	4,000	3,832
Aggregate stone fraction 4/8 mm	ALAS Slovakia	t	0,342	5,300	1,813
Aggregate stone fraction 8/16 mm	ALAS Slovakia	t	0,410	5,000	2,050
Water	Slovakian average	m^3	0,176	2,032	0,358
Aeration additive	S.N.A.I.L.	kg	2,28	1,439	3,281
Summary			**44,882**		

Tab. 5. Material costs of concrete production for strength class C 55/67 with fly ash and Portland concrete using.

Element	Producer	MJ	Volume	Price per MJ	Price
Fly ash	TEKO	t	0,078	0,000	0,000
Cement CEM I 52,5 R	Holcim	t	0,360	114,140	41,090
Aggregate stone fraction 0/4 mm	Eurovia	t	0,947	4,000	3,832
Aggregate stone fraction 4/8 mm	ALAS Slovakia	t	0,338	5,300	1,813
Aggregate stone fraction 8/16 mm	ALAS Slovakia	t	0,405	5,000	2,050
Water	Average in Slovakia	m^3	0,142	2,032	0,289
Aeration additive	S.N.A.I.L.	kg	2,15	1,439	3,094
Together			**52,168**		

The comparison of the total material cost for the concrete production of high strength class C 55/67 has shown that the price of materials for the concrete without the use of Portland cement, only with fly ash using, is several times higher than the cost of conventional concrete using Portland cement.

Tab. 6. Material costs for concrete production from strength class C 55/67.

Material costs for concrete production from strength class C 55/67	Price [€/m^3]
Without using of plasticizing ingredients	**51,340**
By using fly ash and Portland cement	**52,168**
By using plasticizing ingredient	**63,875**
By using fly ash but without cement	**104,329**

In contrast, as we can see from the previous table, such material costs during the production of concrete may be reduced, if the plasticizer is replaced by fly ash.

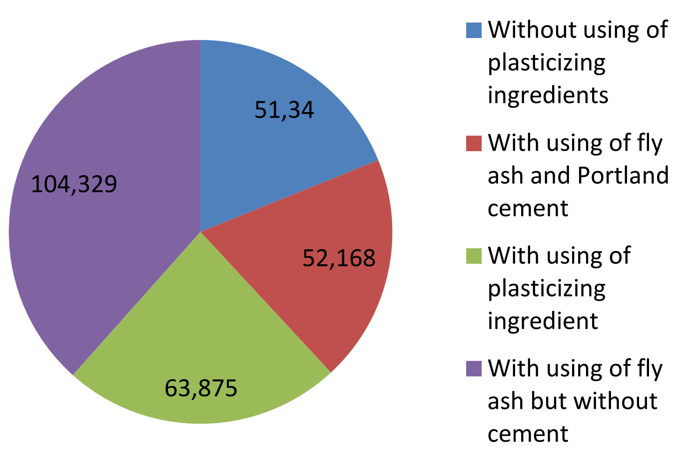

Fig. 2. The comparison of material costs for concrete production, strength class C 55/67 [€/m^3].

As for the price, the water glass, which in the concrete cannot be replaced by another ingredient, is a least accessible component of the fly ash concrete. Therefore, the most economically advantageous option remains the mixing fly ash with Portland cement. Reducing the cost during replacement of part of cement by fly ash is more than 18 % of the material (Fig.2).

Discussion

According to available literature, it has not yet been proposed a composition of concrete mix that would include a higher proportion of ash reaching the strength of at least 50 MPa. If, however, there is used a concrete with the strength of 30 MPa in the precast concrete, it would be possible to replace up to 30 % of cement by fly ash. In that case, the final price would be even lower since the decreased volume of cement needed for production and at the same time, material, which is considered as waste, would be consumed.

Although there is not yet economically effective to introduce a fly ash concrete in practice, the problem of CO_2 production remains during the production of Portland cement, as well as the way of handling with fly ash waste is also the problem. It is only a matter of time when it will be necessary to take much greater action to make more strict measurements to reduce emissions with the aim to slow down at least global warming and the associated global dimming since its complete stopping is not yet in the power of humanity. There is no doubt that the industry will continue to need concrete, so the demand for Portland cement will not fall naturally. Fly ash concrete is an alternative that could replace Portland cement, but only on the condition that the price of water glass would be reduced to a level comparable to the price of Portland cement. Even in this case, it is questionable whether producers reach for not yet sufficiently known alternative, or even in terms when costs are higher, and therefore they would still prefer traditional, proven possibility.

One of the possibilities that could help to solve the problem with the high CO_2 emissions and that is affordable from the view of the price, is using of biomass for the production of cement in order to reduce the emissions that are released into the atmosphere at least partially. Another possibility is to recycle the old concrete that can replace part of an aggregate stone in new concrete due to its characteristics, or it can be used as substratum for road construction. It is also possible to use fly ash as an ingredient in concrete.

Presently, protection of the living environment is still the most important factor in economic and social development, presenting worldwide global problems (Horodníková, et al., 2008). Awareness of the society is not yet sufficiently focused on the opportunities that are offered, recycling is more a matter of public relations for the company, presenting the company to the public. According to statistical indicators of the European Commission, only one-third of the waste, generated from construction, is reused, and the reason for this low number are not technical issues, but the traditional ways in the industry. In this area, Čulková, et al., (2016) analyses, for example, environmental commitments of the company's activities waste dumping in manufacturing company. From the analysis, it is obvious that proper storage of hazardous waste and recycling hazardous waste can decrease cost and influence profit of the company.

A leader in the recycling of concrete waste is the Netherlands, which utilises again up to 95 % of waste, arising from construction activities. By contrast, an average of the Member States of the European Union is only 30-60 %. We can hardly estimate whether we continue to waste scarce resources and, alternatively, the similar qualitative materials to store at the dumping as a waste.

Conclusion

Cement and concrete play an important role in the economies of the European Union. In the case of a decrease in the production of Portland cement, there is remaining an open question of the impact on the economies of individual countries, where the production of cement presents one of the important sectors. The decline in the production of Portland cement could cause a decrease in employment.

Although there is still not effective to introduce fly ash concretes in practice, production of CO_2 in the production of Portland cement remains still an open problem, as well as the process of fly ash management as a waste. It is indisputable that the steel industry will continue to require ash; therefore the demand for it will not naturally fall. Fly ash concrete is an alternative that could replace Portland cement. Another option is recycling of old concrete, which can replace part of the aggregate stone in new concrete by its characteristics.

Awareness of the society is not yet sufficiently focused on the opportunities that are offered. According to statistical indicators of European Commission, only a third of waste is re-used and the reason for such low quantities are not technical issues, but the habitual way in metallurgy. We can hardly say whether we will continue to waste rare resources and alternative sources stored in a landfill as a waste.

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