Utilization of FBC ash in autoclaved aerated concrete technology

Vit Cerny, Rostislav Drochytka

***Abstract*—**There are still a lot of coal combustion products waiting for utilization in the Czech Republic. One of suitable building materials is fly ash aerated concrete. It is as a modern material combining high use value with environmental aspects of its production. Autoclaved aerated concrete is also one of the ways to use besides fly ashes from pulverized boilers fluidized bed combustion ashes. Significant advantage of the utilization of these CCPs from fluidized bed combustion is a saving of lime as the most expensive raw material for the production of aerated concrete. This paper deals about the possibility of fluidized fly ashes utilization in the technology of autoclaved aerated concrete, rheological properties of the mixture, the plastic strength, compressive strength and density of aerated concrete. Another topic of this paper is current state of use and legislative background of use of CCPs in the Czech Republic. Paper also verifies the autoclaving time influence on tobermoritic phase developments and to this related compressive strength of the fly ash aerated concrete.

***Keywords*—**CCP, FBC ash, fly ash, tobermorite, legislation, aerated concrete, by-product.

I. Introduction

A. Origin of coal combustion products

In heating power plants, combusting pulverized coal (PC) are created solid minerals during combustion in a fully controlled process. The considered materials are ashes, i.e. the non-combustible part in coal, and in cases where flue-gas desulfurization equipment is installed, these are flue-gas desulfurization products. Most by-products originate in furnaces with granulating fireplaces, i.e. in the process of combustion with temperatures 1100 – 1400 °C. The process of combustion in a furnace with a granulating fireplace and the origination of energy by-products is shown in Fig. 1. [1]

This paper was elaborated with the financial support of the European Union's "Operational Programme Research and Development for Innovations", No. CZ.1.05/2.1.00/03.0097, as an activity of the regional Centre AdMaS "Advanced Materials, Structures and Technologies" and with the financial support from funds of the state budget through the Ministry of Industry and Trade within the project FR-TI3/727 with the name "Advanced Cellular Concrete Technology based on Industrial Wastes for Energy-Saving Construction".

V. Černý is with the Institute of Technology of Building Materials and Components Brno University of Technology, Faculty of Civil Engineering Veveří 95, 602 00 Brno Czech Republic (corresponding author to provide phone: 00420-541147463; e-mail: cerny.v@fce.vutbr.cz).

R. Drochytka is with the Institute of Technology of Building Materials and Components Brno University of Technology, Faculty of Civil Engineering Veveří 95, 602 00 Brno Czech Republic (e-mail: drochytka.r@fce.vutbr.cz).

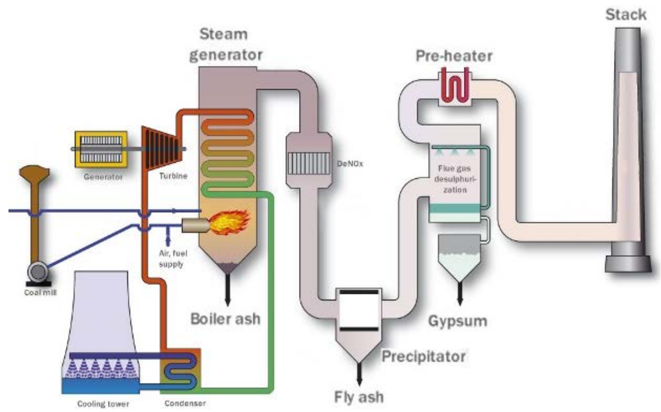

Fig. 1 Diagram of PC boilers power plant [5]

B. CCP and legislation

The previous paragraph referred to the coal combustion products. At this time this formulation is fairly widespread but from the viewpoint of legislation in the Czech Republic this concerns an amendment to the Act on Waste and progress in the direction of support for the use of materials that will not be evaluated in the waste regime. In particular, this concerns the criteria specified in Section 3, par. 5 of the Act:

A movable item originated during production where the primary objective is not the production or gathering this item, does not become waste but a by-product if

a) originated as an integral part of the production,

b) its further use is ensured,

c) its further use is possible without further processing in a manner other than common production practice,

d) its further use is in accordance with special legal regulations 11a) and it will not lead to negative effects on the environment or human health. [4]

Conditions for the fulfillment of three criteria are: The fulfillment of the last of these is the subject of stormy discussions. Very important is that the future use must not to harm the environment. The producer of the material must have a good Quality Management System, which ensure, that the final product will be environmental friendly.

For evaluation of the impact of the CCP on the environment are two ways available. If the producer produces more than 100 tones of CCP per year, must register it under the REACH directive (Registration Evaluation Authorization Restriction of Chemical substances).

In the Czech Republic were after the EU Directive

1907/2006 (REACH Directive) registered and defined as chemical substances the following CCPs:

- Ashes (residues), coal – fly ash, boiler ash and slags from PC (Pulverized coal) boilers
- FBC Ash – Fluidized Bed Combustion Ash – fly ash and boiler ash from FBC boilers
- Ashes (residues), plant – ashes from biomass combustion
- Calcium sulphate – sulphates from wet FGD (Flue-gas desulfurization) process
- SDA Product – products of a semi-dry FGD process [2]

If the producer haven't registered your CCP under the REACH Directive must use other legislation terms. That means to look for harmonized European standards for his selected use according to the European system, Regulation (EU) No 305/2011 of the European Parliament and of the Council (Construction Products Regulation – CPR). If it doesn't exist, Authorized body can use prepared technical guide according to GO No. 163/2002 Coll.

C. CCP utilization in the Czech Republic

Research results show that fly ashes often adequately replace primary raw materials, although in many cases they actually improve the properties of final building products. Current methods for using flying ashes from traditional combustion are as follows:

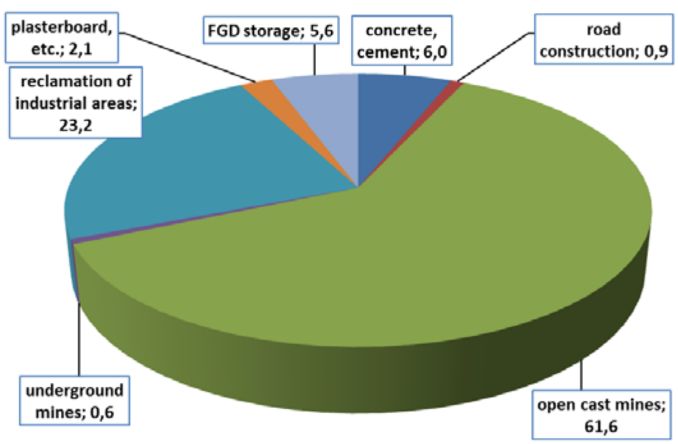

Fig. 2: Main CCP applications in CZ (2012) [2]

As you could see in the previous picture, the main way of CCPs use is as an alternative material to the soil, which is stored in the borrow pits. All of these uses are about make a stable material layer for vegetation, roadway, railway etc.

In the building materials (6.0 %) can be used especially the fly ash for cement concrete. Aerated concrete is however one of the best way to use maximum share of fly ash in the mixture for building material and one of the only, where you can use also the FBC ash (up to 25 %) and the FGD product.

II. USED RAW MATERIALS AND METHODS OF TESTING

The experiment was carried out in the plant producing aerated concrete and followed exactly the whole technological process of production of blocks from aerated concrete. Mix-design was based on real mix-designs. The aim was achieving characteristics of standardly produced aerated concrete P 2 – 480, i.e. compressive strength at least 2.0 N.mm^{-2} and density up to 480 kg.m^{-3}. For the experiment, fluidized bed combustion ash (FBC A) and two samples from pulverized coal boilers (PC A) with chemical composition stated in Table 1.

Table 1: Chemical composition of ash used

		FBC A	PC A1	PC A2
Chemical analysis [%]	**SiO_2**	32.76	50.16	52.5
	Al_2O_3	19.17	27.54	26.5
	Fe_2O_3	8.52	13.08	6.05
	FeO	0.47	3.96	1.04
	CaO	19.4	2.51	1.38
	total SO_3	8.21	0.38	0.27
	sulphate SO_3	8.1	0.07	0.05
	Na_2O	0.7	0.35	0.32
	P_2O_5	0.72	0.19	0.12
	loss on ignition	3.3	0.84	1.85

Further input materials were lime (binder), calcium sulphate (setting regulator), aluminium powder (gas making component), sludge from the waste fresh aerated concrete and water. Production test run in six phases, during which the mix-design was adjusted on the basis of behavior of aerated concrete mass.

Consequently, tests of physic-mechanical properties were carried out. Basic criteria were compressive strength and density, which are the decisive parameters of products from aerated concrete.

As additional was performed an experiment to investigate the effect of autoclaving time on fly-ash aerated concrete compressive strength and microstructure with selected mix-design. An experiment was carried out when the first set of specimens was autoclaved for standard time (11 hours) and with the second specimen set the isothermal holding time was extended by 2 hours during the autoclaving. The autoclaving run under standard conditions, so with temperature 174 °C, pressure 1 MPa and under presence of saturated water vapour. With both specimen sets the compressive strength was carried out together with scanning electron microscope (SEM) analysis.

III. RESULTS AND DISCUSSION

Test dose of fluidized bed combustion ash was 25 % by total amount of ashes in the mixture. The dose was based on calculation of theoretical mixing of ashes to comply with requirements of standards describing chemical composition of ash for production of aerated concrete (CSN 72 2072-5- ash from classic combustion of coal and CSN P 72 2081-4 fluidized bed combustion coal).

Mix-design adjusted on the basis of behavior of mass of aerated concrete. Table 2 gives composition of input materials in individual phases.

Table 2: Phases of production test with fluidized bed combustion ash

Composition	Fluidized bed combustion ash	Lime	Calcium sulphate
Phase1	25%	310 kg	-
Phase2	25%	305 kg	-
Phase3	25%	300 kg	100 kg
Phase4	20%	310 kg	-
Phase5	20%	345 kg	-
Phase6	20%	355 kg	-

In the next figures (Fig. 3, Fig. 4 and Fig. 5) are listed the values of plastic strength, compressive strength and density in individual phases. Plastic strength of the fresh aerated concrete is listed as a number of scale units of the plastometr. The optimum value is 460 - 500. Lower values cause the stickiness and higher cause the difficult cutting.

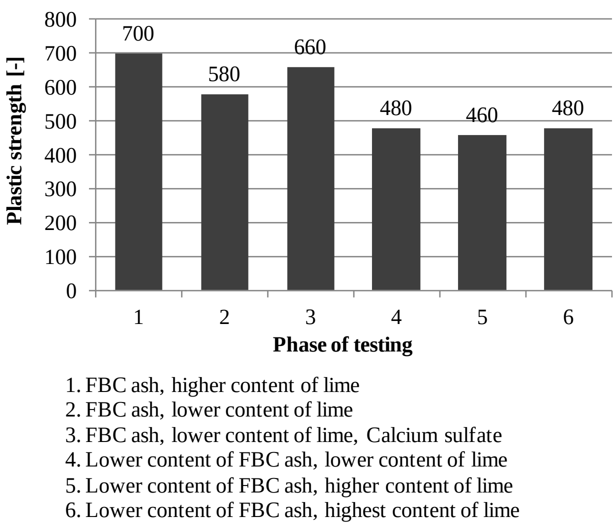

Fig. 3: Compressive strength of individual mixes

In the first phase, setting of aerated concrete was uncontrolled hardening and cutting was very difficult. Therefore, dose of lime was reduced in phase two. However, no major change occurred. I the third phase, energo-gypsum as setting regulator was added. Again, optimal properties were not achieved. Then, content of fluidized bed combustion ash was reduced to 20 %.

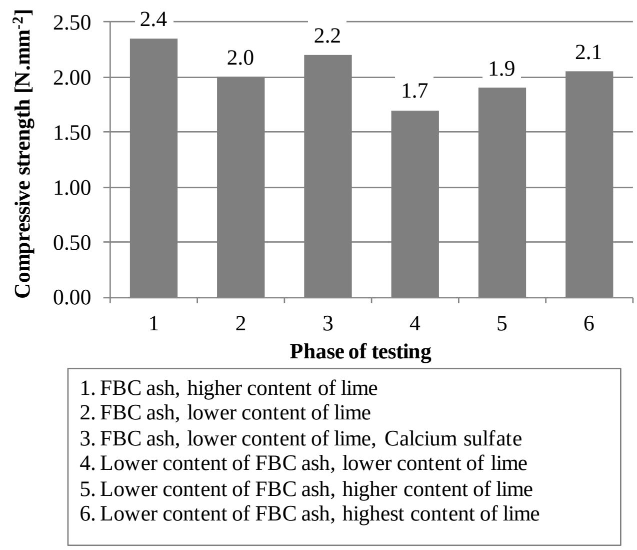

Fig. 4: Compressive strength of individual mixes

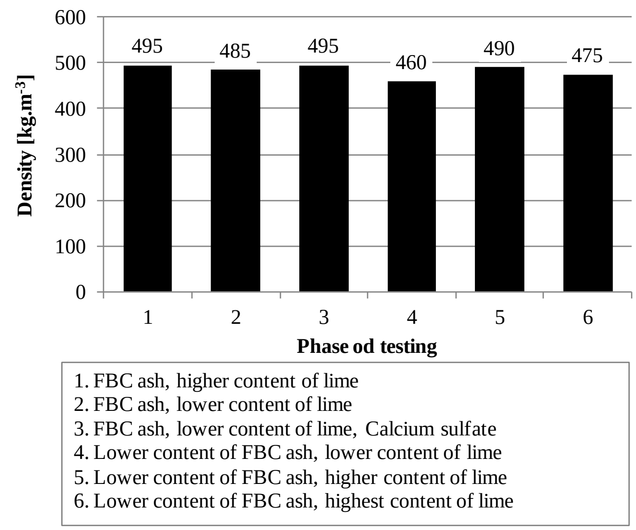

Fig. 5: Density of individual mixes

In the fourth phase, compressive strength decreased to only 1.70 $N.mm^{-2}$, which does not correspond with strength class P2 – 480. Increasing dose of lime in the fifth phase brought slight improvement, however, optimal values were achieved only in the sixth phase, when compressive strength was 2.05 $N.mm^{-2}$ and density 475 $kg.m^{-3}$.

The mix-design from fourth phase was used to verify the effect of autoclaving time on compressive strength and microstructure of autoclaved aerated concrete. Once hardened the aerated concrete material by autoclaving the compressive strength test was carried out. The results are shown in Fig. 6.

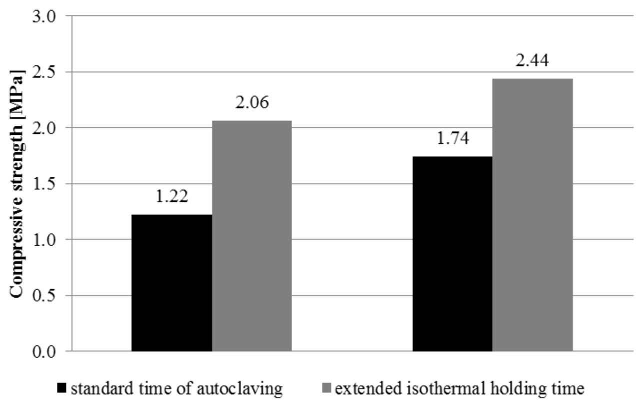

Fig. 6: Compressive strength of the aerated concrete autoclaved for standard time and with extended time of isothermal holding time

According to compressive strength results it can be assumed that the extension of isothermal holding time during autoclaving results in higher compressive strength averagely by 0.8 MPa. This finding was further verified on aerated microstructure when photos were made on the scanning electron microscope. The photos are shown in Fig. 7 to Fig. 10.

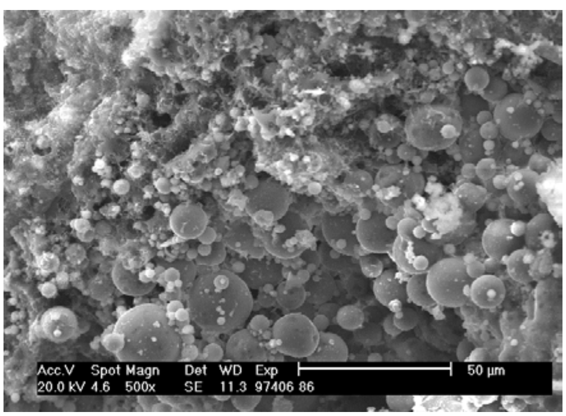

Fig. 7: SEM photo with 500x zoomed specimen without extended holding time

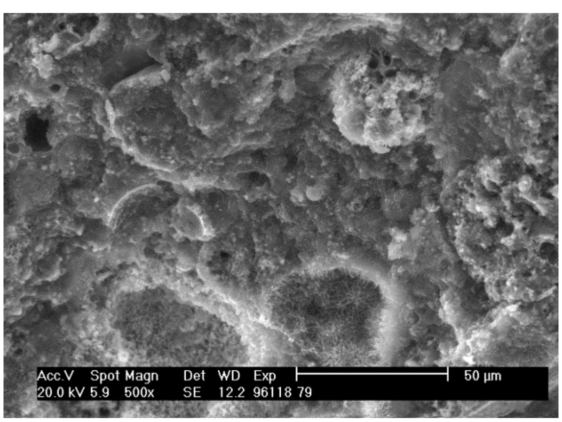

Fig. 8: SEM photo with 500x zoomed specimen with extended holding time

At SEM 500x zoom not reacted fly-ash siliceous grains were recorded with aerated concrete autoclaved for standard time (Fig. 7). The reason is insufficient time of autoclaving when all components were not able to react completely. On photo of aerated concrete with extended autoclaving by 2 hours (Fig. 8) the fly-ash grains are almost imperceptible and relatively well developed tobermorite acicular crystals can be seen.

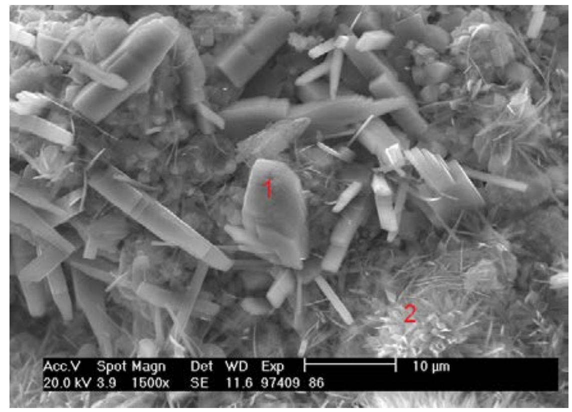

Fig. 9: SEM photo with 1500x zoomed specimen without extended holding time

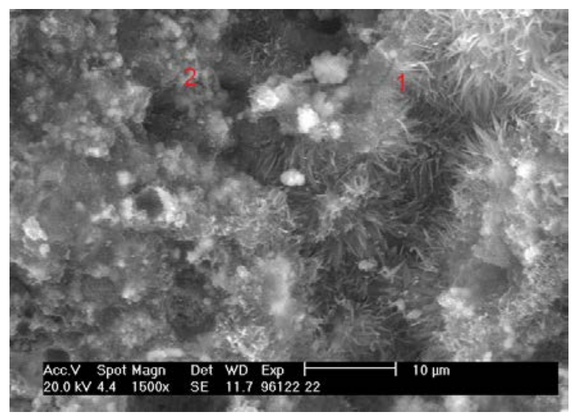

Fig. 10: SEM photo with 1500x zoomed specimen with extended holding time

The SEM 1500x zoom is sufficient for good identification of aerated concrete crystalline structure. In Fig. 9 we can see in surrounding of place 1 idiomorphous crystals of calcite, at place 2 there is a colony of tobermorite acicular crystals in initial status of the development which gradually grow among calcite crystals. The extending of the isothermal holding time during autoclaving has according to the Fig. 10 a positive influence on tobermorite development. In the surroundings of place 1 we can see well developed tobermorite crystals, integrowing among themselves and thus forming a compact and firm structure of the aerated concrete. At place 2 there is the intercellular material formed by CSH gel.

IV. CONCLUSIONS

Use of fluidized bed combustion ash in autoclaved aerated concrete is very topical as production of this material rises. Advantage of considerable increasing of rheology is an important reason for using this raw material. Shortening time before cutting and partial saving of lime are incidental economical parameters.

As a part of this paper, a series of tests was carried out implying that fluidized bed combustion ash can be used for technology of aerated concrete. When FBC ash is used in the proportion of 20% of total amount of ash and 355 kg of lime required properties of aerated concrete are achieved. Higher content of FBC ash causes uncontrolled hardening and difficulty cutting. Use of the FBC ash in the aerated concrete mixture will allow reduce hardening time before cutting by half. The aerated concrete is finished two hours earlier and production can be 15 % faster.

Ideal mix-design was achieved in Phase 6. Very good properties with lower dosage of lime had also mix-design from Phase 4 (20 % FCB, 310 kg lime), but the compressive strength was not sufficient. Therefore, an experiment was conducted where the autoclaving time was extended by two hours in order to increase the compressive strength. This requirement has been achieved and the compressive strength increased averagely by 0.8 MPa with the same density. This was verified in the SEM images and the samples with extended autoclaving time contained more developed tobermorite crystals.

References

[1] Common interpretation EURELECTRIC /ECOBA: Classification of energy by-products according to the revised general directive on waste (2008/98/EC)

[2] SNOP, R.; DONÁT, P.; SOKOL, P. The current status of using fly ash in the Czech Republic - the definition of the coal combustion products as comodity. In Fly ash in building industry 2013. 2013. p. 93-98. ISBN 978-80-87342-17

[3] MELICHAR, T.; BYDŽOVSKÝ, J.; KEPRDOVÁ, Š. Study of alternative raw materials parameters for modification of cement bonded particleboards composition. Advanced Materials Research. 2013. 688(2013)(03). p. 139 - 145. ISSN 1022-6680.

[4] Act No. 185/2001 Coll. on waste and on the change and amendment to other laws, as amended

[5] url:http://www.sick.com/group/EN/home/solutions/industries/power_plant/Pages/power.aspx

[6] CSN 72 2072-5. Fly ash for construction purposes – Part 5: Fly ash for production of aerated concrete. Prague: Czech Standards Institute, 2000.

[7] CSN P 72 2081-4. Fluidized bed ash and fluidized fly ash combustion for building industry purposes- Part 4: Fluidized bed ash and fluidized fly ash combustion for the aerated concrete production Prague, Czech Standards Institute, 2001.

[8] KAPTAN, K; KAVLAK, U; YILMAZ, O. Determination of Concrete Compressive Strength by Non Destructibe Methods. Recent advances in Civil and mining engineering. 2013. p. 232 – 235. ISBN: 978-960-474-337-7.

[9] RAHMAN, A; RASUL, M.G.; KHAN, M.M.K.; SHARMA, S. Industrial Waste as Alternative Fuel in Cement Industry: Its Impact on Environment. Recent researches in environmental and geological sciences. 2012. p. 108 – 114. ISBN: 978-1-61804-110-4.

[10] PLACHY, T; TESAREK, P; WILCZYNSKA, A.; PADEVET, P. Experiment in Real Conditions: Mechanical Properties of Gypsum Block Determined using Non-Destructive and Destructive Methods. Latest trends on engineering mechanics, structures, engineering geology. 2010. p. 418 – 423. ISBN: 978-960-474-203-5.

[11] STEVULOVA, N., et. al. Study of sulphate corrosion simulations on concrete composites. International Journal of Energy and Environment. Vol. 6, p. 276 – 283. 2012. ISSN: 2076-2909.

Vit Cerny was born on 29th of September 1981 in Dacice, Czech Republic. The title Ing. (M.Sc.) in 2006 at Brno University of Technology (further BUT), Faculty of civil engineering (further FCE), Brno, Czech Republic, Ph.D. in 2012 at BUT, FCE, Brno, Czech Republic. His major field of study is use of fly ashes for artificial aggregate.

Vit works at BUT since 2005. He was a cosolver of two projects focused on artificial aggregate from fly ash and also from coal tailings. Now he works also on projects focused on use of FBC ashes for aerated concrete, grouting of embankment dams and on project focused on injection of wet masonry by special sealing gels. Sokol, P.; Drochytka, R.; Cerny, V.; Venhodova, E. Lightweight artificial aggregate based on fly ash for new rehabilitation materials. Advanced Materials Research. Zurich, Switzerland: Trans Tech Publications Inc., 2013. Cerny, V.; Drochytka, R.; Jandora, J. The usability of fly ash for the construction of embankment dams. Advanced Materials Research. Zurich, Switzerland: Trans Tech Publications Inc., 2012. Vit's research interests are use of fly ashes for aerated concrete, artificial aggregates, backfill, embankment dams etc.

Dr. Cerny cooperates with ASVEP, which is a Association for the use of energy products.

Rostislav Drochytka was born on 8th of January 1958 in Moravsky Krumlov, Czech Republic. The title Ing. (M.Sc.) in 1982 at Brno University of Technology (further BUT), Faculty of civil engineering (further FCE), Brno, Czech Republic, CSc. (Ph.D.) in 1986 at BUT, FCE, Brno, Czech Republic, Prof. in 2001 at BUT, FCE, Brno, Czech Republic,. His major field of study is aerated concrete.

Rostislav works at BUT since 1985. He is a solver of many research and development project (Ministry of trade, Ministry of Education, Grant Agency etc.), European projects, cosolver in research centers. Assistant Professor FCE, BUT (1985-1991), head of the Institute of Technology of Building Materials and Components, FCE, VUT (1994-present), Professor, FCE, VUT (2001-present), Vice-Dean (2003-2010), Dean of the FCE, BUT (2010-present). Rostislav wrote 5 monographs, 12 chapters in monographs (4 abroad), 9 articles in internationals journals, 69 contributions to the international conferences, 53 articles in domestic journals, 113 contributions to the conference in the Czech Republic. Rostislav's research interests are building materials, aerated concrete, polymers in construction, corrosion, degradation and durability of building materials, concrete rehabilitation - materials and technologies, coating of buildings, property valuation and businesses..

Prof. Drochytka is Chairman of the panel 104 of Grant Agency of Czech Republic (2009 - present), Chairman WTA CZ (Science and Society for redevelopment of buildings and care Monuments (2006 - present)), chairman of committees "C" FRVŠ (2006 - present), member of WTA International - Wissenschaftlich-Technische Arbeitsgemeinschaft Bauwerkserhaltung und für Denkmalpflege Germany (1999 - present), member of International Union of Testing and Research Laboratories for Materials and Structures (RILEM), Paris, France (2001 - present) etc.