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Fly ash obtained from co-combustion - A report on the situation in Europe

Flugasche, die unter Verwendung eines Anteils an Mitverbrennungsstoffen versorgt wird - Sachstandsbericht über die europäische Situation

Cendres volantes obtenues par co-combustion - Rapport sur la situation en Europe

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Flugasche, die unter Verwendung eines Anteils an Mitvergrennungsstoffen gewonnen wird - Sachstandsbericht über die europäische Situation

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Contents

Page

Foreword 4

Introduction 5

1 Scope 7

2 National regulations 7
2.1 General 7
2.2 Terms and definitions 7
2.3 Experience in different countries 8
2.3.1 The Netherlands 8
2.3.2 Germany 8
2.3.3 Denmark 8
2.3.4 United Kingdom 9
2.3.5 Finland 9
2.3.6 Belgium 9
2.3.7 Other countries 9
2.3.8 Overview of requirements 9

3 Inventory of co-combustion materials 11

4 Properties of fly ash obtained from co-combustion — Test results 16
4.1 General 16
4.2 Chemical properties 16
4.2.1 General 16
4.2.2 Sewage sludge 16
4.2.3 Biomass 16
4.2.4 Petcoke 17
4.2.5 Paper sludge 17
4.2.6 Straw 17
4.2.7 Wood 17
4.2.8 Meat and Bone meal 17
4.2.9 Other co-combustion materials 17
4.3 Physical and chemical properties of fly ash 29
4.4 Environmental compatibility 32
4.4.1 General 32
4.4.2 Netherlands 32
4.4.3 Germany 32
4.5 Compressive strength and activity index of mortar samples according to EN 450 34
4.5.1 General 34
4.5.2 Netherlands 34
4.5.3 Germany 36
4.5.4 Finland 38
4.5.5 Belgium 39

5 Properties of concrete with fly ash obtained from co-combustion 39
5.1 Concepts in Europe — General 39
5.2 Conformity tests on fresh and hardened concrete in the Netherlands (technical properties) 40
5.2.1 General 40
5.2.2 Assessment criteria on technical concrete properties according to CUR 70 40
5.2.3 Test results — Overview 41
5.2.4 Durability of concrete 42
5.2.5 Admixtures in concrete 43
5.2.6 Air-entraining agent 44
5.2.7 Retarding agents 44

5.3 Tests results on fresh and hardened concrete properties from trials in Finland (technical properties) 45
5.4 Assessment of the environmental compatibility of fly ash obtained from co-combustion (leaching tests on concrete) 46
5.4.1 Netherlands 46
5.4.2 Germany 47
Annex A (informative) **50**
Bibliography 51

Foreword

This document (CEN/TR 15677:2008) has been prepared by Technical Committee CEN/TC 104 “Concrete and related products”, the secretariat of which is held by DIN.

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Introduction

The test results included in this report demonstrate, with certain exceptions, that the properties of fly ashes obtained from the co-combustion of biomass and waste used at this time, do not significantly differ from fly ashes obtained from the combustion of pure coal. In some cases, changes in the chemical composition of fly ash occur, which may be of technical relevance to concrete. These changes have to be taken into account. Examples are:

— higher content of alkalis in fly ash from the co-combustion of straw;

— increase of P_2O_5 in case of the co-combustion of sewage sludge;

— increase of vanadium and nickel content in fly ash obtained from the co-combustion of petcoke.

The requirements of the EN 450:1994 regarding harmlessness and the effects of fly ashes in concrete are met. In some cases the maximum amount of combustion materials added to the coal is limited by the requirements of EN 450.

Investigations on concrete with fly ashes from co-combustion did not show any significant change in concrete properties. This applies to properties of fresh concrete, to the efficiency of admixtures like air entraining agents and retarders, as well as to properties of hardened concrete like strength development and ingression of chloride ions into the concrete. In general, tests on the leaching of concrete with fly ash from co-combustion did also not deviate from concrete with fly ashes from pure coal. Merely in the case of co-combustion of petcoke an increase in the leaching of vanadium was found. In this case a limitation of the amount of petcoke added to the coal may be required.

Fly ashes obtained from the combustion of coal have been used as a valuable concrete constituent for more than 30 years in Europe. At the beginning, utilisation was based on national standards in Member States. The European standard EN 450 was first published in 1994 and according to this standard fly ash for concrete is defined as follows:

> *"Fine powder of mainly spherical, glassy particles, derived from burning of pulverized coal, which has pozzolanic properties and consists essentially of SiO_2 and Al_2O_3, the content of reactive SiO_2, defined and determined as described in ENV 197-1, being at least 25 % by mass.*
>
> *Fly ash is obtained by electrostatic or mechanical precipitation of dust-like particles from the flue gases of furnaces fired with pulverised anthracite or bituminous coal."*

Since the beginning of the nineties coal-fired power plants started to burn co-combustion materials such as biomass and waste. As an example, sewage sludge was offered to power plant operators for co-combustion in order to get rid of the material. Power plants made it possible to remove animal meal at low costs when the production of animal food from animal meal was no longer permitted. In addition, biomass is used more and more for co-combustion in order to reduce emissions of CO_2 from the combustion of fossil fuels. In some countries power generators have been committed by their governments to co-combust biomass in order to meet Kyoto targets.

This development was taken into account when the revision of EN 450 began in 1998. Fly ash obtained from co-combustion was included in the scope of the standard by extending the definition mentioned above:

> *"Fine powder of mainly spherical, glassy particles, derived from burning of pulverized coal,* ***with or without co-combustion materials****, which has pozzolanic properties and consists essentially of SiO_2 and Al_2O_3, the content of reactive SiO_2 as defined and described in EN 197-1 being at least 25 % by mass.*
>
> *Fly ash is obtained by electrostatic or mechanical precipitation of dust-like particles from the flue gases of furnaces fired* ***with pulverised coal, with or without co-combustion materials,*** *see clause 4.*

Fly ash may be processed, for example by the classification, selection, sieving, drying, blending, grinding or carbon reduction, or by combination of these processes, in adequate production plants. Such processed fly ash may consist of fly ashes from different sources, each conforming to the definition given in this clause. If one or more of incoming fly ashes are obtained from co-combustion, then the processed fly ash shall be considered as fly ash from co-combustion.

NOTE Municipal and industrial waste incineration ashes do not conform to the definition given in this clause."

A general principle kept in this standard is that properties of fly ash regarding their effects on, and their contribution to concrete properties may not be changed due to co-combustion. This has to be proven by suitability tests and current quality control. In addition, the environmental compatibility of concrete with fly ashes has to be demonstrated.

The data presented in this report were collected by an enquiry, which was launched by CEN/TC 104/WG 4 in January 1998. The information received was supplemented by test results obtained from additional investigations.

1 Scope

This CEN report compiles the experience collected from the co-combustion of biomass and waste by 2002. The data and the test results are given from systematic research projects and from investigations on fly ash obtained from co-combustion in different power plants in the framework of national certification processes or from other co-combustion tests. The report:

— includes the existing national regulations for the demonstration of the suitability of fly ash from co-combustion,

— gives a survey on the combustion materials used so far,

— describes the chemical composition of fly ashes obtained from co-combustion,

— lists the chemical and physical properties of the fly ashes, which are relevant to the technical and environmental properties of concrete,

— includes test results of properties of concrete with fly ashes obtained from co-combustion.

2 National regulations

2.1 General

In most countries of the EC the non-harmonized product standard EN 450:1994-09 entitled “Fly ash for concrete — Definitions, requirements and quality control” is used. The basic experience with EN 450 is very positive.

In the course of environmental regulations, power station operators are forced more and more to fire co-combustion materials alongside the usual hard coal. Some countries of the EU already gained experiences with the co-combustion of high calorific materials and transferred these into appropriate national sets of rules. Information concerning these rules is to be reported in the following after giving some essential definitions.

2.2 Terms and definitions

For the purposes of this CEN Report, the following terms and definitions apply.

2.2.1
fly ash
fly ash is a fine powder of mainly spherical, glassy particles, derived from burning pulverized coal, which has pozzolanic properties and consists essentially of SiO_2 and Al_2O_3, the content of reactive SiO_2 defined and determined as described in ENV 197-1, being at least 25 % by mass; fly ash is obtained by electrostatic or the mechanical precipitation of dust-like particles from flue gases or furnaces fired with pulverized anthracite or bituminous coal

[EN 450:1994-09]

2.2.2
fly ash obtained from co-combustion
fly ash that is generated from firing pulverised coal, to which a certain amount of co-combustion material has been added

2.3 Experience in different countries

2.3.1 The Netherlands

To show whether the quality of fly ash is affected by co-combustion, a broad research program was performed in which both the technical quality and the environmental compatibility of concrete with fly ash obtained from co-combustion was evaluated in comparison with the quality of concrete with reference fly ash (obtained from firing pure coal). In this research program fly ash from co-combustion of demolition wood, sewage sludge, paper sludge and petcoke was evaluated. As a result of this broad research program, a conformity procedure was developed by which fly ash obtained from co-combustion can be checked as to whether it conforms to EN 450. This procedure consists of the tests according to EN 450, extended with a “conformity analysis (see Table 1 through Table 3), in which the effects of the fly ash from co-combustion on durability and on the action of concrete admixtures are established. This procedure has been made part of the Dutch technical standards (CUR 1999, chapter 7).

2.3.2 Germany

Increasing problems with the deposition of municipal sewage sludge led, in the beginning of the nineties, to an increasing co-combustion in German power plants. Under normal operation conditions trials with the co-combustion of municipal sewage sludge have been carried out in several German power plants with the aim to investigate the influence of co-combustion on the physical, chemical and environmentally relevant properties of fly ash. Based on these investigations, a regulation for the production of DIN EN 450 fly ash from the combustion of pulverised coal (anthracite or bituminous) and up to a maximum of 5 % by mass of municipal sewage sludge in relation to the dry coal was added in the attachment 1.6 of the German “Construction products list A (CPL A)” (Bauregelliste A) in 1996.

If the DIN EN 450 requirements and the provisions concerning the maximum amount of sewage sludge and the limit values on trace elements and phosphate in Table 1 are fulfilled, the fly ash produced may be used in reinforced and pre-stressed concrete (pre-tensioned and post-tensioned) according to DIN 1045 and DIN 4227 without any limitations and further quality control measures.

Recently new trials have been launched in some German power plants to assess the influence of the co-combustion of petroleum coke (petcoke) on the physical, chemical and environmentally relevant properties of fly ash. In the framework of technical approval, the maximum amount for the co-combustion of petcoke is limited to that amount which is investigated and proved in the approval procedure. A guideline assessing of the impact of building products on soil and groundwater was set into force by the building authorities (Deutsches Institut für Bautechnik) in 2001. The guidelines describe a procedure for initial testing and give requirements with respect to environmental properties of building materials in the course of the application for national technical approval. The assessment is based on the report of certain trace elements and organic constituents as well as on the leaching of materials, which are harmful to soils and groundwater. In case of cementitious materials like fly ash used as an addition to concrete the leaching from a fly ash concrete as measured in a stand test is compared to limiting values derived from requirements on groundwater quality by using a distribution model. As a result of the assessment procedure fly ashes obtained from co-combustion in certain power plants have got a technical approval. The technical approval restricts the maximum amount of co-combusted petcoke to 10 % by mass related to the coal and limits the content of nickel and vanadium in the fly ash to 600 mg/kg and 1 500 mg/kg respectively.

Beyond the use of municipal sewage sludge and petcoke as co-combustion materials, tests on fly ash obtained from the co-combustion of bone meal and paper sludge are also on going at present (as of January 2002) in Germany.

2.3.3 Denmark

In Denmark only fly ashes according to EN 450 are allowed to be used as a concrete addition. Co-combustion was performed in some trials with straw but until now it is not introduced in national regulations.

2.3.4 United Kingdom

In the UK a trial test series on the co-combustion of petcoke was performed in 1997 to evaluate and the environmental effects of burning blends of petcoke and coal. The results confirm, that there was no impact on the environment in burning petcoke blends.

In the UK mostly environmental criteria are set for the allowance of co-combustion as before proceeding with co-combusting any material, one has to obtain approval from the Environment Agency and Health & Safety Executive. Then a joint assessment of the possible emissions from the power plant, the disposal or utilisation of the fly ash, the risk of contamination from the raw co-combustion material, etc. is assessed. The Environment Agency has the right to prevent any co-combustion from occurring unless they are satisfied with the safety procedures, emissions, disposal of fly ash, etc.

If concrete with fly ash obtained from co-combustion should be applied in contact with drinking water, the situation is different. For materials in contact with drinking water the Drinking Water Inspectorate (DWI) is responsible. Currently concrete within the UK is a blanket approval for use in contact with drinking water (as it is the only material which achieves this). For concrete with fly ash obtained from co-combustion, this approval may not apply and leaching tests may have to be carried out to the satisfaction of the DWI.

2.3.5 Finland

Only limited trial test series on the co-combustion of wood are available and at this time this has not lead to regulations on a national scale. The results, however, generally confirm the findings of the investigations carried out in other countries.

2.3.6 Belgium

In Belgium the reuse of fly ash from co-combustion is regulated by the standard that deals with the reuse of waste material as secondary building material called “Vlarea”. According to this standard, fly ash obtained from co-combustion has to meet requirements regarding the total composition and the leaching of heavy metals.

2.3.7 Other countries

Requirements for co-combustion materials were reported from Italy. There was no response to the inquiry From the other countries, thus information and data for these countries are not available.

2.3.8 Overview of requirements

In Table 1 and Table 2 an overview is given for the requirements for co-combustion materials and fly ash obtained from co-combustion.

Table 1 — Requirements for materials allowed to be used as co-combustion material in different European countries

Country		—	NL[a]	DE		Be	DK	I			
Co-combustion material	Property/ parameter	unit		Sewage sludge		Sewage sludge	Straw	Residues from coal and coke from steel industry [c]	Municipal waste	Sewage sludge	Paper sludge
Reference	—	—	[10]	[12]		[22]	[14]		[13]		
Parameter	—	—	requirement								
General properties	calorific value (LL)	KJ/kg	—	—		—	—	16 000	15 000	8 560	1 200
	humidity (UL)	%		—		—		8/6	25	20	30
	ash content (UL)	%				—		—	20	—	10
Element content (UL)	Chloride	%		—		—		—	0,9		0,9
	Cl (organic)	mg/kg		—		—		—		1	
	Sulfur	%		—		—		2/1,5	0,6	0,6	0,5
	P_2O_5	%		25[b]		—		—	—	—	
Heavy metal content (UL)	Arsenic	mg/kg dry matter	—	—		250	—	—	9	9	9
	Cadmium			10		10		—			
	Chromium			900		1 250		—	100	100	50
	Copper			800		375		—	—	—	300
	Copper (soluble)			—				—	300	300	—
	Mercury			8		5		—	—	—	—
	Mangane			—				—	400	400	150
	Nickel			200		250		—	40	40	20
	Lead			900		1 250		—	—	—	200
	Lead (volatile)			—				—	200	200	—
	Zink			2 500		1 250		—	—	—	—
	Cd+Hg			—		—		—	7	7	7
	Vanadium			—		—		—	—	—	—

LL: lower limit.

UL: upper limit.

[a] In the Netherlands the requirements are based on the framework of emission limits and limits of hazardous wastes and part of the permits for co-combustion. The Dutch power plants analyse the co-combustion streams and reject their policy for the choice of co-combustion materials on the quality of the by-products.

[b] Related to the ash of the sewage sludge.

[c] During the technical process of steel production coal and coke is combusted; from this combustion residues occur.

Table 2 — Technical requirements for fly ash from co-combustion according to EN 450

Reference	EN 450
LOI % by mass	≤ 5
Cl % by mass	≤ 0,10
SO_3 % by mass	≤ 3,0
Free CaO % by mass	≤ 1,0
Fineness % by mass	≤ 40
Activity index %	≥ 75 at 28 d ≥ 85 at 91 d
Soundness mm	≤10

3 Inventory of co-combustion materials

The co-combustion materials included in EN 450-1:2005 are divided into six main groups:

— Vegetable material like wood chips, straw, olive shells and other vegetable fibres;

— Green wood and cultivated biomass;

— Animal meal;

— Municipal sewage sludge;

— Paper sludge;

— Petroleum coke;

— Virtually ash free liquid fuels and gaseous fuels.

In Table 3 an overview is given on co-combustion materials, which have been co-combusted in European countries. The chemical and physical composition of different co-combustion materials are summarised in Table 4a through Table 4c,.

Table 3 — Materials that have been used for co-combustion in different countries of Europe

Country	No.	Power Plant	Origin of coal [a]	Co-combustion material	Amount % by mass [b]	Date
NL	I	HW-8	blend	sewage sludge	3, 6	1995
	II	AC-8	blend	paper sludge	5, 8	1995-12
	III	AC-9	blend	petcoke A and B [c]	5, 10	1995
	IV	AC-9	blend	petcoke A and B	5, 10	1996
	V	CG-13	blend	demolition wood	6, 12	1997-3
	VI	BS12	blend	hydrocarbon gas (phosphorus production)	3, 6*)	1997
	VII	MV-2	blend	biomass pellets	5	1997
	VIII	AC-9	blend	paper sludge	5	1998-3
	IX	MV-2	blend	biomass/citrus pellets	8,5	1998-9
	X	BS-12	Poland	sewage sludge	5, 10	1998-10
	XI	BS-12	blend	paper sludge	5	1998-12
	XII	MV1	blend	biomass pellets	8	1999-05
	XIII	MV-1	blend	meat and bone meal	1,6	1999-08
	XIV	MV1	blend	coffee grounds	3	1999-09
	XV	BS-12	blend	cacao shells	9	1999-11
	XVI	MV1	blend	poultry dung	3	1999-11
	XVII	MV1	blend	meat and bone meal	2,7	2001-04
DE	—	A	Germany/ South Africa	sewage sludge	1,0 to 8,3	1993-09
		B		sewage sludge	0,9 to 4,4	1992/1993
		C		sewage sludge	2/4	1997
		B	Poland	petcoke	5 to 15	1999
	I/II	C	Australia/ South Africa	petcoke	10	1999
	III		South Africa	petcoke: sewage sludge	10:4	1999
	—	D	unknown	petcoke	9,4	1999
DK	—	—	—	straw	10/20	—
	—	—	—	soil contaminated by tar	10	—
FI	—	DBL	Poland	Wood	14	2000
Be		Mol	Poland	sewage sludge	2,8	1998-08
GB	—	DP	blend	petcoke 1 and 2	10, 15, 20	1998

*) Based on energy (GJ) (related to the calorific value of the coal).

[a] Blend: Blends of coal from a different origin (different countries).

[b] Related to coal.

[c] Different sources.

From an environmental point of view, the trace element contents of the co-combustion material may be of interest. In some countries, limit values for the heavy metal contents of the co-combustion material exist (see Table 1). In general, the total concentration of heavy metals of the co-combustion material should not be assessed, but the total concentration in the resulting fly ash.

Table 4a — Chemical composition of co-combustion materials: Part 1

Co-combustion material	petcoke					
Country	**NL**		**GB**		**D**	
Power plant/sample	**A**	**B**	**DP/1**	**DP/2**	**B**	**D**
Ash content [% by mass]	0,5	0,4	3,8	1,3		
Major elements [% by mass]	[a]	[a]	[b]	[b]	—	
SiO_2	24,6	10,5	1,97	3,86	—	
Al_2O_3	6,69	3,5	0,57	1,74	—	
Fe_2O_3	7,15	2,37	0,20	0,61	—	
CaO	5,43	1,03	0,22	0,14	—	—
MgO	0,67	0,35	0,04	0,09	—	
Na_2O	1,53	1,38	0,04	0,10	—	
K_2O	0,43	0,67	0,10	0,15	—	
TiO_2	0,43	0,16	—	—	—	
P_2O_5	0,13	0,16	< 0,01	0,02	< 0,01	
Trace elements [mg/kg]	[b]	[b]	[b]	[b]	[c]	[c]
As	< 1,6	< 1,6	1,0	<0,3	0,33	3,6
Ba	3,5	1,9	—	—	—	—
Cd	<0,02	< 0,02	<0,1	<0,1	0,12	0,01
Co	0,8	1,65	<5	<5	2,2	1,6
Cr	15,5	5,8	5	5	1,1	6,8
Cu	1,6	0,7	7,4	2,9	1,2	1,1
Hg	< 0,01	<0,01	0,06	< 0,02	—	1,1
Mn	4,7	1,9	17	19	—	—
Mo	6,8	15,5	10	24	—	21
Ni	136	340	199	248	330	322
Pb	<1,4	<1,4	0,3	2,5	0,55	2,6
Sb	<0,9	<0,9	1,5	1,0	—	2,3
Se	<0,7	<0,7	0,3	<0,1	—	—
Sn	<1,0	<1,0	—	—	—	2,1
Te	<2,0	<2,0	—	—	—	—
V	462	1718	693	1325[d]	580	1610
Zn	6,3	<4,7	8	7	—	7,7

— Not determined.

[a] Related to ash of the material.

[b] From the given data it becomes not clear whether the concentrations refer to the ash or the dried material.

[c] Related to the dried material.

[d] “Worst case” petcoke; represents refineries processing South American crude oils.