PD CEN/TR 16443:2013

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Backgrounds to the revision of EN 450-1:2005+A1:2007 — Fly ash for concrete

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The UK participation in its preparation was entrusted to Technical Committee B/517/4, Additions for concrete.

A list of organizations represented on this committee can be obtained on request to its secretary.

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The British Standards Institution 2013.

Published by BSI Standards Limited 2013

ISBN 978 0 580 78799 7

ICS 91.100.30

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This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 April 2013.

Amendments issued since publication

Date	Text affected

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Full document details: PD CEN/TR 16443:2013

TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CEN/TR 16443

March 2013

ICS 91.100.30

English Version

Backgrounds to the revision of EN 450-1:2005+A1:2007 - Fly ash for concrete

Contexte de la révision de l'EN 450-1:2005+A1:2007 - Cendres volantes pour béton

Hintergründe zur Überarbeitung der EN 450-1:2005+A1:2007 - Flugasche für Beton

This Technical Report was approved by CEN on 29 October 2012. It has been drawn up by the Technical Committee CEN/TC 104.

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Ref. No. CEN/TR 16443:2013: E

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Foreword

This document (CEN/TR 16443:2013) 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

Following five years of experience using EN 450-1, it was clear that some clauses need improvement within the standards. In the existing standards the maximum amount of fly ash from co-combustion was limited to certain proportions. Experience gained with fly ashes conforming to a European Technical Approval (ETA), where higher co-combustion amounts were permitted, showed that the requirements in the corresponding Common Understanding of Assessment Procedure (CUAP) were sufficient guarantee for fly ashes to produce excellent performance in concretes, mortars, grouts and cements. As agreed in CEN/TC 104, the experience gained with ETA fly ashes should be incorporated in the revision of EN 450-1.

In this background report it is proved that wider ranging limits and types of co-combustion materials can be safely applied in the revised EN 450-1. It is also shown that in practice some requirements in EN 450-1 have been proven to be unrealistic. Improvements have been proposed for the definition of fly ash, the loss on ignition, free calcium oxide, reactive silicon dioxide and the limits for phosphate.

The conformity procedures have also been evaluated, especially the assessment procedure for inspection by variables. Based on this evaluation work, modifications are needed for the LOI[1)] classes B and C.

The revised version of the standard incorporates the European Technical Approvals (ETA) and EU members experience gained with fly ash in concrete. The requirements of the revised standard will result in fly ashes which will perform similarly to those conforming to EN 450-1:2005.

1) LOI – Loss on ignition.

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1 Scope

This Technical Report describes the backgrounds to the revision on EN 450-1:2005+A1:2007, *Fly ash for concrete — Part 1: Definition, specifications and conformity criteria*.

2 List of relevant references

The following references are covered by the present document:

— EN 450-1:2005+A1:2007, *Fly ash for concrete — Part 1: Definition, specifications and conformity criteria*;

— EN 450-1:2012 (revised EN 450-1 [2)]), *Fly ash for concrete — Part 1: Definition, specifications and conformity criteria*;

— EN 450-2:2005, *Fly ash for concrete — Part 2: Conformity evaluation*;

— EN 196-2, *Methods of testing cement — Part 2: Chemical analysis of cement*;

— EN 197-1:2000, *Cement — Part 1: Composition, specifications and conformity criteria for common cements*;

— EN 14588:2010, *Solid biofuels — Terminology, definitions and descriptions*.

3 General

3.1 General and objective

Fly ash has been used for many decades in concrete as an addition for its positive influence on workability, heat of hydration, strength development and durability. After the encouraging pilot projects some decades ago with positive results, licenses for regular use and later on technical approvals were granted by the national building authorities, certificates and standards. Today, regulations and standards exist for the use of fly ash in mortar and concrete.

In 1995, the first EU standard was published, namely EN 450, *Fly ash for concrete — Definitions, requirements and quality control*. This edition was followed up by a harmonised standard based on Mandate M 128 in 2005 (EN 450-1:2005), together with a second standard (EN 450-2:2005), specific for conformity evaluation.

The scope of EN 450-1:2005 states that fly ashes with percentages of co-combustion material higher than those covered in EN 450-1:2005, Clause 4 or with other types of co-combustion material are outside the scope of EN 450-1:2005.

In some countries, the use of fly ash with a higher percentage of co-combustion material was already common practice and it was not accepted by these countries that these fly ashes, containing higher amounts of co-combustion and other co-combustion materials, were excluded from CE marking.

It was agreed that European Technical Approvals (ETAs) could be granted for this product according to Article 8.2 of the Construction Products Directive. The mandate M 128 was updated with the clarification that fly ash produced with other types than those covered by EN 450-1 and fly ash produced with a percentage of co-combustion material outside the limits defined in EN 450 (all parts), can be subject to ETAs, in order to allow these products to be CE marked. The experience gained with the fly ashes conforming to these ETAs has been used for the next revision of EN 450-1.

Due to the regular five-year revision, WG 4 of CEN TC 104 incorporated the knowledge gained with the fly ashes conforming to these ETAs with EN 450-1. Other issues for the revision were identified as a lack of clarity regarding the conformity evaluation and some of the other requirements.

2) In this present Technical Report a reference to the revised EN 450-1 always refers to EN 450-1:2012.

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The objective of this report is to provide insight into the background to the modifications that have been taken up in EN 450-1:2012 (revised EN 450-1) and of those requirements that have been deleted from EN 450-1:2005+A1:2007

3.2 Structure of the report

Clause 4 provides an overview of the requirements of EN 450-1:2005+A1:2007 and EN 450-1:2012. In Clause 5 the background for the modifications of the requirements within EN 450-1 is described. Clause 6 gives the background for the statistical evaluation for assessment procedure by variables, Clause 7, the background for the required test methods, regarding chemical composition and the determination of fineness. In Clause 8, an overview how fly ash quality is assured within the production process itself, the quality control system and the conformity evaluation of toxicological and environmental aspects is given. Clause 9 deals with the impact of co-combustion on the release of regulated dangerous substances.

More background information about the generation of fly ash can be found in Annex B.

4 Overview of requirements in EN 450-1:2005+A1:2007 and EN 450-1:2012

An overview of the requirements in the revised EN 450-1 is presented in Table 1. The requirements are related to fresh and hardened concrete. The chemical requirements concern Loss On Ignition (LOI), chloride (Cl), reactive and free Calcium Oxide or lime (CaO), reactive Silicon Dioxide (SiO_2), the sum of SiO_2 + Al_2O_3 + Fe_2O_3, Magnesium Oxide (MgO) and soluble Phosphorus Pentoxide (P_2O_5). The physical requirements concern (or: are related to) fineness and the maximum deviation of particle density. The performance based requirements are water requirement, initial setting, activity index and soundness.

In relation to the previous standard, the following changes have been adapted:

— The definition of fly ash has been modified (EN 450-1:2012, 3.2).

— The permitted amount and type of co-combustion materials have been changed (EN 450-1:2012, 4.1).

— The requirement for the lower limit of LOI for category B and C fly ash has been deleted (EN 450-1:2012, 5.2.2).

— The requirement for free lime (CaO) has been changed (EN 450-1:2012, 5.2.5).

— The amount of total phosphate has been limited by a new requirement (EN 450-1:2012, 5.2.11).

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Table 1 — Properties and requirements of fresh and hardened mortar and concrete

Phase	Property	Unit	EN 450-1:2005+A1:2007	EN 450-1:2012
workability	loss on ignition (LOI) class A class B class C	% by mass	≤ 5,0 2,0 – 7,0 4,0 – 9,0	≤ 5,0 ≤ 7,0 ≤ 9,0
	water requirement [a]	%	≤ 95	n.m. [e]
	fineness fraction > 45 μm	% by mass	≤ 40 (cat. N) [d] ≤ 12 (cat. S)	n.m. [e]
initial strength development	soluble phosphate (P_2O_5)	mg/kg	≤ 100	n.m. [e]
	total phosphate (P_2O_5)	% by mass	—	≤ 5,0
	initial setting	min.	2C [b]	n.m. [e]
strength development	sum $SiO_2 + Al_2O_3 + Fe_2O_3$	% by mass	≥ 70	n.m. [e]
	reactive SiO_2	% by mass	≥ 25	n.m. [e]
	activity index 28 days 91 days	%	≥ 75 ≥ 85	n.m. [e] n.m. [e]
alkali silica reaction (ASR)	total content of alkalis (Na_2O equivalent)	% by mass	≤ 5,0	n.m. [e]
	reactive calcium oxide (CaO)	% by mass	≤ 10,0	n.m. [e]
soundness/ durability	sulphuric anhydride (SO_3)	% by mass	≤ 3,0	n.m. [e]
	free calcium oxide (CaO)	% by mass	≤ 2,5 [c]	[f]
	soundness	mm	≤ 10	n.m. [e]
	magnesium oxide (MgO)	% by mass	≤ 4,0	n.m. [e]
	chloride (Cl^-)	% by mass	≤ 0,10	n.m. [e]

a Only applicable for category S fly ash.
b Initial setting of fly ash cement paste shall not be more than twice as long as the initial setting time of the test cement alone.
c If the content of free lime is greater than 1,0 % by mass, the fly ash shall be tested for conformity to the requirement for soundness.
d The fineness shall not vary by more than ±10 % from the declared value.
e n.m. = not modified.
f If the content of free lime is greater than 1,5 % by mass, the fly ash shall be tested for conformity to the requirement for soundness.

5 Background for modification of the requirements in EN 450-1

5.1 Definition of fly ash

5.1.1 Text of EN 450-1:2005+A1:2007

Fine powder of mainly spherical, glassy particles, derived from the burning of pulverised 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.

5.1.2 Text of EN 450-1:2012 (revised EN 450-1)

Fine powder of mainly spherical, glassy particles, derived from the burning of pulverised coal, with or without co-combustion materials, which has pozzolanic properties and consists essentially of SiO_2 and Al_2O_3.

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5.1.3 Background

The requirement of reactive SiO_2 has been deleted in the definition of the revised EN 450-1, but still exists as requirement for initial type testing (EN 450-1:2012, 5.2.7).

By definition fly ash has to be derived from the burning of pulverised coal and co-combustion materials. This is only possible in dedicated boilers where combustion of finely ground fuel takes place in a cloud, with combustion temperatures of 1 300 – 1 500 °C. This means that ashes from other boilers like grate-fired and fluidised bed combustion boilers do not meet this definition. In other words, the definition guarantees that combustion takes place at high temperature, which is high enough to facilitate glass formation in the fly ash.

The definition includes co-combustion, but, in EN 450-1:2012, 4.1, the amount and type of combustion material are further restricted. Also, as noted in EN 450-1, municipal and industrial waste incineration ashes do not conform to the definition of this clause. This implies that the fuel always contains coal. Coal contains mineral matter that will form the glass phase during combustion. Also part of the secondary fuel also contains mineral matter that contributes to glass formation. On a performance level, the requirement for the activity index after 28 and 91 days provide enough assurance for a sufficient pozzolanic behaviour of the fly ash. The presence of the glass phase is further assured by the requirement for the minimum total amount of $SiO_2 + Al_2O_3 + Fe_2O_3$ (as a main fraction of potential glass forming matter).

5.2 Co-combustion materials

5.2.1 Text of EN 450-1:2005+A1:2007

Fly ash from co-combustion as defined in 3.2 is obtained from pulverised coal fired simultaneously with co-combustion materials as listed in Table 1 (Table 2 of this report). The minimum percentage, by dry mass, of coal (K_c) shall not be less than 80 % and the maximum proportion of fly ash derived from co-combustion materials (M) shall not be greater than 10 % when calculated from Formula (1).

Table 2 (Table 1 of EN 450-1:2005+A1:2007) — Types of co-combustion materials

1	Vegetable material like wood chips, straw, olive shells and other vegetable fibres
2	Green wood and cultivated biomass
3	Animal meal
4	Municipal sewage sludge
5	Paper sludge
6	Petroleum coke
7	Virtually ash free liquid and gaseous fuels

5.2.2 Text of EN 450-1:2012 (revised EN 450)

Fly ash from co-combustion as defined in 3.2 is obtained from pulverised coal fired simultaneously with or without co-combustion materials as listed in Table 1 (Table 3 of this report). The minimum percentage, by dry mass, of coal (K_c) shall be not less than 60 % or 50 % if the co-combustion material is only green wood. The maximum proportion of ash derived from co-combustion materials (M) shall not be greater than 30 % by dry mass when calculated from Formula (1).

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Table 3 (Table 1 of the revised EN 450-1) — Types of co-combustion materials

1	Solid Bio Fuels conforming to EN 14588:2010 including animal husbandry residues as defined in 4.3 and excluding waste wood as defined in 4.40, 4.107 and 4.136
2	Animal meal (meat and bone meal)
3	Municipal sewage sludge
4	Paper sludge
5	Petroleum coke
6	Virtually ash free liquid and gaseous fuels

NOTE Other types of co-combustion materials not included in Table 3 (Table 1 of the revised EN 450-1) may be subject to an ETA.

5.2.3 Background

The classification of secondary fuels has been changed in the revised EN 450-1. The secondary fuels listed in line 1 and 2 of table 3 have been merged as these are from the same origin and compiled in EN 14588. As “green wood” is not defined in that report a definition was added in the revised EN 450-1 as:

"3.13
green wood
green wood is wood originating from trees, bushes and shrubs created when processing wood as cross-cut ends, planings, saw dust and shavings used in the form of dust, chips and pellets".

The minimum proportion of coal has been decreased from 80 % by mass to 60 % by mass. Further, the maximum proportion of ash derived from secondary fuels has been increased from 10 % to 30 % by mass.

Since 2005, ETAs have been used for testing the technical and environmental suitability of fly ash from co-combustion for use as addition in concrete. Generated fly ashes from co-combustion exceeding the co-combustion limits of EN 450-1:2005+A1:2007 were tested according to these ETAs. Before ETAs were available, Dutch fly ashes from co-combustion were tested according to CUR recommendations (since 1999). The tested fly ashes are presented in Annex C.

Co-combustion may increase the content of Ca, K, P and Mg in some cases. The other macro elements (Fe, Al, Si, Na, and Ti) are mainly indirectly influenced by becoming impoverished due to the enrichment of other macro elements. In most secondary fuels from vegetable and animal origin these macro-elements are present in low concentrations (ash based), related to coal. The situation in fuels from industrial origin may be different like the presence of Al, Si, Fe and Ti in demolition wood, Al, Si and P in sewage sludge and Al, Si and Ca in paper sludge. The revised EN 450-1 contains an adequate set of requirements that covers these influences; see Table 5. As can be derived from this table the influence of Ca, K, Mg and P is directly covered by at least one requirement of the revised EN 450-1.

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Table 4 — Requirements for fly ash for fresh and hardened concrete in relation to the effects of co-combustion

Phase	Requirement of EN 450-1	Main influence co-combustion			
		Ca	K	Mg	P
workability	LOI	—	—	—	—
	water requirement	—	—	—	—
	fineness fraction > 45 μm	—	*V*	—	—
initial strength development	soluble P_2O_5	—	—	—	*VV*
	total P_2O_5	—	—	—	*VV*
	initial setting	—	—	—	*VV*
strength development	sum $SiO_2 + Al_2O_3 + Fe_2O_3$	*V*	*V*	*V*	*V*
	activity index	—	—	—	*V*
Alkali Silica Reaction	Na_2O equivalent	—	*VV*	—	—
	reactive CaO	*VV*	—	—	—
soundness/ durability	SO_3	—	—	—	—
	free CaO	*VV*	—	—	—
	Soundness	*V*	—	—	—
	total MgO	—	—	VV	—
	Cl^-	—	—	—	—

Key
VV direct relation between the requirement and the influence of co-combustion
V in-direct relation between the requirement and the influence of co-combustion
— no relation

The test results showed that in nearly all cases, the chemical requirements of the ETA were met with one exception, which in that case fly ash was rejected for use in concrete. This can be explained by the fact that the co-combustion amount was adjusted to the chemical requirements or to operational conditions (fuel feed, slagging, corrosion, etc.). An overview of limiting parameters for co-combustion materials is given in Table 5.

The results showed also that the XRD analyses of fly ash did not provide any extra information for quality control purposes. In all cases no minerals were identified other than listed in the ETA. Therefore this criterion was not included in the revised EN 450-1.

For a selection of these fly ashes, concrete specimens were produced to check if the proposed test methodology is adequate. The performance of the concrete did not show significant influence of co-combustion. The results are described in several reports and presentations (see CUR, 2003; Sarabèr, 2004; Sarabèr and Van den Berg, 2005; Sarabèr and Van den Berg, 2006; CTSC, 2008). It was shown that the performance of fly ash obtained from different co-combustion materials could be explained by the mineralogical composition of the fly ash and that this could be related to the origin of the co-combustion material. It was shown that depending on the origin of the fuel high co-combustion percentages are possible up to 25 % by mass.

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Table 5 — Limiting parameters for co-combustion materials (basis Table 1 of the revised EN 450-1)

	Type	Limited by
1	**Solid Bio Fuels conforming to EN 14588:2010 including animal husbandry residues as defined in 4.3 and excluding waste wood as defined in 4.40, 4.107 and 4.136.**	
	green wood 1	Co-combustion fuel based
	green wood 2	Co-combustion fuel based
	green wood 3	Co-combustion fuel based
	bark wood	reactive CaO
	Cacao shells	Na_2O equivalent (K)
	palm kernels	total P_2O_5
2	**Animal meal (meat and bone meal)**	
	Meat and bone meal	total P_2O_5
3	**Municipal sewage sludge**	
	Municipal sewage sludge	total P_2O_5
4	**Paper sludge**	
	Paper sludge	CaO
5	**Petroleum coke**	
	Petroleum coke	—[a]
6	**Virtually ash free liquid and gaseous fuels**	
	Industrial HC liquid	Co-combustion fuel based

[a] Prevented by National environmental regulations.

As already stated, the actual amount of co-combustion material is not only limited by the maximum requirement for co-combustion, but also by the chemical requirements of EN 450-1. This means that in practice, the actual amount of coal combustion (K_c) will be higher than 60 % by mass and the maximum proportion of ash derived from co-combustion materials (M) will be less than 30 % by mass. To illustrate this, the maximum amount of co-combustion has been studied in relation to the chemical requirements (KEMA, 2008). The minimum proportion of coal combustion and the maximum proportion of ash derived from co-combustion materials (M) adjusted to meet the requirements of EN 450-1 by calculating chemical compositions using the "KEMA TRACE MODEL®"[3)] The study shows that co-combustion of most secondary fuels will be limited by the chemical requirements or by the definition regarding the fuel based maximum co-combustion. In Annex D all results are summarised.

5.3 Loss on ignition

5.3.1 Text of EN 450-1:2005+A1:2007

The loss on ignition shall be determined in accordance with the principles of the method described in EN 196-2 but using an ignition time of 1 h, and shall fall within the limits of the categories specified below:

Category A: Not greater than 5,0 % by mass

Category B: Between 2,0 % and 7,0 % by mass

3) KEMA TRACE MODEL® is the trade name of a product. This information is given for the convenience of the users of this Technical Report and does not constitute an endorsement by CEN of the product named. Similar products may be used if they can be shown to lead to equivalent results.

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