



Designation: **C150/C150M—18** **C150/C150M – 19**

Standard Specification for Portland Cement¹

This standard is issued under the fixed designation C150/C150M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers ten types of portland cement, as follows (see [Note 2](#)):

1.1.1 *Type I*—For use when the special properties specified for any other type are not required.

1.1.2 *Type IA*—Air-entraining cement for the same uses as Type I, where air-entrainment is desired.

1.1.3 *Type II*—For general use, more especially when moderate sulfate resistance is desired.

1.1.4 *Type IIA*—Air-entraining cement for the same uses as Type II, where air-entrainment is desired.

1.1.5 *Type II(MH)*—For general use, more especially when moderate heat of hydration and moderate sulfate resistance are desired.

1.1.6 *Type II(MH)A*—Air-entraining cement for the same uses as Type II(MH), where air-entrainment is desired.

1.1.7 *Type III*—For use when high early strength is desired.

1.1.8 *Type IIIA*—Air-entraining cement for the same use as Type III, where air-entrainment is desired.

1.1.9 *Type IV*—For use when a low heat of hydration is desired.

1.1.10 *Type V*—For use when high sulfate resistance is desired.

NOTE 1—Some cements are designated with a combined type classification, such as Type I/II, indicating that the cement meets the requirements of the indicated types and is being offered as suitable for use when either type is desired.

NOTE 2—Cement conforming to the requirements for all types are not carried in stock in some areas. In advance of specifying the use of cement other than Type I, determine whether the proposed type of cement is, or can be made, available.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. Values in SI units [or inch-pound units] shall be obtained by measurement in SI units [or inch-pound units] or by appropriate conversion, using the Rules for Conversion and Rounding given in [IEEE/ASTM SI 10](#), of measurements made in other units [or SI units]. Values are stated in only SI units when inch-pound units are not used in practice.

1.3 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards*:²

[C33 Specification for Concrete Aggregates](#)

[C51 Terminology Relating to Lime and Limestone \(as used by the Industry\)](#)

[C109/C109M Test Method for Compressive Strength of Hydraulic Cement Mortars \(Using 2-in. or \[50-mm\] Cube Specimens\)](#)

[C114 Test Methods for Chemical Analysis of Hydraulic Cement](#)

[C115 Test Method for Fineness of Portland Cement by the Turbidimeter](#)

[C151/C151M Test Method for Autoclave Expansion of Hydraulic Cement](#)

[C183/C183M Practice for Sampling and the Amount of Testing of Hydraulic Cement](#)

¹ This specification is under the jurisdiction of ASTM Committee C01 on Cement and is the direct responsibility of Subcommittee C01.10 on Hydraulic Cements for General Concrete Construction.

Current edition approved April 1, 2018/April 1, 2019. Published April 2018/April 2019. Originally approved in 1940. Last previous edition approved in 2017/2018 as [C150/C150M – 17](#)/[C150/C150M – 18](#). DOI: [10.1520/C0150-C0150M-18](#)/[10.1520/C0150-C0150M-19](#).

² For referenced ASTM standards, visit the ASTM website, [www.astm.org](#), or contact ASTM Customer Service at [service@astm.org](#). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard



- C185 Test Method for Air Content of Hydraulic Cement Mortar
 C191 Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle
 C204 Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus
 C219 Terminology Relating to Hydraulic Cement
 C226 Specification for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Hydraulic Cement
 C266 Test Method for Time of Setting of Hydraulic-Cement Paste by Gillmore Needles
 C451 Test Method for Early Stiffening of Hydraulic Cement (Paste Method)
 C452 Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate
 C465 Specification for Processing Additions for Use in the Manufacture of Hydraulic Cements
 C563 Guide for Approximation of Optimum SO₃ in Hydraulic Cement
 C1038/C1038M Test Method for Expansion of Hydraulic Cement Mortar Bars Stored in Water
 C1702 Test Method for Measurement of Heat of Hydration of Hydraulic Cementitious Materials Using Isothermal Conduction Calorimetry
 C1778 Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete
 E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
 IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric System

3. Terminology

3.1 *Definitions*—See Terminology C219.

4. Ordering Information

4.1 Orders for material under this specification shall include the following:

4.1.1 This specification number and date,

4.1.2 Type or types allowable. If no type is specified,

Type I shall be supplied,

4.1.3 Any optional chemical requirements from Table 2, if desired, and

4.1.4 Any optional physical requirements from Table 4, if desired.

TABLE 1 Standard Composition Requirements

Cement Type ^A	Applicable Test Method	I and IA	II and IIA	II(MH) and II(MH)A	III and IIIA	IV	V
Aluminum oxide (Al ₂ O ₃), max, %	C114	...	6.0	6.0	...	...	...
Ferric oxide (Fe ₂ O ₃), max, %	C114	...	6.0 ^B	6.0 ^{B,C}	...	6.5	...
Magnesium oxide (MgO), max, %	C114	6.0	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO ₃) ^D , max, %	C114	...	...	...	...	...	...
When (C ₃ A) ^E is 8 % or less		3.0	3.0	3.0	3.5	2.3	2.3
When (C ₃ A) ^E is more than 8 %		3.5	^F	^F	4.5	^F	^F
Loss on ignition, max, %	C114	...	...	...	...	...	...
When limestone is not an ingredient		3.0	3.0	3.0	3.0	2.5	3.0
When limestone is an ingredient		3.5	3.5	3.5	3.5	3.5	3.5
Insoluble residue, max, %	C114	1.5	1.5	1.5	1.5	1.5	1.5
Equivalent alkalis (Na ₂ O + 0.658 KO), %	C114	^G	^G	^G	^G	^G	^G
Tricalcium silicate (C ₃ S) ^E , max, %	See Annex A1	...	...	...	...	35 ^C	...
Dicalcium silicate (C ₂ S) ^E , min, %	See Annex A1	...	...	...	...	40 ^C	...
Tricalcium aluminate (C ₃ A) ^E , max, %	See Annex A1	...	8	8	15	7 ^C	5 ^B
Sum of C ₃ S + 4.75C ₃ A ^G , max, %	See Annex A1	...	...	100 ^{C,H}	...	...	...
Sum of C ₃ S + 4.75C ₃ A ^H , max, %	See Annex A1	...	...	100 ^{C,I}	...	...	...
Tetracalcium aluminoferrite plus twice the tricalcium aluminate (C ₄ AF + 2(C ₃ A)), or solid solution (C ₄ AF + C ₂ F), as applicable, max, %	See Annex A1	...	...	...	...	...	25 ^B

^A See Note 2.

^B Does not apply when the sulfate resistance limit in Table 4 is specified.

^C Does not apply when the cement complies with the heat of hydration limit in Table 4 is specified.

^D It is permissible to exceed the values in the table for SO₃ content, provided it has been demonstrated by Test Method C1038/C1038M that the cement with the increased SO₃ will not develop expansion exceeding 0.020 % at 14 days. When the manufacturer supplies cement under this provision, supporting data shall be supplied to the purchaser. See Note 67.

^E See Annex A1 for calculation.

^F Not applicable.

^G See Report equivalent alkalis as part of the manufacturer's certification. See Note 5.

^H See Note 6.

^I In addition, three-day heat of hydration testing by Test Method C1702 shall be conducted at least once every six months. Such testing shall not be used for acceptance or rejection of the cement, but results shall be reported for informational purposes.

TABLE 2 Optional Composition Requirements^A

Cement Type	Applicable Test Method	I and IA	II and IIA	II(MH) and II(MH)A	III and IIIA	IV	V	Remarks
Tricalcium aluminate (C ₃ A) ^B , max, %	See Annex A1	...	...	...	8	...	...	for moderate sulfate resistance
Tricalcium aluminate (C ₃ A) ^B , max, %	See Annex A1	...	...	...	5	...	...	for high sulfate resistance
Equivalent alkalis (Na ₂ O + 0.658K ₂ O), max, %	C114	0.60 ^C	0.60 ^C	0.60 ^C	0.60 ^C	0.60 ^C	0.60 ^C	low-alkali cement

^A These optional requirements apply only when specifically requested. Verify availability before ordering. See Note 2.

^B See Annex A1 for calculation.

^C Specify this limit when the cement is to be used in concrete with aggregates that are potentially reactive and no other provisions have been made to protect the concrete from deleteriously reactive aggregates. Refer to Specification C33 for information on potential reactivity of aggregates.

TABLE 3 Standard Physical Requirements

Cement Type ^A	Applicable Test Method	I	IA	II	IIA	II(MH)	II(MH)A	III	IIIA	IV	V
Air content of mortar, ^B volume %:	C185										
max		12	22	12	22	12	22	12	22	12	12
min		...	16	...	16	...	16	...	16	...	...
Fineness, specific surface, m ² /kg											
Air permeability test	C204										
min		260	260	260	260	260	260	...	...	260	260
max		...	...	...	...	430 ^C	430 ^C	...	...	430	...
Autoclave expansion, max, %	C151+	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Autoclave expansion, max, %	C151/ C151M	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Strength, not less than the values shown for the ages indicated as follows: ^D											
Compressive strength, MPa [psi]:	C109/ C109M										
1 day		...	...	...	...	...	...	12.0	10.0	...	...
								[1740]	[1450]	...	...
3 days		12.0	10.0	10.0	8.0	10.0	8.0	24.0	19.0	...	8.0
		[1740]	[1450]	[1450]	[1160]	[1450]	[1160]	[3480]	[2760]	...	[1160]
						7.0 ^E	6.0 ^E				
						[1020] ^E	[870] ^E				
3 days		12.0	10.0	10.0	8.0	10.0	8.0	24.0	19.0	...	8.0
		[1740]	[1450]	[1450]	[1160]	[1450]	[1160]	[3480]	[2760]	...	[1160]
7 days		19.0	16.0	17.0	14.0	17.0	14.0	...	...	7.0	15.0
		[2760]	[2320]	[2470]	[2030]	[2470]	[2030]	...	...	[1020]	[2180]
						12.0 ^E	9.0 ^E				
						[1740] ^E	[1310] ^E				
7 days		19.0	16.0	17.0	14.0	17.0	14.0	...	...	7.0	15.0
		[2760]	[2320]	[2470]	[2030]	[2470]	[2030]	...	...	[1020]	[2180]
28 days		...	...	...	...	...	...	...	...	17.0	21.0
										[2470]	[3050]
28 days		...	...	...	...	...	...	...	...	17.0	21.0
										[2470]	[3050]
Time of setting; Vicat test: ^E	C191+										
Time of setting; Vicat test: ^E	C191										
Time of setting, minutes, not less than		45	45	45	45	45	45	45	45	45	45
Time of setting, minutes, not more than		375	375	375	375	375	375	375	375	375	375

^A See Note 2.

^B Compliance with the requirements of this specification does not necessarily ensure that the desired air content will be obtained in concrete.

^C Maximum fineness limits do not apply if the sum of C₃S + 4.75C₃A is less than or equal to 90-90, or the cement complies with the heat of hydration limit in Table 4.

^D The strength at any specified test age shall be not less than that attained at any previous specified test age.

^E When the optional heat of hydration in Table 4 is specified.

^F The time of setting is that described as initial setting time in Test Method C191.

5. Ingredients

5.1 The cement covered by this specification shall contain no ingredients except as follows:

5.1.1 Portland cement clinker.

5.1.2 Water or calcium sulfate, or both. The amounts shall be such that the limits shown in Table 1 for sulfur trioxide and loss-on-ignition are not exceeded.

TABLE 4 Optional Physical Requirements^A

Cement Type	Applicable Test Method	I and II	IA and IIA	II(MH)	II(MH)A	III	IIIA	IV	V
False set, final penetration, min, %	C451	50	50	50	50	50	50	50	50
Heat of hydration:									
Isothermal Conduction Calorimetry:									
3 days, max, kJ/kg [cal/g]	C1702	...	...	255 [60] ^B	255 [60] ^B	...	...	200 [50] ^C	...
3 days, max, kJ/kg [cal/g]	C1702	...	...	335 [80] ^B	355 [80] ^B	...	...	200 [50] ^C	...
7 days, max, kJ/kg [cal/g]		...	...	...	...	...	...	225 [55] ^C	...
Strength, not less than the values shown:									
Compressive strength, MPa [psi]	C109/C109M								
28 days		28.0 [4060]	22.0 [3190]	28.0 [4060] 22.0 ^B [3190] ^B	22.0 [3190] 18.0 ^B [2610] ^B	...	...	...	...
28 days		28.0 [4060]	22.0 [3190]	28.0 [4060]	22.0 [3190]	...	...	...	...
Sulfate resistance, ^D 14 days, max, % expansion	C452	... ^E	... ^E	... ^E	... ^E	...	...	...	0.040
Gillmore test:	C266								
Initial set, min, not less than		60	60	60	60	60	60	60	60
Final set, min, not more than		600	600	600	600	600	600	600	600
Turbidimeter test	C115								
min		150	150	150	150	...	...	150	150
max		...	...	245 ^F	245 ^F	...	...	245	...

^A These optional requirements apply only when specifically requested. Verify availability before ordering. See Note 2.

^B The limit for the sum of C₃S + 4.75C₃A in Table 1 shall not apply when this optional limit is requested. These strength requirements apply when the optional heat of hydration requirement is requested; the cement complies with this limit.

^C When the heat of hydration limit is specified, it shall be instead of the limits of C₃S, C₂S, C₃A, and Fe₂O₃ listed in Table 1; shall not apply when the cement complies with this limit.

^D When the sulfate resistance is specified, it shall be instead of the limits of C₃A, C₄AF + 2 C₃A, and Fe₂O₃ listed in Table 1.

^E Cement meeting the high sulfate resistance limit for Type V is deemed to meet the moderate sulfate resistance requirement of Type II and Type II(MH).

^F Maximum fineness limits do not apply if the sum of C₃S + 4.75 C₃A is less than or equal to 90.

5.1.3 Limestone. The amount shall not be more than 5.0 % by mass such that the chemical and physical requirements of this standard are met (see Note 3). The limestone, defined in Terminology C51, shall be naturally occurring and consist of at least 70 % by mass of one or more of the mineral forms of calcium carbonate. If limestone is used, the manufacturer shall report the amount used, expressed as a percentage of cement mass, as determined using Annex A2, along with the oxide composition of the limestone.

NOTE 3—This standard permits portland cement to contain limestone, but does not require that limestone be an ingredient in the cement. Cement without ground limestone can be specified in the contract or order.

5.1.4 Inorganic processing additions. The amount shall be not more than 5.0 % by mass of cement. Not more than one inorganic processing addition shall be used at a time. For amounts greater than 1.0 %, they shall have been shown to meet the requirements of Specification C465 for the inorganic processing addition in the amount used or greater. If an inorganic processing addition is used, the manufacturer shall report the amount used, expressed as a percentage of cement mass, along with the oxide composition of the processing addition. See Note 4.

NOTE 4—These requirements are based on data and recommendations by Taylor.³

5.1.5 Organic Processing additions. They shall have been shown to meet the requirements of Specification C465 in the amounts used or greater and the total amount of organic processing additions used shall not exceed 1.0 % by mass of cement.

5.1.6 Air-entraining addition (for air-entraining portland cement only). The interground addition shall conform to the requirements of Specification C226.

6. Chemical Composition

6.1 Portland cement of each of the ten types shown in Section 1 shall conform to the respective standard chemical requirements prescribed in Table 1. In addition, optional chemical requirements are shown in Table 2.

NOTE 5—The standard composition requirements in Table 1 require reporting of equivalent alkalis. Cements with a maximum of 0.60 % equivalent alkalis were historically designated as “low-alkali cements” and recommended for use with aggregates susceptible to alkali-silica reaction (ASR). However, low-alkali cements (in the absence of other mitigation measures) may not be effective in mitigating ASR. Guidance on formulating concrete mixtures, including calculating alkali loading using equivalent alkali content of cement to minimize the potential for ASR, is provided in Guide C1778.

NOTE 6—The limit on the sum, C₃S + 4.75C₃A, in Table 1 provides control on the heat of hydration of the cement and is consistent with a Test Method C1702 three-day heat of hydration limit of 315 kJ/kg [75 cal/g].

NOTE 7—There are cases where performance of a cement is improved with SO₃ in excess of the Table 1 limits in this specification. Guide C563 is one of several methods a manufacturer can use to evaluate the effect of sulfate content on cement characteristics. Whenever SO₃ content of a cement

³ Taylor, P., “Specifications and Protocols for Acceptance Tests on Processing Additions in Cement Manufacturing,” NCHRP Report 607, Transportation Research 3 Board, Washington, DC 20008, 96 pp. Available at www.trb.org.



exceeds [Table 1](#) limits, Test Method ~~C4038~~[C1038/C1038M](#) results provide evidence that excessive expansion does not occur at this higher sulfate content.

7. Physical Properties

7.1 Portland cement of each of the ten types shown in [Section 1](#) shall conform to the respective standard physical requirements prescribed in [Table 3](#). In addition, optional physical requirements are shown in [Table 4](#).

8. Sampling

8.1 When the purchaser desires that the cement be sampled and tested to verify compliance with this specification, perform sampling and testing in accordance with Practice ~~C483~~[C183/C183M](#).

8.2 Practice ~~C483~~[C183/C183M](#) is not designed for manufacturing quality control and is not required for manufacturer's certification.

9. Test Methods

9.1 Determine the applicable properties enumerated in this specification in accordance with the following test methods:

9.1.1 *Chemical Analysis*—Test Methods [C114](#).

9.1.2 *Air Content of Mortar*—Test Method [C185](#).

9.1.3 *Fineness by Air Permeability*—Test Method [C204](#).

9.1.4 *Autoclave Expansion*—Test Method ~~C454~~[C151/C151M](#).

9.1.5 *Strength*—Test Method [C109/C109M](#).

9.1.6 *Time of Setting by Vicat Needles*—Test Method [C191](#).

9.1.7 *False Set*—Test Method [C451](#).

9.1.8 *Heat of Hydration*—Test Method [C1702](#).

9.1.9 *Sulfate Resistance*—Test Method [C452](#) (sulfate expansion).

9.1.10 *Time of Setting by Gillmore Needles*—Test Method [C266](#).

9.1.11 *Fineness by Turbidimeter*—Test Method [C115](#).

9.1.11 *Calcium Sulfate (Expansion of) Mortar*—Test Method ~~C4038~~[C1038/C1038M](#).

10. Inspection

10.1 Inspection of the material shall be made as agreed upon between the purchaser and the seller as part of the purchase contract.

11. Rejection

11.1 The cement shall be rejected if it fails to meet any of the requirements of this specification.

11.2 At the option of the purchaser, retest, before using, cement remaining in bulk storage for more than six months or cement in bags in local storage in the custody of a vendor for more than three months after completion of tests and reject the cement if it fails to conform to any of the requirements of this specification. Cement so rejected shall be the responsibility of the owner of record at the time of resampling for retest.

11.3 Packages shall identify the mass contained as net weight. At the option of the purchaser, packages more than 2 % below the mass marked thereon shall be rejected and if the average mass of packages in any shipment, as shown by determining the mass of 50 packages selected at random, is less than that marked on the packages, the entire shipment shall be rejected.

12. Manufacturer's Statement

12.1 At the request of the purchaser, the manufacturer shall state in writing the nature, amount, and identity of any air-entraining addition and of any processing addition used, and also, if requested, shall supply test data showing compliance of such air-entraining addition with Specification [C226](#) and of such processing addition with Specification [C465](#).

12.2 When limestone is used, the manufacturer shall state in writing the amount thereof and, if requested by the purchaser, shall supply comparative test data on chemical and physical properties of the cement with and without the limestone (see [Note 78](#)). The comparative tests do not supersede the normal testing to confirm that the cement meets chemical and physical requirements of this standard. The amount of limestone in cement shall be determined in accordance with [Annex A2](#).

NOTE 8—Comparative test data may be from qualification tests performed by the manufacturer during formulation of the cement with limestone.

12.3 At the request of the purchaser, the manufacturer shall report the chloride content as determined using Test Methods [C114](#), in percent by mass of the cement, in the manufacturer's report (see [Note 89](#)).

NOTE 9—Chlorides in concrete come from multiple ingredients and cement chloride content may be required to estimate concrete chloride content. Requirements for concrete chloride content are provided in building codes and other documents.



13. Packaging and Package Marking

13.1 When the cement is delivered in packages, the words “Portland Cement,” the type of cement, the name and brand of the manufacturer, and the mass of the cement contained therein shall be plainly marked on each package. When the cement is an air-entraining type, the words “air-entraining” shall be plainly marked on each package. Similar information shall be provided in the shipping documents accompanying the shipment of packaged or bulk cement. All packages shall be in good condition at the time of inspection.

NOTE 10—With the change to SI units, it is desirable to establish a standard SI package for portland cements. To that end 42 kg [92.6 lb] provides a convenient, even-numbered mass reasonably similar to the traditional 94-lb [42.6-kg] package.

14. Storage

14.1 The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building that will protect the cement from dampness and minimize warehouse set.

15. Manufacturer’s Certification

15.1 Upon request of the purchaser in the contract or order, a manufacturer’s report shall be furnished at the time of shipment stating the results of tests made on samples of the material taken during production or transfer and certifying that the cement conforms to applicable requirements of this specification.

NOTE 11—Guidance on preparing the manufacturer’s report is provided in [Appendix X1](#).

16. Keywords

16.1 hydraulic cement; portland cement; specification

iTeh Standards

ANNEXES

(<https://standards.itih.ai>)

(Mandatory Information)

A1. CALCULATION OF POTENTIAL CEMENT PHASE COMPOSITION

A1.1 All values calculated as described in this annex shall be rounded according to Practice [E29](#). When evaluating conformance to a specification, round values to the same number of places as the corresponding table entry before making comparisons. The expressing of chemical limitations by means of calculated assumed phases does not necessarily mean that the oxides are actually or entirely present as such phases.

A1.2 When expressing phases, C = CaO, S = SiO₂, A = Al₂O₃, F = Fe₂O₃. For example, C₃A = 3CaO·Al₂O₃. Titanium dioxide and phosphorus pentoxide (TiO₂ and P₂O₅) shall not be included with the Al₂O₃ content. See [Note A1.1](#).

NOTE A1.1—When comparing oxide analyses and calculated phases from different sources or from different historic times, be aware that they may not have been reported on exactly the same basis. Chemical data obtained by Reference and Alternate Test Methods of Test Methods [C114](#) (wet chemistry) may include titania and phosphorus as alumina unless proper correction has been made (see Test Methods [C114](#)), while data obtained by rapid instrumental methods usually do not. This can result in small differences in the calculated phases. Such differences are usually within the precision of the analytical methods, even when the methods are properly qualified under the requirements of Test Methods [C114](#).

A1.3 When the ratio of percentages of aluminum oxide to ferric oxide is 0.64 or more, the percentages of tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite shall be calculated from the chemical analysis as follows:

$$\begin{aligned} \text{Tricalcium silicate (C}_3\text{S)} &= (4.071 \times \% \text{ CaO}) - (7.600 \times \% \text{ SiO}_2) \\ &\quad - (6.718 \times \% \text{ Al}_2\text{O}_3) - (1.430 \times \% \text{ Fe}_2\text{O}_3) - (2.852 \times \% \text{ SO}_3) \end{aligned} \tag{A1.1}$$

$$\text{Dicalcium silicate (C}_2\text{S)} = (2.867 \times \% \text{ SiO}_2) - (0.7544 \times \% \text{ C}_3\text{S}) \tag{A1.2}$$

$$\text{Tricalcium aluminate (C}_3\text{A)} = (2.650 \times \% \text{ Al}_2\text{O}_3) - (1.692 \times \% \text{ Fe}_2\text{O}_3) \tag{A1.3}$$

$$\text{Tetracalcium aluminoferrite (C}_4\text{AF)} = 3.043 \times \% \text{ Fe}_2\text{O}_3 \tag{A1.4}$$