Towards Reviving Lime-Based Mortar Utilisation as a Sustainable Building Material: An Imperative for Review of the Existing Building Standards

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Abstract— Prior to the beginning of this century, lime-based mortar dominance as a building material was incontrovertible as reminiscence of this is reflected in many buildings of historic references which stand till date. This is premised on lime's durability features predominantly attributed to its flexibility, plasticity, breathability, autogenous healing property, relatively low carbon dioxide emissions (during its manufacture) and its carbon dioxide adsorption (in the course of its carbonation), among others. However, urbanisation, changes in construction technology and overwhelming acceptability of cement in the twentieth century due to its (cement) faster setting, higher mechanical strength, compositional constancy, etc., put lime usage into decline and the traditional craftsman experience was almost lost, especially in developed countries. Nonetheless, cement is related with large CO_2 emissions (approximately 5-8% per tonne) with its attendant climate change induced negative impacts. Thus, the imperative to protect the environment and conserve energy resources necessitate the need for evaluation and thus, revival of more sustainable alternative building materials like lime. This paper, through a review-based approach therefore examines fundamental properties and historical relevance of lime with an emphasis on lime-based mortars. As a point of departure, the paper focuses on Natural Hydraulic Lime type and identifies the need to review relevant existing building standards with a view to making case for lime's revitalisation and re-acceptability as a sustainable building material for environmental protection, and overall wellbeing.

Index Terms— Building Lime, Building Standards, Built Environment, CO_2 emissions, Energy, Masonry, Mortar, Sustainable.

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1 Introduction

RESEARCH on alternative cementitious materials is strongly focused in responding to the current climate change related ecological–economical challenges for which the Portland cement (PC) industry has an important share of the responsibility [1], [2]. Consequently, environmental awareness and actions need to be taken to develop and use alternative binders in new eco-friendly and preferably low cost construction materials. As construction processes are required to develop infrastructures, they equally constitute major sources of carbon dioxide production and energy consumption [3]. As a matter of facts, building activities are responsible for a large amount of harmful emissions(about 30% of greenhouse gases due to their operation, and an additional 18% indirectly associated with material exploitation and transportation [4], [5], [6, [7]. Portland cement (PC) is unquestionably the primary cementitious material used in construction nowadays and its vast production occasionally results in environmental problems in terms of energy consumption as well as pollution emission. Its CO_2-emission coefficient from a Life Cycle Assessment is commonly evaluated to be 0.8–1.0 ton-CO_2/ton as its production was responsible for 2.83 billion tonnes of CO_2 emissions (i.e. roughly 2.3% of the total emissions) worldwide in 2008 alone [8], [9]. Thus, rising concerns emanating from potential climate change adversities from materials, growing energy costs and continuous impacts of human activities on the environment, necessitate compelling needs for environmental consideration as a factor in building design and material selection. Thus, global reduction policies on the pressure exerted by the building sector on the environment are leading towards construction of eco-compatible buildings. These result in structures characterized by low environmental impact with assured health safety to inhabitants [10]. This effort is particularly evident in exploring alternative methods and the search for new technical standards, capable of providing criteria in terms of energy consumption and environmental performances of buildings [11], [12]. One such approach is renewal of interests in a partially abandoned age-long environmentally sustainable building material, lime.

Lime, Calcium Oxide (CaO) refers to a caustic alkaline material which is a product of calcining (i.e. burning/heating) calcium-based rocks (hard-rock carboniferous limestone and chalks) of variable purity, as well as seashells and corals [13], [14], [15], [16], [17]. Thus, building lime (lime hydrate or calcium hydroxide – Ca(OH)2) encompasses a group of lime products used as materials for building construction and civil engineering works. It is one of the oldest building materials and has a variety of applications ranging from lime mortar, lime wash, lime rendering, to hemp-crete production, among others. The properties of limes from various sources are sometimes modified with addition of admixtures for specific desirable effects [18], [19], [20].

Prior to the beginning of this century, lime dominance as a building material particularly, lime-based mortars, was incontrovertible. Reminiscence of this is reflected in many buildings of historic references which stand till date. This is premised on lime's long term performance features predominantly attributed to its flexibility, plasticity, breathability, Autogenous healing property, relatively low carbon dioxide emissions

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(during its manufacture) and adsorption (in the course of its carbonation), among others [21], [22], [23]. Despite these sterling qualities, introduction of PC in the late 19th century put lime use into decline consequent upon characteristic lime mortars' shortcomings. These include low mechanical strength, poor internal cohesion and some exhibited volumetric changes [24], [25], [26], [27], [28], [29]. In view of the identified lime shortcomings, significant roles of lime's inherent properties to its performance and durability as exhibited in many buildings of historical reference appear to have been relegated to the background. By the latter half of the 20th century, lime mortars had become rarely used and poorly understood in construction [30], [31]. The tradition and techniques associated with lime mortars were almost entirely lost in many western countries after the industrial revolution. This has contributed to diminution of its production and a gradual disappearance of the traditional skills required. Thus, despite the disadvantages of the use of cement based mortars in restoration and modern architecture (where natural stone is used), new uses of lime mortars were not always successful because they were handled in the same way as PC mixtures. In ancient times (until 19th century), lime was mixed with many different additives to improve and modify its properties (such as the setting time, adhesion, impermeability, and hardness). These mixtures have been totally lost in the modern ''rediscovery'' of lime mortars due to a lack of rigorous studies on the properties of lime-based mortars [32], [33], [34]. This paper therefore seeks to promote low carbon sustainable building lime by reviewing its relevant fundamental features, historical acceptability and subsequent decline in usage, with a view to making case for its revival. This in effect, would facilitate overall lime revival and re-acceptability, minimise carbon emissions and ultimately, protect natural environment from construction standpoint.

2 Methodology

This submission adopts a literature review approach which includes historical background of building lime, important features of lime that facilitated its historical pre-eminence as an acceptable sustainable material, and more importantly, the rationale behind its (lime) relegation and subsequent decline in usage, with a view to making case for its revival.

3 Historical Background of Building Lime

Mortar is one of the constituents of the composite anisotropic material denominated 'masonry' [10]. Fundamentally, masonry mortar refers to a mixture of binder(s) (such as Portland cement, lime, etc.) and aggregates (sand) with sufficient water, which presents hardening capacity and adherence (on the masonry units) [10], [45], [46]. Used in a plastic state, mortar can be utilised for bedding and bonding of masonry units, distribution of loads, absorption of deformations, sealing of joints and rendering of masonry surfaces (plaster and render) [18], [45], [47], [48], [49]. Although mortar accounts for as little as 7% of the total volume of masonry, it influences performance far more than this proportion [50], [51], [52]. Bond strength and deformability of the masonry are clearly influenced by the mortar, the material at the bed joints. Historical evidence has also shown use of mortars to meet several other needs such as isolating lining materials (in cisterns, wells, aqueducts, shafts and duct drains) and as supporting materials for pavements, mosaics and frescoes [40], [53], [54].lime. Documented use of lime as a binder dates back to the 6th millennium BC as their earliest use could be traced to Palestine and Turkey. A terrazzo floor excavated in Canjenü in Eastern Turkey laid with a lime mortar has been dated between 12 000 and 5000 BC. A lime mortar used for flooring fishermen's huts excavated at Livinski Vir in Serbia–Montenegro is also dated at about 5600 BC [36]. It has also been shown that lime was used as a building material within the Epipaleolithic period, some 10,300 years ago (8300 BC) and numerous examples of ancient structures built in lime post-dated this period as evident throughout Israel, Egypt, Turkey and Italy. The early Egyptians, Greeks and Romans adopted lime as a primary building material, the empirical knowledge of which was passed on from generation to generation through these civilisations [37], [38], [39], [40]. Limes were used in form of lime mortars that were made from non-hydraulic (fat) lime. The Greeks and Romans also produced hydraulic limes which set by a chemical reaction with water. By the 18th century, non-hydraulic lime had been replaced by hydraulic lime, due to the latter's improved features. Although mud and gypsum were used in Europe during certain time periods and in certain regions, the majority of ancient mortars in Europe were also lime-based. Its conceptual usage in buildings was brought to Britain in the first century AD by the Romans, who used it to produce lime mortar [36], [41], [42].

With their strong observational and philosophical influences derived from the Grecian Empire, Romans were the first of these civilisations to attempt to document observations regarding the physical and chemical properties of lime. They experimented with lime mortars, concretes and pozzolans as reflected in Vitruvius's 'Ten Books on Architecture' in which lime was categorically listed as one of the suitable building materials. The Romans (299 BC to 476 AD) also discovered that as a consequence of mixing burnt lime with Pozzolana, a cementing material with hydraulic properties was produced. This material was used to build many famous Roman structures such as the Appian Way, the Basilica of Maxentius, Pantheon in Rome, the Coliseum, the Roman Baths of Caracalla and the Pont du Gard aqueduct in southern France [35], [39], [43].

However, after the fall of the Roman Empire, scientific documentation and experimentation of lime stopped and did not resurge for almost 1000 years until the beginning of the early Medieval period, about 500-1000AD. Consequently the period after the fall of the Roman Empire was associated with a regression in the understanding of mortar technology. The early medieval period saw the continuance of the use of traditional construction techniques and materials, and more specifically, the use of lime mortars. This was largely demonstrated by the Norman Builders who obviously understood the applications of lime mortars, to which their cathedrals (like Durham Cathedral) stand a testimony. It is interesting to note that structures such as this have lasted for approximately 1000 turbulent years. Unfortunately no real documented evidences were made or survived from this period, despite its extensive usage [35]. The 18th century saw a rise in interest in the subject of durable natural and artificial cements. This is premised on research undertaken by a number of engineers and scientists of the day such as Semple (1758) and John Smeaton, a British engineer (1797). Prior to this, it was traditionally believed that the most suitable and durable lime mortars were those produced from hard limestone, and in contrast, soft stones, such as chalk, would only produce soft mortars. This confusion about durable hydraulic mortars prevailed until Smeaton undertook his research in 1757 for the construction of the Eddystone Lighthouse (off the coast of Cornwall, England). Clays and chalks were calcined individually, and subsequently blended together to create artificial cement. He observed that the combination of the silicates, aluminates and calcium oxide, led to the formation of a material which was extremely strong in hydraulic capacity. Louis Vicat, 1812, one of the most significant post-Smeaton researchers, prepared artificial hydraulic lime by calcining synthetic mixtures of limestone and clay, as James Frost of England (1822) also prepared artificial hydraulic lime, similar to Vicat's and tagged it "British Cement". Their pioneering works on artificial hydraulic lime and more specifically, the development of the Hydraulic Index, may be considered the true forerunner to Joseph Aspdin (a bricklayer from Leeds), the man associated with the discovery of Ordinary Portland cement (OPC) in 1824. In this period, addition of Portland cement to lime mortars increased the speed of the construction process for masonry building. This was due to faster strength development as mix designs incorporating different amounts of lime and Portland cement were developed [35], [39], [44].

4 LIME BASED MORTAR: WHY DOES IT MATTER AS A SUSTAINABLE BUILDING MATERIAL?

Mortar is one of the constituents of the composite anisotropic material denominated 'masonry'. Fundamentally, masonry mortar refers to a mixture of binder(s) (such as Portland cement, lime, etc.) and aggregates (sand) with sufficient water, which presents hardening capacity and adherence (on the masonry units) [10], [45], [46]. Used in a plastic state, mortar can be utilised for bedding and bonding of masonry units, distribution of loads, absorption of deformations, sealing of joints and rendering of masonry surfaces (plaster and render) [18], [45], [47], [48], [49]. Although mortar accounts for as little as 7% of the total volume of masonry, it influences performance far more than this proportion [50], [51], [52]. Bond strength and deformability of the masonry are clearly influenced by the mortar, the material at the bed joints. Historical evidence has also shown use of mortars to meet several other needs such as isolating lining materials (in cisterns, wells, aqueducts, shafts and duct drains) and as supporting materials for pavements, mosaics and frescoes [40], [53], [54].

Thus, Lime mortar specifically is made by skilfully mixing lime with clean, well-graded masonry sand or other form of aggregates, and sufficient water (to produce a plastic, workable mixture), the ratios of which are determined by the final application. In addition may be inclusion of specific additives (such as pozzolana, crushed brick, air entraining agents, polymer, etc.), hair or other form(s) of reinforcement, pigments, etc., for impacting more specific characteristic features. This is to improve mortars' performance towards better adhesion, workability or compatibility [55], [56], [57], [58], [59]. While the manufacture of limes consumes less energy and produces less greenhouse gases (compared with Portland cement), its exposure to the atmosphere as lime based mortars absorb most or all of the carbon dioxide that was driven off during its calcination, a phenomenon called re-carbonation. With growing emphasis on the need for reduced energy consumption and minimised atmospheric CO_2 concentration, continued use of lime mortar in building has significant environmental benefits. In addition, masonry laid using lime based mortar has lower bond strength (than cement) that the units can be prised off easily thereafter, thereby facilitating recycling of the materials, a major feature of sustainability. Besides, building structures finished with lime mortars are usually characterised with low thermal conductivity as this affects the interior surface temperatures of buildings, and may therefore perform better as an insulating material [38], [60].

Lime mortar exhibits phenomenal 'breathability' through which moisture and vapour transfer from the external environment are freely dissipated via its permeable material, in view of its capillary porosity. As a result, they also weather through the dissolution of their carbonated lime binders and the crystallization of soluble salts within their pores. These materials act sacrificially and deteriorate in preference to the substrate, which increases the longevity of the structure. It also enhances the performance of the materials and structure holistically [38], [39], [46] [49]. In particular, Lime mortar possesses excellent permeability feature via its relatively large interconnected pore structures. These pore structures allow ice crystal growth in frost periods, thereby accommodating the crystals within the pore structures without causing deterioration of the matrix [39], [61]. This feature enhances durability of lime mortars in a building fabric against environmental conditions. A very common cause of deterioration is the formation of ice inside the porous system of mortars during freezing. This phenomenon is of great importance in countries where near-zero temperatures conditions are frequent. When water changes from a liquid to a solid state, its volume increases by 9%, applying pressure of around 500 kg/cm^2 [60], [62], [63].

Lime binder has the flexibility to cushion masonry joints to absorb strains, prevent cracking and result in medium to high flexural bond strengths [46]. The modulus of rupture and the bond strength of an appropriate, well cured mature lime mortar are such that movement joints are not normally required in new (traditional) construction and any movement experienced (i.e. structural, seasonal and thermal) is taken up by minute adjustment over many joints due to their 'plastic' and 'self-healing' properties. Cracks may provide a route by which carbon dioxide diffuses into the mortar, reacts within the fracture and restores strength. If the mortar is fully carbonated, dissolution and re-precipitation of calcium carbonate by the movement of moisture through the structure may also contribute to strength. These mechanisms are commonly associated with lime mortar Autogenous healing property [17], [23], [51]. Elastic modulus also relates to mortar stiffness and the ability to deform or strain on stress application. This is often more important than the ultimate strength (at peak load) as it is desirable for mortars to exhibit an ability to deform under stress without cracking [64]. Lime mortar, by virtue of its reasonably high flexibility exhibits low elastic modulus, thereby displaying capability to deform more on load application relative to Portland cement.

Water retention and air contents are essential properties of a mortar. Water retention allows the paste to remain workable and retain water for proper curing and bonding. A mortar with high water retention maintains flow (workability) enhancing contact with masonry units. An increase in water retention results in increased bond strength [64]. Lime mortars have superior water retention as values from 94.2 to 99.5% have been consistently measured against those of 60-80% of PC equivalents. High water retention enhances workability which improves contact between mortar and substrate, thereby increasing bond. On the other hand, high air contents undermine bond and compressive strength of mortars. As a result, ASTM standards [65] restrict air content to a maximum of 12-14%. Bond strength decreased from 0.3 to 0.1 N/mm^2 as the entrained air rose from 2 to 18% [46], [64]. Bond strength between the mortar and the masonry unit is significant because it ensures the structural integrity of masonry (adequate resistance to compressive and tensile loading) and seals against weathering agents. The strength of the bond is largely determined by air content, water retention and the moisture transfer between the mortar and the unit. High water retention enhances workability which improves contact between mortar and substrate, thereby increasing the bond. Hanley and Pavía [46] showed that the bond strength of hydraulic lime mortar masonry increases proportionally with the mortar's water retention.

In general, lime possesses a vast array of beneficial properties including good adhesion, ductility, reasonably high values of porosity [66], [67] and shows greater water vapour permeability than PC, enabling them to reduce moisture entrapment [39], [63]. A lime binder will enable good adhesion between surfaces and effective penetration into voids. It will cushion masonry joints to absorb strains and prevent cracking and will be the primary route of passage of moisture, making a structure permeable and protecting the masonry units from the harmful effect of salts and moisture. Thus, acting sacrificially to protect the overall structure [61].

5 Decline in the Use of Lime: A review of the underlying Factors

Despite distinguishing features of lime particularly, lime-based mortars as highlighted in the previous section, lime is connected with exaggeratedly long setting and hardening periods, low internal cohesion, volumetric changes (i.e. shrinkage, particularly, aerial lime), relatively low mechanical strengths and a high water absorption capacity through capillarity. These have substantially impacted negatively on project delivery periods and significantly resulted in its relegation and relative disuse [57], [68], [69], [70]. Of great importance also are the existing relevant building standards as the following British and American Standards present some of the specifications related to masonry mortars in general: Eurocode 6 [71]; Published Document (PD 6697:2010) [72]; Published Document (PD 6678:2005b) [73]; BS EN 5628 (BSI, 2005c) [74]; BS EN 5628 (BSI, 2005d) [75]; BS EN 4551 (BSI, 2005e) [76]; ASTM C110 (ASTM, 2016) [77]; ASTM C206 (ASTM, 2014) [78]; ASTM C207 (ASTM, 2011) [79]; and ASTM C780 (ASTM, 2016) [80].

Additionally, and in particular, BS EN 459-1 [81] and BS EN 459-2 [82] cover matters related to the use of all building limes in construction industry. While the former dwells on limes' definitions, specifications and conformity criteria, the latter indicates useful test methods relevant to limes' assessments. BS EN 459-1 [81] identifies two major types of lime as 'Air Lime' and 'Lime with hydraulic properties'. This review is particularly focused on 'limes with hydraulic properties', and the review shall be limited to this specific subject area.

Based on the constituent raw materials and the presence or absence of additions, the Standard defines three classes of 'limes with hydraulic properties' as Natural Hydraulic Limes (NHL), Formulated Limes (FL) and Hydraulic Limes (HL). Of these classes, this review is based on NHL. NHLs are identified and sub-divided into further three categories according to the compressive strength developments after 28 days curing, as well as the extent of $Ca(OH)_2$ contents as follows: NHL2, NHL3.5 and NHL5. The number in each case denotes compressive strength (in MPa) at 28 days as these limes are traditionally classified as feebly, moderately and eminently hydraulic respectively. In general, the Standard covers physical requirements such as particle size, free water content, soundness, mortar penetration tests, air content, setting times etc., as illustrated in Annex ZA (Table ZA.1) of BS EN 459-1 [81], reproduced as shown in Appendix A (Table A.2.1).

However, the Standard is silent on other requirements such as permeability, Modulus of Elasticity and more importantly flexibility. Vapour permeability is a key consideration for masonry applications. Walls that cannot "breath" trap moisture that cause problems with mould on interior finishes or freeze-thaw damage to the masonry. Even in composites, studies have shown that the vapour permeability of mortar increases with increasing lime content [83], [84]. Also, since lime mortars are slow-hardening, they remain elastic or flexible, with low moduli of elasticity. Thus, lime enhances the ability of the assemblage to accommodate stresses caused by building movements and cyclical changes without excessive cracking. Tall industrial masonry chimneys are known to sway significantly during periods of high wind and builders of these structures typically use mortars with high lime content [84], [85].

These unrecognised requirements (permeability, flexibility, etc.) largely describe the features of lime upon which its performance is based. However, the information provided on the procedure for AVCP of Building limes (i.e. Assessment and Verification of the Constancy of Performance of construction products) as reflected in Annex ZA (Table ZA.2 and Table ZA.3) of BS EN 459-1 [81] reproduced as shown in Appendix A (Table A.2.2 and Table A.2.3), is considered inadequate. It should be noted that all historic buildings have unique requirements and operate upon construction principles that may be considered radically different from modern construction. High strength is not generally an essential design parameter for historic buildings as most historic mortars may have low strength requirements but will require greater permeability and flexibility to attain an appropriate structure enabling higher overall levels of their characteristic long term performance. This is also applicable to new buildings, particularly in earthquake zones where flexibility and self-healing are important. Hence, the fixation upon lime's strength within modern construction must be re-examined [39]. Additionally, lime attains superior permeability to Portland cement via its relatively large interconnected pore structure. These pore systems allow ice crystal growth in frost periods, thereby accommodating the crystals within the pore structure without causing deterioration of the matrix. This enhances lime performance and sustainability (relative to Portland cement), essential features for its excellent performance in historic buildings.

Despite evident long term performance of building limes as reflected in the existing old traditional buildings [10], [86], [87], current assessment parameters in Table A.2.1 (Appendix A) are limited to Air content, setting times, etc., and particularly, compressive strength. This is incomparable to BS EN 196-1 [88] for cement, which truly reflects inherent property of cement (high compression strength). On the other hand, BS EN 459-2 [82] also covers lime physical tests inclusive of particle size, bulk density, soundness, setting times, reactivity, standard mortar by mass and water demand (for values of flow and penetration), water retention, determination of air content and compressive strength. However, specific requirements for assessment of lime characteristic feature of permeability and flexibility is missing. Thus, the current lime assessments in the existing building standards, [81], [82] place too much emphasis on compressive strength thereby relegating the inherent properties of lime to the background. This lack of specific standardisation and consequently, inadequate knowledge of the material's assessment properties, could partly be responsible for reluctance in limes' revival.

5 Conclusion

In view of the pandemic climate change induced carbon emissions related challenges experienced in the built environment [89], this paper has reviewed the outstanding features of lime particularly, its historical pre-eminence as an acceptable sustainable building material. With reference to lime-based mortars, the paper reveals the rationale behind lime's relegation and subsequent decline in its usage. Examining lime assessment parameters in the existing building standards [81], [82], what constitutes long term performance aspect of lime is considered missing. As such, there is the need for relevant assessment parameters which equally reflect inherent property of lime that underscores its long term performance features (comparable to BS EN 196-1 [88]), which provides for cement. The paper therefore concludes by making case for lime's revitalisation, and its overall re-acceptability, with a view to reducing carbon dioxide emissions, for overall protection of the environment and conservation of energy resources.

6 Appendix A - Physical requirements of building lime

Table A.2.1 — Relevant clauses for Building lime, and for construction and manufacture of construction products

Product:	22 different building lime products (see Tables 1, 8, 15, 19 and 23)		
Intended use:	Preparation of binder for mortar (for masonry, rendering and plastering) and production of other construction products (e.g. calcium silicate bricks, aerated autoclaved concrete, concrete, etc.), and for civil engineering applications (soil treatment, asphalt mixtures, etc.).		
Essential Characteristics *[2]*	Clauses[a] in this and other European Standard(s)	Regulatory classes *[4]*	Notes *[5]*
Compressive strength	5.3.3.1, Table 17 5.4.4.1, Table 21 5.5.3.1, Table 25	-	for NHL, FL and HL Compressive strength requirements expressed in terms of strength classes and limits[b]
Setting time	5.3.3.2, Table 18 5.4.4.2, Table 22 5.5.3.2, Table 26	-	for NHL, FL and HL Requirements expressed in terms of limits[b]

Air content	5.3.3.2, Table 18 5.4.4.2, Table 22 5.5.3.2, Table 26	-	for NHL, FL and HL Requirements expressed in terms of upper limits[b]
Content of constituents for: - CaO + MgO - MgO - CO_2 - SO_3	4.4.2, Table 2 4.5.2, Table 9	-	only for air lime (CL and DL) Requirements expressed in terms of classes and limits[b]
- SO_3	5.3.2, Table 16 5.4.3, Table 20 5.5.2, Table 24	-	for NHL, FL and HL Requirements expressed in terms of classes and limits[b]
Product:	22 different building lime products (see Tables 1, 8, 15, 19 and 23)		
Intended use:	Preparation of binder for mortar (for masonry, rendering and plastering) and production of other construction products (e.g. calcium silicate bricks, aerated autoclaved concrete, concrete, etc.), and for civil engineering applications (soil treatment, asphalt mixtures, etc.).		
Essential Characteristics *[2]*	Clauses[a] in this and other European Standard(s)	Regulatory classes *[4]*	Notes *[5]*
Product:	22 different building lime products (see Tables 1, 8, 15, 19 and 23)		
Intended use:	Preparation of binder for mortar (for masonry, rendering and plastering) and production of other construction products (e.g. calcium silicate bricks, aerated autoclaved concrete, concrete, etc.), and for civil engineering applications (soil treatment, asphalt mixtures, etc.).		
Available lime	4.4.2, Table 2 5.3.2, Table 16 5.4.3, Table 20 5.5.2, Table 24	-	for CL, NHL, FL and HL Requirements expressed in terms of lower limits[b]
Reactivity	4.4.3, Table 4 4.5.3, Table 11	-	only for quicklime Requirements expressed in terms of upper limits[b]
Soundness	4.4.3, Table 3 4.4.4, Table 6 4.5.3, Table 10 4.5.4, Table 13 5.3.3.2, Table 18 5.4.4.2, Table 22 5.5.3.2, Table 26	-	all types of building lime Requirements expressed in terms of limits[b]
Particle size	4.4.4, Table 6 4.5.4, Table 13 5.3.3.2, Table 18 5.4.4.2, Table 22 5.5.3.2, Table 26	-	all types of hydrated lime and NHL, FL and HL Requirements expressed in terms of upper limits[b]
Particle size distribution	4.4.3, Table°5 4.5.3, Table°12	-	only for quicklime Requirements expressed in terms of limits[b]
Penetration	5.3.3.2, Table 18 5.4.4.2, Table 22 5.5.3.2, Table 26	-	all types of hydrated lime and NHL, FL and HL Requirements expressed in terms of limits[b]
Durability	4.4.6, 4.5.6, 5.5.5	-	-
a These requirements are an integral part of this harmonized European Standard for building lime. b These limits are included in the definition of the products covered by this building lime standard.			

Note: All the referenced 'Tables' as so indicated are as contained in the standard, BS EN 459-1 [83]
(Source: Table ZA.1 of Annex ZA, BS EN 459-1 [83], p41)

Table A.2.2 — System of AVCP

Product(s)	Intended use(s)	Level(s) or class(es) of performance	AVCP system
Building lime, including: — Calcium lime — Dolomitic lime — lime with hydraulic properties	Preparation of concrete, mortar, grout and other mixes for construction and for the manufacture of construction products	-	2+
System 2+: See Regulation (EU) No. 305/2011 (CPR) Annex V, 1.3 including certification of the factory production control by a notified production control certification body on the basis of initial inspection of the manufacturing plant and of factory production control as well as of continuous surveillance, assessment and evaluation of factory production control.			

(Source: Table ZA.2 of Annex ZA, BS EN 459-1 [83], p43)

Table A.2.3 — Assignment of AVCP tasks for Building limes

Tasks		Content of the task	AVCP clauses to apply
Tasks for the manufacturer	Factory production control (FPC)	Parameters related to essential characteristics of Table 4.1 relevant for the intended use which are declared	EN 459–3:2015, 4.1 to 4.3, and EN 459–1:2015, 4.4.7 (calcium lime), 4.5.7 (dolomitic lime), 5.6 (natural hydraulic lime, formulated lime and hydraulic lime)
	determination of the product-type on the basis of type testing (including sampling), type calculation, tabulated values or descriptive documentation of the product	Parameters related to essential characteristics of Table 4.1 relevant for the intended use which are declared	EN 459–3:2015, 4.4, and EN 459–1:2015, 4.4.7 (calcium lime), 4.5.7 (dolomitic lime), 5.6 (natural hydraulic lime, formulated lime and hydraulic lime)
	Further testing of samples taken at factory according to the prescribed test plan	Essential characteristics of Table ZA.1 relevant for the intended use which are declared	EN 459–3:2015, 4.3
Tasks for the notified production control certification body	Initial inspection of the manufacturing plant and of FPC	Parameters related to essential characteristics of Table ZA.1, relevant for the intended use which are declared, namely Compressive strength (for lime with hydraulic properties only) Initial and final setting time (for lime with hydraulic properties only) Air content (for lime with hydraulic properties only)	EN 459–3:2015, 4.1 to 4.3, and Clause 5, and EN 459–1:2015, 4.4.7 (calcium lime), 4.5.7 (dolomitic lime), 5.6 (natural hydraulic lime, formulated lime and hydraulic lime
	Continuous surveillance, assessment and evaluation of FPC		

		Content of active constituents (for air lime only) Soundness-maximum expansion Particle size, Particle size distribution, Penetration, Reactivity Available lime. Documentation of the FPC.	

(Source: Table ZA.3 of Annex ZA, BS EN 459-1 [83], p44)

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