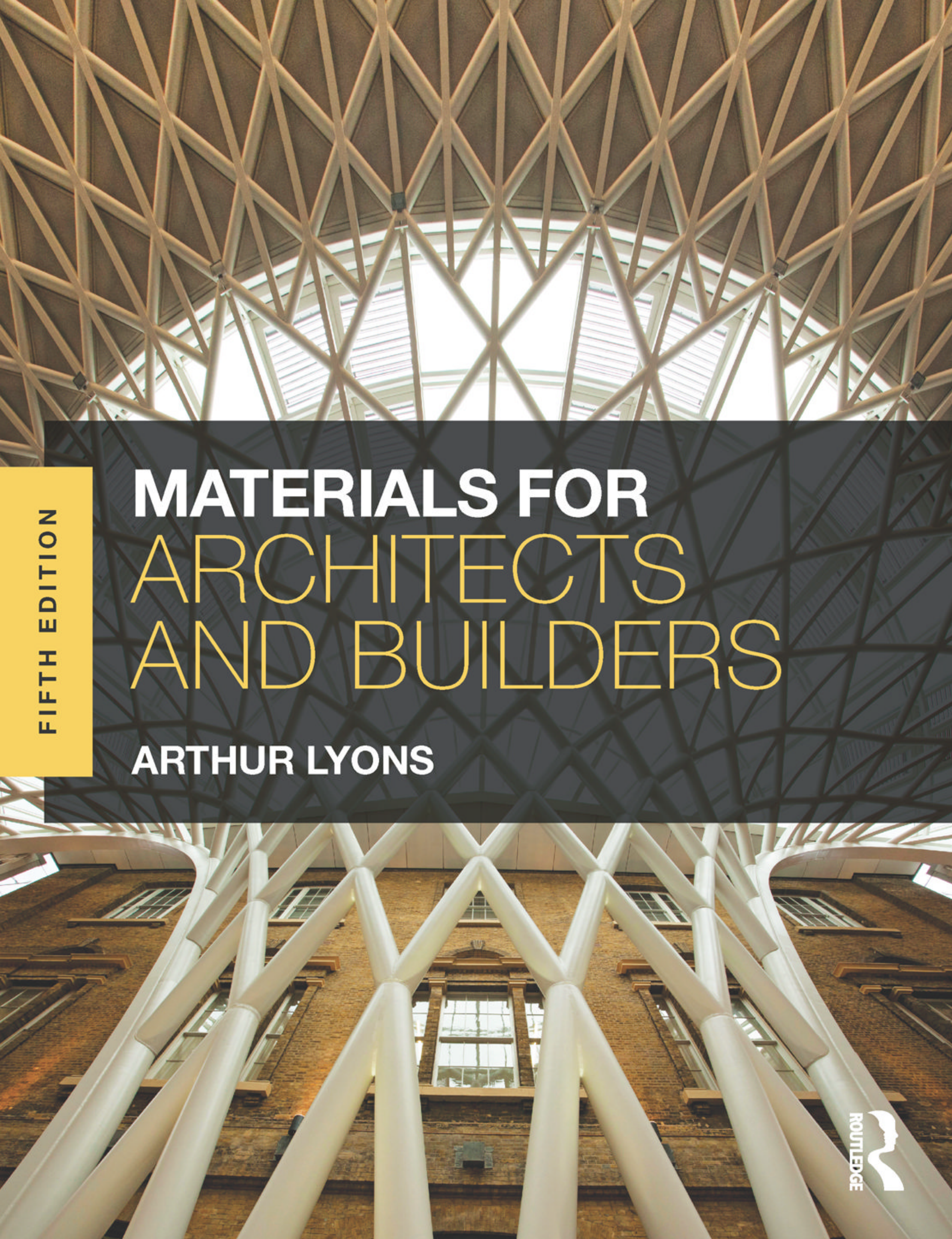

MATERIALS FOR ARCHITECTS AND BUILDERS

FIFTH EDITION

ARTHUR LYONS

ROUTLEDGE

MATERIALS FOR ARCHITECTS AND BUILDERS

Materials for Architects and Builders provides a clear and concise introduction to the broad range of materials used within the construction industry and covers the essential details of their manufacture, key physical properties, specification and uses.

Understanding the basics of materials is a crucial part of undergraduate and diploma construction or architecture-related courses, and this established textbook helps the reader to do just that with the help of colour photographs and clear diagrams throughout.

This new edition has been completely revised and updated to include the latest developments in materials research, new images, appropriate technologies and relevant legislation. The ecological effects of building construction and lifetime use remain an important focus, and this new edition includes a wide range of energy-saving building components.

Arthur Lyons was formerly Head of Quality, principal lecturer and Teacher Fellow for building materials in the Leicester School of Architecture, Faculty of Art, Design & Humanities, De Montfort University, UK. He was a lecturer in building materials within schools of architecture and surveying for thirty-five years, and is now an established writer on construction materials.

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MATERIALS FOR ARCHITECTS AND BUILDERS

Fifth Edition

ARTHUR LYONS

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ABOUT THE AUTHOR

Dr Arthur Lyons, author of texts on building materials, was formerly Head of Quality, principal lecturer and Teacher Fellow for building materials in the Leicester School of Architecture, Faculty of Art and Design, De Montfort University, Leicester, UK. He was educated at Trinity Hall Cambridge, Warwick and Leicester Universities in the fields of natural sciences and polymer science, and has a postgraduate diploma in architectural building conservation. He was a lecturer in building materials within schools of architecture and surveying for thirty-five years. In recognition of his services to architects and architecture, Arthur Lyons was honoured with life membership of the Leicestershire and Rutland Society of Architects and he is a Fellow of the Higher Education Academy. He retains his active interest in architecture through liaison with the local society of architects and the Leicester School of Architecture of De Montfort University, where he is an honorary visiting researcher. In addition to this text, Arthur Lyons has written chapters in the *ICE Manual of Construction Materials* (2009, Institution of Civil Engineers); the *Metric Handbook – Planning and Design Data* (4th edn, 2012, Routledge); and the *Construction Materials Reference Book* (2013, Routledge). Arthur Lyons also authored the first and current second edition of *The Architecture of the Universities of Leicester*, published by Anchorprint.

PREFACE TO FIFTH EDITION

Materials for Architects and Builders is written as an introductory text to inform students at undergraduate degree and national diploma level of the relevant visual and physical properties of the widest range of building materials. The fifth edition has been significantly enhanced by the addition of more colour images, illustrating the materials and in many cases their use in new buildings of architectural merit. The text embraces the broad environmental issues with sections on energy-saving and recycled materials. The chapter on sustainability reflects the current debate on climate change and governmental action to reduce carbon emissions and ameliorate global warming. There are 18 chapters covering the wide range of materials under standard headings. Each chapter describes the manufacture, salient properties and typical uses of the various materials, with the aim of ensuring their appropriate application within awareness of their ecological impact.

European Standards are taking over from the previous British Standards, and the European Norms have now been published for most key materials. Generally, this has led to an increase in the number of relevant standards for building materials. However, in some cases, both the British and European Standards are current, and are therefore included in the text and references.

New and rediscovered old materials, where they are becoming well integrated into standard building processes, are described, together with innovative products yet to receive general acceptance. Other materials no longer in use are generally disregarded, except where increased concern for environmental issues has created renewed interest. The use of chemical terminology is kept to the minimum required to understand each subject area, and is only significantly used within the context of the structure of plastics. Tabulated data is restricted to an informative level appropriate to student use. An extensive bibliography and listed sources of technical information are provided at the end of each chapter to facilitate direct reference where necessary.

The text is well illustrated with over 300 line drawings and colour photographs, showing the production, appearance and appropriate use of materials, but it is not intended to describe construction details, as these are illustrated in the standard texts on building construction. Environmental concerns including energy-conscious design and the effects of fire are automatically considered as part of the broader understanding of the various materials.

The text is essential reading for honours and foundation degree, BTEC and advanced GNVQ students of architecture, building, surveying and construction, and those studying within the broad range of built environment subjects, who wish to understand the principles relating to the appropriate use of construction materials.

Arthur Lyons
January 2014

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The text uses the generic names for building materials and components wherever possible. However, in a few cases, products are so specific that registered trade names are necessarily used. In these cases the trade names are italicised in the text.

INTRODUCTION

Specific information relating to the materials described in each chapter is given at the end of the appropriate section; however, the following are sources of general information relating to construction materials.

- Building Regulations, including current Amendments and Approved Documents to 2013
- RIBA Office Library and Barbour Index
- Building Research Establishment (BRE) publications
- Trade association publications
- Trade exhibitions
- Trade literature
- Architecture and built environment journals
- British Board of Agrément certificates
- British Standards
- European Standards
- Eurocodes
- The Construction Information Service

European Standards (EN) have been published for a wide range of materials. A full European Standard, known in the UK as BS EN, is mandatory and overrules any conflicting previous British Standard which must be withdrawn. Prior to full publication, the draft European Standards are coded pr EN and are available for comment, but not implementation. BRE Information Paper IP 3/99 (1999) identifies the issues relating to the adoption in the UK of the structural Eurocodes.

The Construction Products Regulation (2013) makes CE marking of all products defined by harmonised European Product Standards mandatory. This is designed to ensure a unified set of rules to underpin the performance characteristics of construction products across the European Union. Under the Construction Products Regulation, technical specifications are defined in either the appropriate European Standards (ENs) or in a relevant European Assessment Document. Defined performance characteristics include mechanical properties, stability, reaction to fire, health and safety issues, energy and sustainability. Within the European Standards (ENs) issues relating to harmonised product standards including CE marking are defined in the Annex ZA.

The Building Research Establishment (BRE) publishes informative and authoritative material on a wide range of subjects relating to construction. Trade associations and manufacturers produce promotional literature and websites relating to their particular area of interest within the building industry. Architecture and building journals give news of innovations and illustrate their realisation in quality construction. Much literature has recently been presented, including from governmental organisations, in respect of the need to reduce energy consumption within the built environment sector to ameliorate the effects of global warming and climate change.

Information for this text has been obtained from a wide selection of sources to produce a student text with an overview of the production, nature and properties of the diverse range of building materials. New individual products and modifications to existing products frequently enter the market; some materials become unavailable. Detailed information and particularly current technical data relating to any specific product for specification purposes should therefore be obtained directly from the manufacturers or suppliers, and cross-checked against current standards and regulations.

ABBREVIATIONS

General

AAC	autoclaved aerated concrete
ABS	acrylonitrile butadiene styrene
AC	aggressive chemical (environment)
ACD	approved construction details
ACEC	aggressive chemical environment for concrete
APAO	atactic poly α-olefin
APM	additional protective measures
APP	atactic polypropylene
AR	alkali-resistant
ASR	alkali-silica reaction
BER	building emission rate
BFRC	British Fenestration Rating Council
BRE	Building Research Establishment
BREEAM	BRE environmental assessment method
BS	British Standard
CAC	calcium aluminate cement
CAD	computer-aided design
CCA	chromated copper arsenate
CEN	European committee for standardisation
CFCs	chlorofluorocarbons
CG	cellular glass
CIGS	copper indium gallium selenide
CIS	copper indium selenide
CL	air lime
CLT	cross-laminated timber
CMYK	cyan magenta yellow black
CO_2e	carbon dioxide equivalent emissions
COSHH	control of substances hazardous to health
CPE	chlorinated polyethylene
CPR	construction products regulation
CPVC	chlorinated polyvinyl chloride
CS	calcium silicate
CSA	Canadian Standards Association
CSM	chlorosulphonated polyethylene
DC	design chemical (class)
DC	direct current
DD	draft for development
DER	door energy rating
DFEE	dwelling fabric energy efficiency
DPC	damp-proof course
DPM	damp-proof membrane
DR	dezincification-resistant
DRF	durability of reaction to fire
DS	design sulphate (class)
DSA	design stage assessment
DSER	door set energy rating
DZR	dezincification-resistant
EN	Euronorm
ENV	Euronorm pre-standard
EP	expanded perlite
EPC	energy performance certificate
EPDM	ethylene propylene diene monomer
EPR	ethylene propylene rubber
EPS	expanded polystyrene
ETFE	ethylene tetrafluorethylene copolymer
EV	exfoliated vermiculite
EVA	ethylene vinyl acetate
EVOH	ethyl vinyl alcohol copolymer
FEES	fabric energy efficiency standards
FEF	flexible elastomeric foam
FL	formulated lime
FPA	flexible polypropylene alloy
FRP	fibre-reinforced polymer
FSC	Forest Stewardship Council
GGBS	ground granulated blast furnace slag
GRC	glassfibre-reinforced concrete
GRG	glassfibre-reinforced gypsum
GRP	glassfibre-reinforced plastic or polyester
GS	general structural (timber)

HAC high alumina cement
HACC high alumina cement concrete
HB hardboard
HCFCs hydrochlorofluorocarbons
HD high density
HDPE high-density polythene
HIP home information pack
HL hydraulic lime
HLS hue lightness saturation
HS structural tropical hardwood
ICB insulating corkboard
ICF insulating concrete formwork
IGU insulating glass unit
LA low alkali (cement)
LD low density
LDPE low-density polythene
LED light-emitting diode
LRV light reflectance value
LVL laminated veneer lumber
MAC minor additional constituents
MAF movement accommodation factor
MB mediumboard
MDF medium-density fibreboard
MF melamine formaldehyde
MMC modern methods of construction
MPa mega Pascal
MTCS Malaysian Timber Certification Scheme
MW mineral wool
NA National Annex (British Standard)
NAOBL National Windspeed Database
NCS Natural Colour System®
NHL non-hydraulic lime
ODP ozone depletion potential
OPC ordinary Portland cement
OSB oriented strand board
PAR processed all round
PAS publicly available specification
PB polybutylene
PBAC polystyrene-bead aggregate cement
PC polycarbonate
PCM phase change materials
PCS post-construction stage assessment
PD published document
PE polyethylene
PEF polyethylene foam
PEFC programme for the endorsement of forest certification
PET polyethylene terephthalate
PEX cross-linked polyethylene
PF phenolic foam/phenol formaldehyde
PFA pulverised fuel ash
PHA partially halogenated alkane
PIB polisobutylene
PIR polyisocyanurate foam
PMMA polymethyl methacrylate
PP polypropylene
pr EN draft Euronorm
PS polystyrene
PTFE polytetrafluroethylene
PUR rigid polyurethane foam
PV photovoltaic
PVA polyvinyl acetate
PVB polyvinyl butyral
PVC polyvinyl chloride (plasticised)
PVC-U polyvinyl chloride (unplasticised)
PVC-UE extruded polyvinyl chloride
PVDF polyvinylidene fluoride
RBM reinforced bitumen membrane
RGB red green blue
SAP standard assessment procedure
SB softboard
SBEM simplified building energy model
SBS styrene butadiene styrene
SCC self-compacting concrete
SFI sustainable forest initiative
Sg specific gravity
SIP structural insulated panel
SS special structural (timber)
ST standard (concrete mix)
SuDS sustainable drainage systems
T tolerance (class)
TER target emission rate
TFEE target fabric energy efficiency
TFS thin film silicon
TH temperate hardwood
THF tetrahydro furan
TMT thermally modified timber
TPE thermoplastic elastomer
TPO thermoplastic polyolefin
TRADA Timber Research and Development Association
TRM total relative movement
UF urea formaldehyde
UHPC ultra-high performance concrete
UV ultraviolet (light)
VET vinyl ethylene terpolymer
VIP vacuum insulation panel
VOC volatile organic compounds
WER window energy rating
WF wood fibre
WPC wood plastic composite
WRAP net waste tool

WW	wood wool
XLAM	cross-laminated timber
XPS	extruded polystyrene

Units

dB	decibel
GPa	giga Pascal (1 GPa = 1000 MPa)
MPa	mega Pascal (1 MPa = 1 N/mm^2)
µm	micron (10^{-6}m)
nm	nanometre (10^{-9}m)

Chemical symbols

Al	aluminium
As	arsenic
C	carbon
Ca	calcium
Cd	cadmium
Cl	chlorine
Cr	chromium
Cu	copper
F	fluorine
Fe	iron
Ga	gallium
In	indium
Mn	manganese
Mo	molybdenum
N	nitrogen
Ni	nickel
O	oxygen
S	sulphur
Se	selenium
Si	silicon
Sn	tin
Te	tellurium
Ti	titanium
Zn	zinc

Cement notation

C_2S	dicalcium silicate
C_3S	tricalcium silicate
C_3A	tricalcium aluminate
C_4AF	tetracalciumaluminoferrite

1

BRICKS AND BRICKWORK

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Introduction

Originally, bricks were hand-moulded from moist clay and then sun-baked, as is still the practice in certain arid climates. The firing of clay bricks dates back well over 5000 years, and is now a sophisticated and highly controlled manufacturing process; yet the principle of burning clay, to convert it from its natural plastic state into a dimensionally stable, durable, low-maintenance ceramic material, remains unchanged.

The quarrying of clay and brick manufacture are high-energy processes, which involve the emission of considerable quantities of carbon dioxide and other pollutants including sulphur dioxide. The extraction of clay also has long-term environmental effects, although in some areas former clay pits have now been converted into bird sanctuaries or put to recreational use. However, well-constructed brickwork has a long life with low maintenance, and although the use of Portland cement mortar prevents the recycling of individual bricks, the crushed material is frequently recycled as aggregate in further construction.

The elegant cathedral at Evry near Paris (Fig. 1.1), designed by Mario Botta, illustrates the modern use of brickwork. The cathedral of Saint Corbinian, built with 670,000 bricks, was dedicated in 1997. The

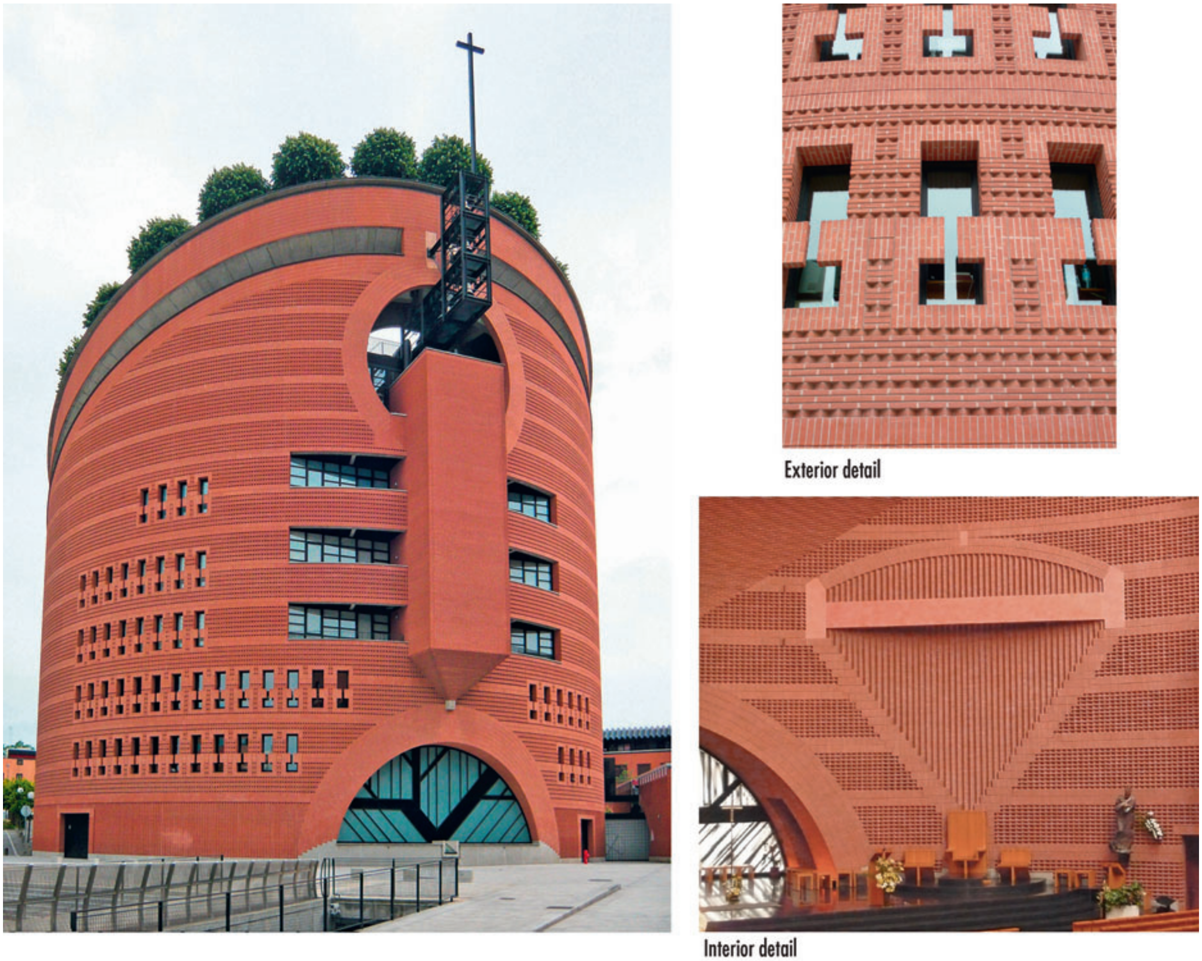


Fig. 1.1 Brick construction – Evry Cathedral, Essonne, France. *Architect*: Mario Botta. *Photographs*: Arthur Lyons

building exhibits fine detailing both internally and externally. Externally the cylindrical form rises to a circle of trees. Internally the altar is surmounted by a corbelled structure leading one's view upwards to the central rooflight. Three-dimensional internal brickwork is finely detailed to generate the desired acoustic response.

Clay bricks

The European Standard BS EN 771–1: 2011 refers only to clay masonry units. However, the National Annex to BS EN 771–1: 2011 refers to bricks as currently understood within the UK construction industry, and described in this chapter.

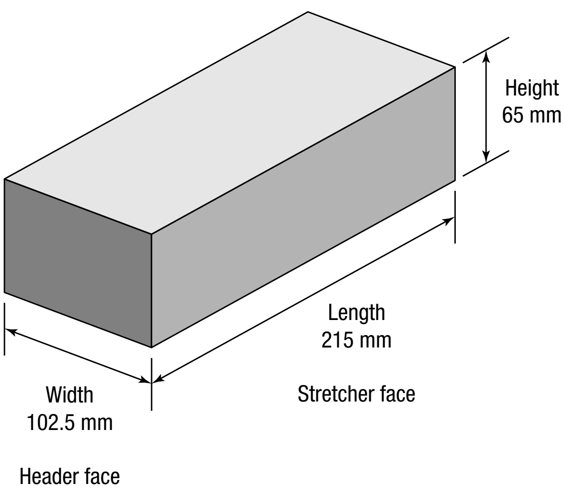
The wide range of clays suitable for brick making in the UK gives a diversity to the products available. This variety is further increased by the effects of blending clays, various forming processes, the application of surface finishes and the adjustment of firing conditions. In the early twentieth century most areas had their own brickworks with characteristic products; however, ease of road transportation and continuing amalgamations within the industry have left a reduced number of major producers and only a few small independent works. Most UK bricks are defined as high-density (HD) fired-clay masonry units with a gross dry density greater than 1000 kg/m^3. The European Standard BS EN 771–1: 2011 also refers to low-density (LD) fired-clay masonry units and these blocks for unprotected masonry are described in Chapter 2, together with the larger high-density units.

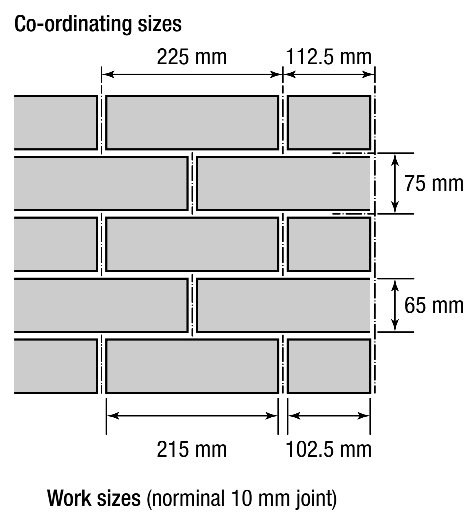
The main constituents of brick-making clays are silica (sand) and alumina, but with varying quantities of chalk, lime, iron oxide and other minor constituents such as fireclay, according to their source. The largest UK manufacturer uses the Lower Oxford clays of Bedfordshire, Buckinghamshire and Cambridgeshire to produce the *Fletton* brick. This clay contains some carbonaceous content that reduces the amount of fuel required to burn the bricks, lowering cost and producing a rather porous structure. Other particularly characteristic bricks are the strongly coloured *Staffordshire Blues* and *Accrington Reds* from clays containing high iron content and the yellow *London stocks* from the Essex and Kent chalky clays with lower iron content.

Brick manufacturers are endeavouring to reduce the environmental impact of production by improving energy efficiency of the firing process and the incorporation of recycled materials such as quarry fines, pulverised fuel ash, ground granulated blast furnace slag and waste glass into the extracted clay. The majority of clay bricks manufactured in the UK qualify for the maximum number of credits in the 'Materials' category of the 'Code for Sustainable Homes'. External walls built with clay bricks are generally classified as A+ in 'The Green Guide to Specification'.

SIZE

Within Europe, the dimensions of clay masonry units (BS EN 771–1: 2011) have not been standardised, but in the UK, the standard metric brick referred to in the National Annex (informative) to BS EN 771–1: 2011 is 215 × 102.5 × 65 mm, although this size is not a specified requirement. Dimensions are given in the order, length, width and height, respectively. These UK dimensions match those in BS 4729: 2005, which relates to special shapes and sizes of bricks. The standard brick weighs between 2 and 4 kg, and is easily held in one hand. The length (215 mm) is equal to twice its width (102.5 mm) plus one standard 10 mm joint and three times its height (65 mm) plus two standard joints (Fig. 1.2).





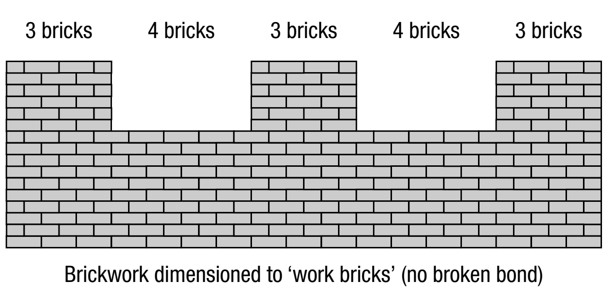


Fig. 1.2 Brick and co-ordinating sizes

Table 1.1 Tolerances on brick sizes to BS EN 771–1: 2011

	HD type clay brick dimensions (mm)	Limits for the deviation (±) from work size of mean of ten units (mm)					Maximum range of work size of mean of ten units (mm)				
		T1	T1+	T2	T2+	Tm	R1	R1+	R2	R2+	Rm
Length	215	6	6	4	4	*	9	9	4	4	*
Width	102.5	4	4	3	3	*	6	6	3	3	*
Height	65	3	1	2	1	*	5	1	2	1	*

Notes:
The reduced height tolerances for categories T1+, T2+, R1+ and R2+ are relevant when thin layer mortars are specified.
* Limits for Tm and Rm are as declared by the manufacturer (these may be wider or closer than the other categories).

The building industry modular coordination system (BS 6750: 1986) is based on the module (M) of 100 mm and multimodules of 3M, 6M, 12M, 15M, 30M and 60M. For metric brickwork, the base unit is 3M or 300 mm. Thus four courses of 65 mm brickwork with joints give a vertical height of 300 mm, and four stretchers with joints coordinate to 900 mm.

Table 1.1 illustrates the two types of dimensional tolerance limits set for clay masonry units including the metric brick, which relate to the square root of the work size dimension. Measurements are based on a random sample of ten bricks. The calculation based on the use of the square root of work size ensures that the dimensional tolerance limits are appropriate for the wide range in size of clay masonry units used within the European Union (BS EN 771–1: 2011).

Tolerances

Mean value

Tolerance limits are set for the difference between the stated work size (e.g. 215, 102.5 and 65 mm) and the measured mean from the samples, for each of the three brick dimensions (length, width and height). These are categorised as T1, T2 and Tm where Tm is a tolerance quoted by the manufacturer.

T1 ± 0.40 √(work size dimension) mm or 3 mm if greater
T2 ± 0.25 √(work size dimension) mm or 2 mm if greater
Tm deviation in mm declared by the manufacturer

Range

The maximum range of size for any dimension is designated by categories R1, R2 and Rm.

R1 0.6 √(work size dimension) mm
R2 0.3 √(work size dimension) mm
Rm range in mm declared by the manufacturer

There is no direct correlation between the limits on mean value (T) and those for the range (R); thus, a brick conforming to category T2 may be within the wider range R1. Category R2 bricks may only be required for very tight dimensional control, as in short runs of brickwork.

Alternative sizes

The metric standard evolved from the slightly larger Imperial sizes, which varied significantly, but typically were 9 × 4⅜ × 2⅞ in (228 × 110 × 73 mm) or 8⅝ × 4⅛ × 2⅝ in (219 × 105 × 68 mm). Some manufacturers offer a range of bricks to full Imperial dimensions, or alternatively to an appropriate height (e.g. 50, 68, 70, 73, 75 or 80 mm) for bonding in to Imperial brickwork for restoration and conservation work.

The 1970s also saw the introduction of metric modular bricks with coordination sizes of either 200 or 300 mm in length, 100 mm wide and either 75 or 100 mm in height. These bricks have now been replaced by a range of linear bricks up to 490 mm in length, which give the architect opportunities for increasing the horizontal emphasis within traditional brickwork (Fig. 1.3). Sizes include 327 × 50 or 65 mm, 440 × 50 or 65 mm and 490 × 50 or 65 mm with standard widths of 102 mm. A range of colours and textures is available for normal, quarter or third bonding, or alternatively stack bonding in non-load-bearing situations.

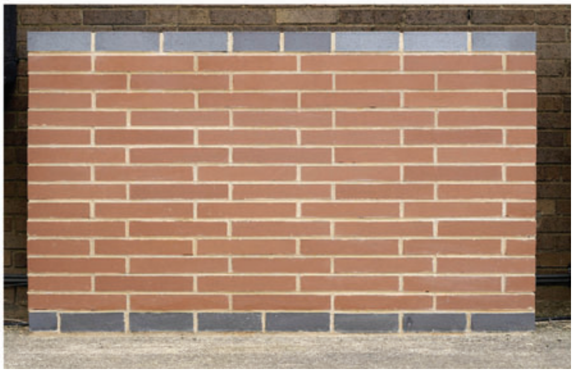


Fig. 1.3 Linear bricks. *Photographs*: Courtesy of Ibstock Brick Ltd

MANUFACTURE OF CLAY BRICKS

There are five main processes in the manufacture of clay bricks:

- extraction of the raw material;
- forming processes;
- drying;
- firing;
- packaging and distribution.

Extraction of the raw material

The process begins with the extraction of the raw material from the quarry and its transportation to the works, by conveyor belt or road transport. Topsoil and unsuitable overburden is removed first and used for site reclamation after the usable clay is removed.

The raw material is screened to remove any rocks, then ground into fine powder by a series of crushers and rollers with further screening to remove any oversize particles. Small quantities of pigments or other clays may be blended in at this stage to produce various colour effects; for example, manganese dioxide will produce an almost black brick and fireclay gives a teak brown effect. Occasionally, coke breeze is added into the clay as a source of fuel for the firing process. Finally, depending on the subsequent brick-forming process, up to 25% water may be added to give the required plasticity.

Forming processes

Handmade bricks

The handmade process involves the throwing of a suitably sized clot of wet clay into a wooden mould on a bench. The surplus clay is struck off with a framed wire and the green brick removed. The bricks produced are irregular in shape with soft arrises and interestingly folded surfaces. Two variations of the process are pallet moulding and slop moulding.

In pallet moulding, a stock board, the size of the bed face of the brick, is fixed to the bench. The mould fits loosely over the stock board, and is adjusted in height to give appropriate thickness to the green brick. The mould and board are sanded to ease removal of the green brick, which is produced with a *frog* or depression on one face. In the case of slop moulding, the stock mould is placed directly on the bench, and is usually wetted rather than sanded to allow removal of the green brick which, unlike the pallet moulded brick, is smooth on both bed faces (Fig. 1.4).

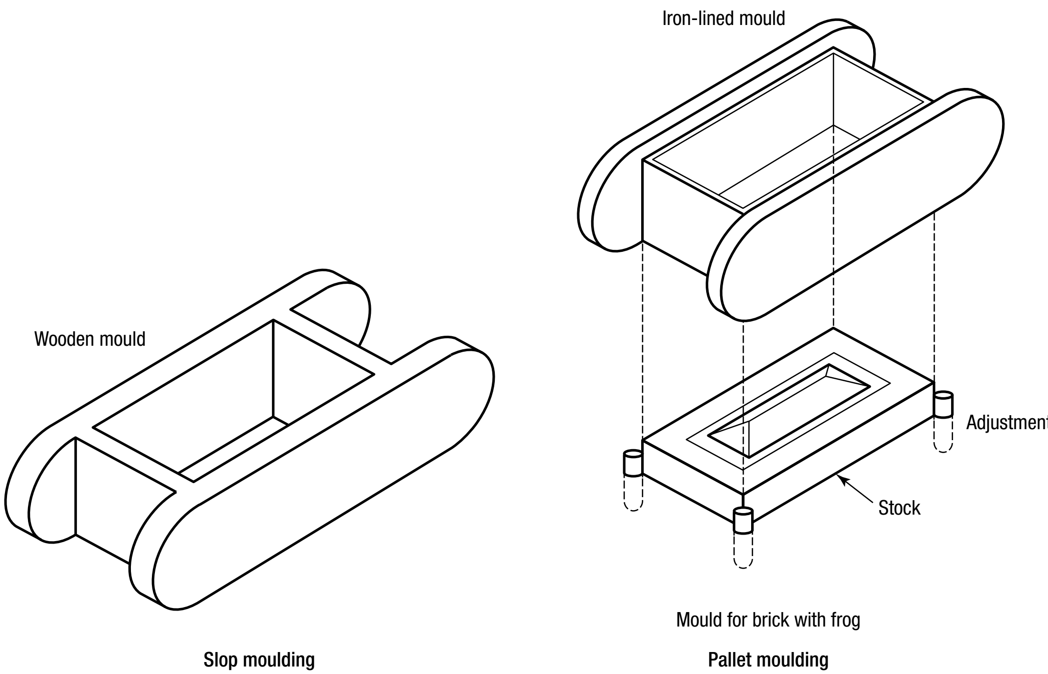


Fig. 1.4 Moulds for handmade bricks

Soft mud process

The handmade process has now been largely automated, with the clay being mechanically thrown into pre-sanded moulds; the excess clay is then removed and the bricks released from the mould. These *soft mud* process bricks retain much of the individuality associated with true handmade bricks, but at a lower cost.

Pressed bricks

In the *semi-dry* process used for *Fletton* bricks the appropriate quantity of clay is subjected to a sequence of four pressings within steel moulds to produce the green brick. These bricks usually have a deep frog on one bed face. For facing bricks, texturing on both headers and one stretcher may be applied by a series of rollers. A water spray to moisten the surface, followed by a blast of a sand/pigment mixture, produces the sand-faced finish.

With clays that require a slightly higher water content for moulding, the *stiff plastic* process is used in which brick-size clots of clay are forced into the moulds. A single press is then required to form the brick. Engineering bricks made by this process often have shallow frogs on both bed faces. In all cases the size of the mould is calculated to allow for the anticipated drying and firing shrinkage.

Extruded wire-cut bricks

In this process clay with a water content of up to 25% is fed into a screw extruder which consolidates the clay and extracts the air. The clay is forced through a die and forms a continuous column with dimensions equal to the length and width of a green brick (Fig. 1.5). The surface may then be textured or sanded, before the clay column is cut into brick units by a series of wires. The bed faces of wire-cut bricks often show the drag marks where the wires have cut through the extruded clay. Perforated wire-cut bricks are produced by the incorporation of rods or tines between the screw extruder and the die. The perforations save clay and allow for a more uniform drying and firing of the bricks without significant loss of strength. Thermal performance is not significantly improved by the incorporation of voids.

Drying

To prevent cracking and distortion during the firing process, green bricks produced from wet clays must be allowed to dry out and shrink. Shrinkage is typically 10% on each dimension depending upon the moisture content. The green bricks, laid in an open chequerwork pattern to ensure a uniform loss of moisture, are stacked in, or passed through, drying chambers which

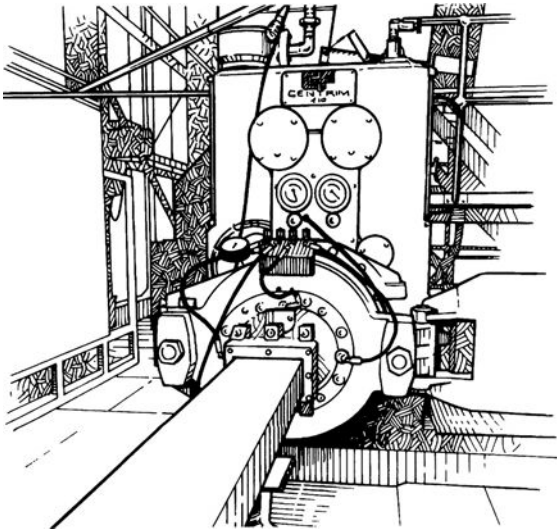


Fig. 1.5 Extruding wire cut bricks

are warmed with the waste heat from the firing process. Drying temperatures and humidity levels are carefully controlled to ensure shrinkage without distortion.

Firing

Both intermittent and continuous kilns are used for firing bricks. The former is a batch process in which the single kiln is loaded, fired, cooled and unloaded. In continuous kilns, the firing process is always active; either the green bricks are moved through a fixed firing zone, or the fire is gradually moved around a series of interconnecting chambers to the unfired bricks. Both continuous systems are more energy efficient than the intermittent processes. Generally, for large-scale production, the continuous tunnel kiln (Fig. 1.6) and the Hoffman kiln (Fig. 1.7) are used. Clamps and intermittent gas-fired kilns are used for the more specialised products. Depending on the composition of the clay and the nature of the desired product, firing temperatures are set to sinter or vitrify the clay. Colour variations called *kiss-marks* occur where bricks were in contact with each other within the kiln and are particularly noticeable on *Flettons*.

Tunnel kiln

In the tunnel kiln process the bricks are loaded 10 to 14 high on kiln cars which are moved progressively through the preheating, firing and cooling zones. A carefully controlled temperature profile within the kiln and an appropriate kiln car speed ensure that the green bricks are correctly fired with the minimum use of fuel, usually natural gas. The maximum firing temperature within the range 940–1200°C depends on the clay, but is normally around 1050°C, with an average kiln time of three days. The oxygen content within the atmosphere of the kiln will affect the colour of the brick products. Typically a high temperature and low oxygen content are used in the manufacture of blue bricks. A higher oxygen content will turn any iron oxide within the clay red.

Hoffman kiln

Introduced in 1858, the Hoffman kiln is a continuous kiln in which the fire is transferred around a series of chambers which can be interconnected by the opening of dampers. There may be 12, 16 or 24 chambers, although 16 is usual. The chambers are filled with typically 100,000 green bricks. The chambers in front of the fire, as it moves around, are preheated, then firing takes place (960–1000°C), followed by cooling, unloading and resetting of the next load. The sequence moves on one chamber per day, with three days of burning. The usual fuel is natural gas, although low-grade coal and landfill methane are used by some

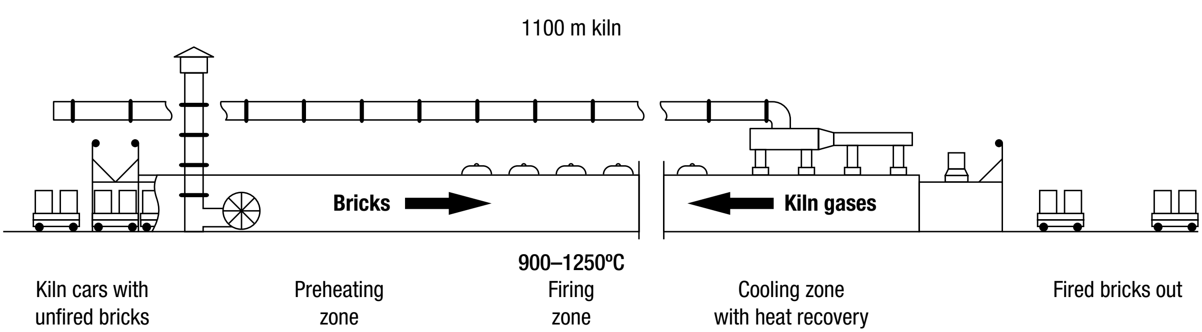


Fig. 1.6 Tunnel kiln

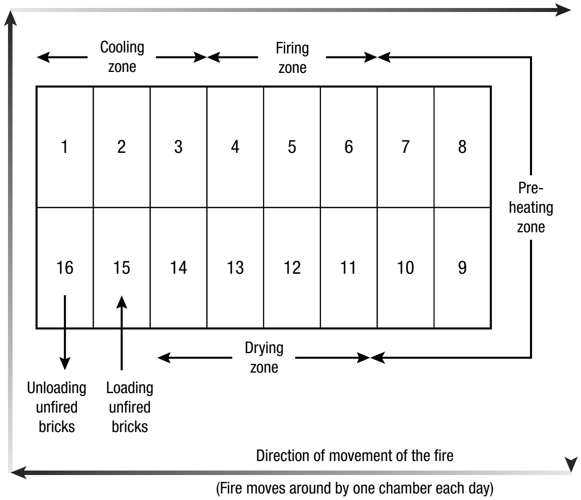


Fig. 1.7 Hoffman kiln plan

manufacturers. Hoffmann kilns are being phased out of production in the UK.

Intermittent gas-fired kilns
Intermittent gas-fired kilns are frequently used for firing smaller loads, particularly *specials*. In one system, green bricks are stacked onto a concrete base and a mobile kiln is lowered over the bricks for the firing process. The firing conditions can be accurately controlled to match those within continuous kilns.

Clamps
The basis of clamp firing is the inclusion of coke breeze into the clay, which then acts as the major source of energy during the firing process. In the traditional process, alternate layers of unfired bricks and additional coke breeze or wood are stacked up and then sealed over with waste bricks and clay. The clamp is then ignited with kindling material and allowed to burn for two to five weeks. After firing, the bricks are hand selected because of their variability from under- to over-fired. Currently some handmade bricks are manufactured in gas-fired clamps which give a fully controlled firing process but still produce bricks with the characteristic dark patches on their surfaces due to the burnt breeze content.

Packaging and distribution

Damaged or cracked bricks are removed prior to packing. Most bricks are now banded and shrink-wrapped into packs of between 300 and 500, for easy transportation by fork-lift truck and specialist road vehicles. Special shapes are frequently shrink-wrapped onto wooden pallets.

SPECIFICATION OF CLAY BRICKS

To specify a particular brick it is necessary to define certain key criteria which relate to form, durability and appearance. The European Standard BS EN 771–1: 2011 requires an extensive minimum description for masonry units, including the European Standard number and date (e.g. BS EN 771–1: 2011), the type of unit (e.g. high density – HD), dimensions and tolerances from mean value, configuration (e.g. a solid or frogged brick), compressive strength and freeze/thaw resistance. As well, depending on the particular end use, additional description may be required. This may, as appropriate, include dry density, dimensional tolerance range, water absorption, thermal properties, active soluble salt content, moisture movement, reaction to fire and vapour permeability.

Within the building industry the classification usually also includes some traditional descriptions:

- place of origin and particular name (e.g. Staffordshire smooth blue);
- clay composition (e.g. Gault, Weald or Lower Oxford Clay, Etruria Marl, Keuper Marl [Mercian Mudstones] or shale);
- variety – typical use (e.g. Class A engineering, common or facing);
- type – form and manufacturing process (e.g. solid, frogged, wire-cut);
- appearance – colour and surface texture (e.g. coral red rustic).

Variety

Bricks may be described as common, facing or engineering.

Common bricks
Common bricks have no visual finish, and are therefore usually used for general building work especially where the brickwork is to be rendered, plastered or will be unseen in the finished work.

Facing bricks
Facing bricks are manufactured and selected to give an attractive finish. The particular colour, which may be uniform or multicoloured, results from the blend

Table 1.2 Properties of traditional UK engineering and DPC bricks (NA to BS EN 771–1: 2011)

Performance characteristic	Clay engineering bricks	
	Class A	Class B
Minimum compressive strength (MPa)	125	75
Maximum water absorption (% by mass)	4.5	7.0
(also when used as DPC units)	(and DPC1)	(and DPC2)
Freeze/thaw resistance category	F2	F2
Active soluble salts content category	S2	S2

of clay used and the firing conditions. In addition, the surface may be smooth, textured or sand-faced as required. A slightly distressed appearance, similar to that associated with reclaimed bricks, is obtained by tumbling either unfired or fired bricks within a rotating drum. Facing bricks are used for most visual brickwork where a pleasing and durable finish is required.

Engineering bricks

Engineering bricks are dense and vitreous, with specific load-bearing characteristics and low water absorption. The National Annex NA (informative) to BS EN 771–1: 2011 relates the properties of the two classes (A and B) of clay engineering bricks to their minimum compressive strengths, maximum percentage water absorption, freeze/thaw resistance and soluble salt content (Table 1.2). Engineering bricks are used to support heavy loads, and also in positions where the effects of impact damage, water absorption or chemical attack need to be minimised. They are generally *reds* or *blues* and more expensive than other machine-made facing bricks because of their higher firing temperature.

Type

Type refers to the form of the brick and defines whether it is solid, frogged, cellular, perforated or of a special shape (Figs 1.8 and 1.9). Bricks may be frogged on one or both bed faces; perforations may be few and large or many and small. Cellular bricks have cavities closed at one end. Keyed bricks are used to give a good bond to plaster or cement rendering. Because of the wide range of variation within brick types, the manufacturer is required to give details of the orientation and percentage of perforations in all cases.

For maximum strength, weather resistance and sound insulation, bricks should be laid with the frogs uppermost so that they are completely filled with mortar; with double-frogged bricks the deeper frog should be uppermost. However, for cheapness, speed and possibly minimisation of the dead weight of construction, frogged bricks are frequently laid frog down. Inevitably this leads to a resultant reduction in their load-bearing capacity.

Standard specials

Increasingly, *specials* (special shapes) are being used to enhance the architectural quality of brickwork. British Standard BS 4729: 2005 illustrates the range of standard specials, which can normally be made to order to match standard bricks (Fig. 1.9).

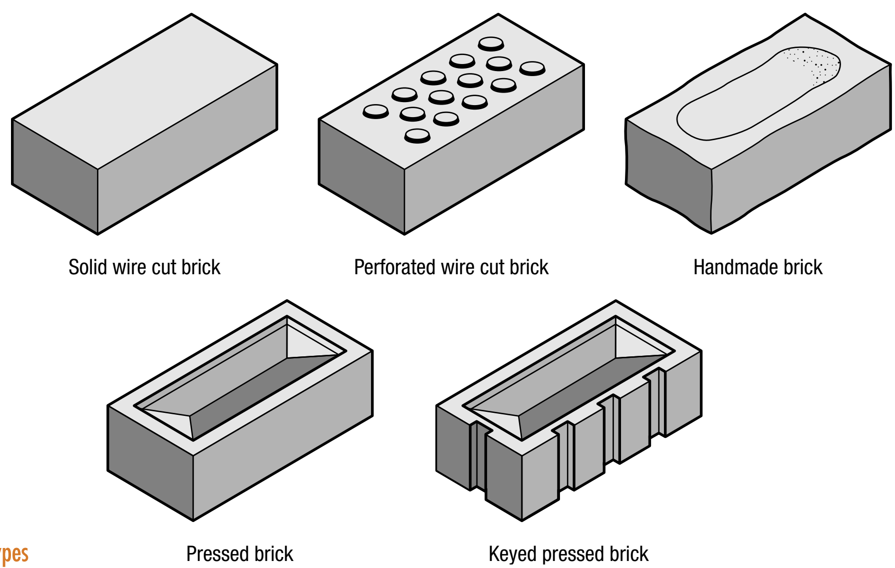


Fig. 1.8 Brick types