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Special construction materials

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Introduction to current building materials

Current building industry processes both, conventional materials used in constructions for many generations and brand new materials manufactured based on the latest scientific knowledge. The number of used materials purposefully developed for a specific important building project or special use in a building industry continuously increases. Great attention is paid to improving features of existing building materials, and originally special materials change gradually to regular materials.

The assortment of currently used building materials is broad. It is not an easy task to select a material solution for a building. Legislation, technical, economical, and subjective requirements are crucial for selection of building materials for each specific purpose.

Alloys.

Alloys are formations of two or more metals, or metals and non-metals. Microscopically, they might be homogenous or heterogeneous. The shape and size of crystals of individual alloy components depend on various factors. Alloys are produced most frequently by mixing their melted parts or dissolving a solid part in the excess of melted metal. They may also be generated by diffusion, elimination of components by galvanic process from solutions, with concurrent reduction of metals from oxides.

Melted alloys are cast into moulds of blocks, which final products formed under hot or cold conditions.

Most common metal-metal alloys:

- Copper and tin alloys (bronzes)
- Copper and zinc alloys (brasses)
- Copper, nickel, and other metal alloys
- Lead, tin, and antimony alloys
- Mercury alloys (amalgams)
- Light metal alloys (aluminium-copper, aluminium-magnesium, aluminium-zinc)
- Other

Metal and non-metal alloys:

- Aluminium and silicon
- Cast irons (iron and carbon)

Fibre, particle, and laminar composites.

General definition:

The composite is a material system of several (at least 2) phases, at least one of which is solid, with a macroscopically recognizable interface between phases that achieves characteristics, which cannot be achieved even by absolute summation – synergic effect.

By suitable selection of matrix material and the reinforcing phase and by selection of their mutual volume ratio, atypical characteristics can be achieved.

- Reinforcement - harder, more rigid, stronger discontinuous phase
- Matrix – continuous, usually more elastic phase with the reinforcement bind function

Basic types of composites according to the structure nature:

- Fibre composites (short, long-fibre)
- Particle composites (macro-dispersion, dispersion, diffusion of particles in matrix)
- Laminas
- Other composite structure methods (joining)

Reinforcing Fibres - Short Fibres:

- • α-Al_20_3 (whisker crystals)

- • o-Al_20_3 + SiO_2,

Reinforcing Fibres - Continuous Fibres: (inorganic)

Reinforcing Fibres - Continuous Fibres: (organic)

- Aromatic polyamide (Kevlar)
- Polyethylene (UHMW)

Types of common fibres

- glass fibres
- carbon fibres
- silicon carbide
- alumina and alumina/silica compounds
- organic fibres
- metallic fibres

Styles of reinforcement

Particle:

- The size of particles should be more than 1 μm
- Particles must be diffused evenly in the matrix, otherwise the composite strength drops as compared with the matrix, even with relatively small shares of particles

The matrix may be from metal, polymer, ceramics.

Particles may be: metals, metal oxides, structural ceramics, other.

Particle types: short fibres and whiskers l/d up to 200, spherical particles (aspect ration equal to 1).

Structure types of particle composites: macro-dispersion (concrete), dispersion, diffusion.

Examples: aluminium matrix + Al_2O_3 or SiC particles, rubber particles (resin filled with carbon black or SiO_2)

Laminar:

Laminas are formed by lamination of planar materials and their mutual joining. In cased of one-way layer orientation, mechanical and physical features of the laminate depend significantly on the orientation of layers.

The laminate becomes plane isotropous (i.e. elasticity module and laminate plain strength are identical in all directions) when layers are compounded [0°/+45°/-45°/90°]. Long-fibre laminated composite is also considered a laminate.

Examples:

Laminar composites with a metal matrix reinforced with continuous fibres, plywood (wooden, foil, etc.)

Nano-composites, nano-materials.

Nano-composites – material consisting of two or more different compounds, at least one of which occurs in the material as particles with the size of several or several tens of nano-meters. The reason for using an active substance in a nano-particle form is its qualitatively different physical characteristics as compared with the main material.

Examples of use in the building industry:

Surfaces and surface paints (photocatalytic paints, hydrophobization of surfaces), purification of waste water, air and combustion gas filtration, solar technology, etc.

Adhesives.

Adhesion means joining materials (adherents), which forms a permanent joint.

Adhesive is a substance capable of forming a **fixed** and **permanent** joint.

Advantages:

- High strength of the resulting joint
- Relative simplicity (as compared with other joint types)

Disadvantages:

- Bonded joints cannot be designed (their characteristics are verified)
- Emphasis on preparation of surfaces and technological discipline
- Bonded joints cannot be additionally remediate

The strength of bonded joint depends on:

- Adhesion of the glue to bonded surface
- Adhesiveness of the mass of the cured glue (cohesion)
- Surface glue wettability of adherents
- Adhesiveness and strength of bonded material (adherents)

Basic classification:

- Liquid: reactive two-component, reactive single-component, solvent, water solution, water dispersion
- Solid: fluxing, redispersible powders

Currently, liquid reactive adhesives are used most commonly in the building industry. Basic types include:

- Epoxy
- PUR –single-component and two-component
- Silicon
- Phenol-formaldehyde
- Resorcinol-formaldehyde
- Urea-formaldehyde
- Melamine-formaldehyde
- Cyan-acrylic

Binders and foams.

Great progress was reported in the area of bonding **cements** and mortars for ceramic tiles and flooring. Current products include mainly redispersible powders.

The separate group of jointing materials is represented by binders for sealing joints. For their trouble-free function, they must show sufficient and long-term elasticity corresponding with dilatation movements of respective joint. Tensile strength of elastic joint cements usually does not exceed 2.5 MPa; with respect to low value of the modulus of elasticity, they however sustain significant repeated (cyclical) elongation.

Joint cements are usually supplied in cartouches.

As to their resistance against oil products, polysulphide cements are the most beneficial. Also their resistance to weather conditions is excellent. Their disadvantage is low adhesion to some materials, which requires auxiliary anchoring paint (primer). In common building practice, single-component cartouches filled with acrylic, silicon, or polyurethane binders prevail. Also butyl binder based on butyl-rubber and polyisobutylene is still used.

The current top of elastic joint cements is represented by products based on hybrid polymers, indicated today often as MS polymers. Hybrid nature of these polymers is given by concurrent presence of the carbonaceous and organosilicon structure.

Mounting **foams** form a separate (and very specific) group of filling materials. They are supplied either in pressure cartouches designed for special guns, or in pressure packages provided with a valve (spray vessels).

In addition to the standard mounting foam, a fast-curing foam (for prompt fixation of building components), winter foam (applicable at temperatures under 5 ºC), low-expansion foam (designed for filling mechanically low-resistant cavities), and high-expansion foam (with increased fixation strength) are also supplied.

Paints.

Painting materials may be classified according to the material of the treated structure as paints for:

- Concrete structures
- Masonry and plasters
- Wooden structures
- Steel structures
- Multi-purpose painting materials

With respect to the function of the paint in the building structure, we classify paints as:

- Decorative paints
- Protective paints
- Fire-resistant paints
- Sealing paints
- Other (reflective, biocidal, …)

Paint systems with multiple functions are currently preferred, in particular due to minimization of hazardous waste (packages).

Concrete paints have mainly following functions:

- Protection against water, climatic effects, carbonatization, road salts, other chemical substances
- Protection against mechanical load, surface wear due to abrasion
- Protection against temperature effects, fire protection

Masonry and plaster paints have mainly following functions:

- Decorative (pigmentation, surface unification)
- Protective paints
- Reinforcing paints
- Remedial paints (systems)

Paint matter types according to the binding component:

- Acrylic
- Alkyd (indicated as “synthetic” in the CR)
- Asphalt
- Epoxy
- Chlorinated rubber
- Nitrocellulose
- Oil
- Polyester
- Polyurethane
- Silicon
- Vinyl

Insulation compounds.

Classification of building insulations:

- Insulation against water and moisture (water-proofing)
- Insulation against heat and cold (thermal insulations)
- Insulation against noise and shocks (acoustic insulations)
- Other and special insulations

Water insulations prevent water penetration in or from the structure. Requirements for materials creating water-proofing layers include: temperature resistance, sufficient strength and expansibility, small volume changes, resistance against climatic effects and aggressive substances, water and vapour tightness.

Tightness is expressed by following variables:

- Water-vapour diffusion coefficient δ[s]
- Diffusion resistance factor μ[-]

Water-proofing is according to its arrangement within the structure classified as follows:

- Insulation of roofs and aboveground building sections

- Insulation of underground building sections
- Insulation of pits, pools, and reservoirs
- Insulation of road structures and bridges

According to the material content, water-proofing is classified as follows:

- Foil insulations from plastic and rubber (PVC-P, EVA-PVC, PO (PP a PE)
- Bitumen insulations
- Mixed insulation materials
- Synthetic rubbers

Asphalt water-proofing strips are made from oxidised and modified asphalts. The type of stiffener pad is determining for characteristic of asphalt strips. Types of stiffener pads:

L - raw underlying felt

ST – glass fabric

SR – glass-fibre mat

PR – polyester mat (also batting)

K - metal (Al, Cu, Pb)

KO - combined (composite) ST+PR, SR+PR, SR+K

Asphalt strips are melted on or anchored to the base.

For **thermal insulations**, we define their temperature– technical characteristics:

- Thermal conductivity coefficient λ[$W.m^{-1}.K^{-1}$]
- Heat penetration coefficient U [$W.m^{-2}.K^{-1}$]
- Heat transmission resistance R [$m^2.K.W^{-1}$] reciprocal value of U
- Specific heat capacity c [$J.kg^{-1}.K^{-1}$] (specific heat)

According to the material content, thermal insulations are classified as follows:

- Light silicate materials

- Foam inorganic materials
- Foam organic materials
- Fibre materials
- Masses from organic materials
- Special materials

Light silicate materials are for example: pearlite, agloporite, siopor, etc. These materials may be used for thermal–insulation banks, backfills, or as a filling compound in infill (thermal-insulation) concretes.

Typical representative of foam inorganic materials is foam glass.

Typical representative of foam organic materials is expanded polystyrene. Expanded polystyrene is widely used, e.g. as panels and moulded products for insulation of roof shells, floors, pipes, etc.

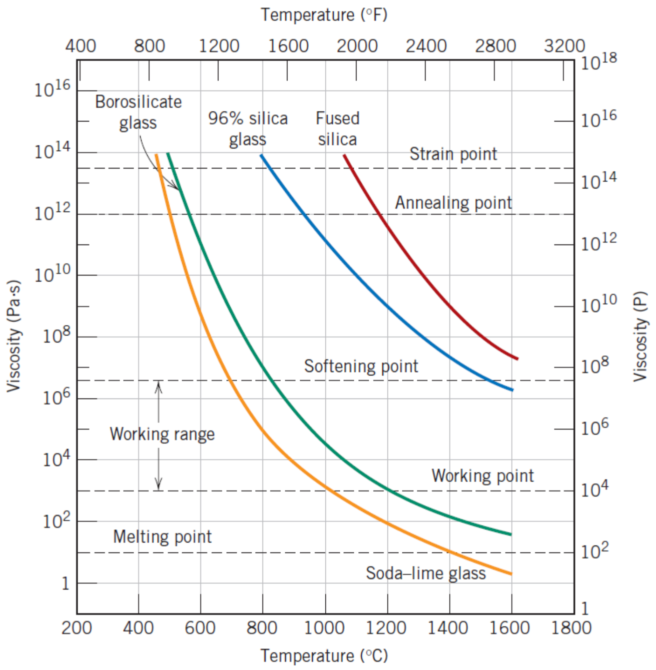
Fibre insulation materials are made from fibres extracted from melted inorganic materials (basalt, dross). Fibre materials are used in building structures mostly as mats, panels, and moulded products for insulation of peripheral shells, roofs, and floors. They may at the same time perform the function of acoustic insulation.

GLASSES

The glasses are a familiar group of ceramics. They are noncrystalline silicates containing other oxides, notably CaO, Na_2O, K_2O, and Al_2O_3, which influence the glass properties. A typical soda–lime glass consists of approximately 70 wt% SiO_2, the balance being mainly Na_2O (soda) and CaO (lime).
The term glass covers a far wider range of materials. At its broadest the term applies to any material that has been cooled from a liquid into a solid while maintaining the molecular arrangement it had when in a liquid, i.e. it may have short-range order, but on a large scale it is random or amorphous.
In theory, all materials that can be turned into a liquid state can be formed into a glass state, but many materials crystallise so readily when they solidify that it is extremely difficult (and in many cases practically impossible) to solidify them sufficiently quickly that they do not form crystals. This is the case, for example, with most metals.

- **Silicate glass definitions**
- **Raw materials -** Glass making ingredients, stabilizers, melting agents, ripple agents, pigments.
- **Glass processing -** Glassy, or noncrystalline, materials do not solidify in the same sense as do those that are crystalline. Upon cooling, a glass becomes more and more viscous in a continuous manner with decreasing temperature; there is no definite temperature at which the liquid transforms to a solid as with crystalline materials.
- **Glass Properties, melting, annealing -** For crystalline materials, there is a discontinuous decrease in volume at the melting temperature Tm. However, for glassy materials, volume decreases continuously with temperature reduction; a slight decrease in slope of the curve occurs

at what is called the glass transition temperature, or fictive temperature, Tg. Below this temperature, the material is considered to be a glass; above, it is first a supercooled liquid, and finally a liquid. Also important in glass-forming operations are the viscosity–temperature characteristics of the glass.



Logarithm of viscosity versus temperature for fused silica and three silica glasses.

Figure above plots the logarithm of viscosity versus the temperature for fused silica, high silica, borosilicate, and soda–lime glasses. On the viscosity scale, several specific points that are important in the fabrication and processing of glasses are labeled:

1. The melting point corresponds to the temperature at which the viscosity is 10 Pa.s; the glass is fluid enough to be considered a liquid.
2. The working point represents the temperature at which the viscosity is 10^3 Pa.s; the glass is easily deformed at this viscosity.
3. The softening point, the temperature at which the viscosity is 4×10^6 Pa.s, is the maximum temperature at which a glass piece may be handled without causing significant dimensional alterations.
4. The annealing point is the temperature at which the viscosity is 10^{12} Pa.s; at this temperature, atomic diffusion is sufficiently rapid that any residual stresses may be removed within about 15 min.
5. The strain point corresponds to the temperature at which the viscosity becomes 3×10^{13} Pa.s; for temperatures below the strain point, fracture will occur before the onset of plastic deformation. The glass transition temperature will be above the strain point.

Glass as a material - Material characteristics

Stress and strain

Homogeneity and isotropy

The effect of the glass structure on its properties

Glass and water

Glass strength testing

Glass Toughening

- Compression effects

- Thermal toughening
- Chemical strengthening

Production techniques and common glass products
Roman window glass, Crown glass, Cylinder glass, Sheet glass, Plate glass, Rolled glass, Wired glass, Float glass.
Common glass products

- Basic glass (Float glass, sheet glass, patterned glass, Polished wired glass, Wired patterned glass)
- Laminated glass
- Toughened glass
- Heat-strengthened glass
- Heat-soaked toughened glass
- Fire-resistant glass
- Enamelled glass
  Enamelling is the process of applying a glass material to a substrate. This process can be applied to many substrate materials; enamelled baths and cooking items immediately spring to mind. It is also applied to pottery and china, where it is usually called a glaze.
- Coated glass
  The term coated glass could be used to describe any number of types of glass where a base glass has something applied to the surface.
    - Vacuum deposition coating
    - Online coating
    - Dip coating
    - Sputter coating
    - Coated laminated glass
- Water Glass, Shaped Glass, Foamed Glass, Glass Fibres, Optical Fibres,
- **General Glass defects**

GLASS-CERAMICS

Glass-ceramics are initially fabricated as glasses, and then, by heat treatment, crystallized to form fine-grained polycrystalline materials. Most inorganic glasses can be made to transform from a noncrystalline state to one that is crystalline by the proper high-temperature heat treatment. This process is called **crystallization**, and the product is a fine-grained polycrystalline material that is often called a **glass-ceramic**. Glass-ceramic materials have been designed to have the following characteristics: relatively high mechanical strengths; low coefficients of thermal expansion (to avoid thermal shock); relatively high temperature capabilities; good dielectric properties (for electronic packaging applications); and good biological compatibility. Some glass-ceramics may be made optically transparent; others are opaque. Possibly the most attractive attribute of this class of materials is the ease with which they may be fabricated; conventional glass-forming techniques may be used conveniently in the mass production of nearly pore-free ware.
The most common uses for these materials are as ovenware, tableware, oven windows, and range tops—primarily because of their strength and excellent resistance to thermal shock. They also serve as electrical insulators and as substrates for printed circuit boards and are used for architectural cladding and for heat exchangers and regenerators. Typical composition (in wt %) of Glass ceramic (Pyroceram) is 43.5 % SiO_2 , *14.0 %* Na_2O, *0%* CaO *30 %*Al_2O_3 *5.5*B_2O_3 *6.5* TiO_2, and *0.5 %* As_2O_3.
The properties of glass ceramics can be tailored to have specific properties to fit the desired application. These include:

- Thermal expansion, which can be made to match that of the material to which the glass ceramic is to be fused, or possibly to approach zero;
- Refractoriness;
- Transmission of light;
- Colour, or Machinability.

CERAMICS

Ceramics are defined as inorganic, nonmetallic materials. In general, ceramic materials are hard, brittle, wear resistant, and corrosion resistant. These properties reflect the strong atomic bonds that exist between atoms in many ceramic materials. From a chemical composition perspective, ceramics are commonly chemical compounds rather than single element compositions.

Ceramics can be single crystal or polycrystalline in nature. Polycrystalline ceramics often have their individual grains held together by a glassy “binder” phase located along the grain boundaries. The binder glass is typically 0-10 wt.% of the ceramic. Traditional oxide ceramics include Al203 (alumina), Be0 (beryllia), and Si02 (silica or “fused” silica). Single-crystal variations of Al203 and Si02 are, respectively, sapphire and “single-crystal quartz.

Ceramics tend to be hygroscopic (surfaces attract water). The thermal stability of most ceramics is excellent.

Raw materials and their characterization

- Fundamentals and mineralogy
- Plastic raw materials for ceramic technology
- Non-plastic raw materials for ceramic technology
- characterization techniques for ceramic raw materials

Shaping

- Dry pressing
- Plastic forming
- Casting techniques
- Other techniques (Hot pressing, Hot isostatic pressing)

Drying

- Principles of drying
- Drying techniques

Firing and sintering

Firing is the high-temperature treatment in ceramic technology, by which the consolidated powder compact (green body) is transformed into a rigid ceramic (dense or porous) and sintering is the corresponding process occurring in the material.

ADVANCED CERAMICS

Advanced ceramics and glasses are carefully engineered materials that have been developed for their particular mechanical, electrical, magnetic, or optical properties. Advanced ceramics and glasses include a wide range of chemical compositions, crystal phases, and varying microstructures. Structural ceramics for high-stress, high-temperature, or corrosive environments where metals fail. Applications include engines, wear parts, thermal management, processing equipment, and biomedical and dental components. Compositions in this category include alumina, silicon nitride, silicon carbide, zirconia, boron nitride, mullite, cordierite, and molybdenum disilicide.

Clay-based ceramics

- **Technical porcelains** are ceramics based on clay and other silicates with added alumina.

Used primarily for electrical purposes (fine-grain) but coarser grain size for chemical stoneware and kiln furniture are also included. These are well vitrified and therefore non-porous.

- **Porous ceramics** may be based on clay, cordierite or alumina up to about 80%. They are used primarily as electrical heating and thermocouple insulations where their porosity confers resistance to thermal shock and machinability

Oxide-based ceramics

Consist of synthetic oxides together with bonding materials which sometimes form a glassy phase. The amount and composition of the glass has a significant influence on the engineering properties. In general, a low glass content gives a high refractoriness, a large grain size, high electrical resistance and low dielectric loss. On the other hand, strength and wear resistance are favoured by a low grain size which requires more glass to reduce the firing temperature.

- High alumina ceramics
- Zirconium ceramics
- Titanium ceramics
- Magnesia ceramics
- Beryllium ceramics
- Other oxide ceramics (includes lime, thorium, uranium dioxide, ferrites, titanates

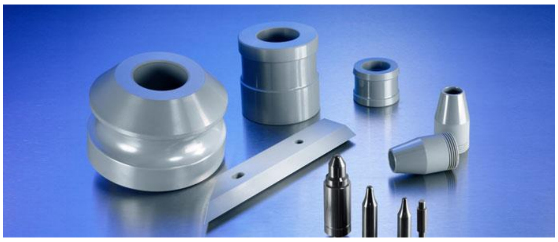
Non-oxide ceramics

Non-oxide ceramics differ essentially from oxide ceramics in that they oxidize at high temperatures in air and cannot therefore be fabricated by a conventional oxide-sintering process. The most important are carbides, silicides, borides and carbons.

- Silicon carbide (carborundum)
- Silicon nitride-based materials
- Sialons
- Boron carbide
- Boron nitrides

Graphite and Carbon

Graphite-fireclay refractory shaped products based on graphite/Carbon and refractory grog with a ceramic bond.



Application of ceramics

Piezoelectric ceramics—generate electric fields when mechanical strains (i.e.,dimensional changes) are imposed.

Microelectromechanical systems (MEMS)—smart systems that consist of miniaturized mechanical devices integrated with electrical elements on a substrate (normally silicon).
Ceramic ball bearings—for some bearing applications, bearing steel balls are being replaced by Si_3N_4 balls. Silicon nitride is harder and less dense and has a higher compressive strength than bearing steels.
Cermets - Another important class of ceramic-like materials are the cermets, a contraction of "ceramic-metal'' composites. Cermets are cemented ceramics, that is, particles of ceramic, e.g., Sic, A1203, etc., that are bonded together using a metal or metal-alloy binder. Cemented WC is a material in which Co is the binder for WC particles. The Co content is very small, approximately 6 wt.%, and binds the individual WC particles together.
Abrasive ceramics - The abrasive ceramics are used to cut, grind, and polish other softer materials. This group of materials must be hard and tough and be able to withstand high temperatures that arise from frictional forces. Silicon carbide, tungsten carbide, corundum, and silica sand are the most common abrasive materials.
Porous and cellular ceramics - Refractory insulation materials, Thermal and acoustic insulation materials, Lightweight materials , Catalyst supports, High-temperature filters or membranes.
Bioceramics - Bioinert ceramics are mainly used in load-bearing applications (alumina, zirconia, alumina-zirconia composites) or as low-friction coatings (pyrolytic or diamond-like carbon), while bioactive ceramics are used for non-load bearing applications, e.g. fillers (hydroxyapatite, bioactive glasses and glass ceramics) or as biodegradable (resorbable) materials in bone tissue engineering (tricalcium phosphate).

REFRACTORY CERAMICS

Refractory materials are used as thermal insulation in high-temperature kilns and furnaces. Refractory ceramics are materials with heat resistance min. 1500°C. Highly refractory materials withstand temperatures > 1800 °C. They resist mechanical loading and degradation by corrosive gases, liquids, or solids at elevated temperatures without chemical or mechanical damage.
Shaped refractories - These materials consist of precision graded coarse and fine refractory grains. The most common binder used in castables is HAC (high alumina cement). Grog bricks – grog is calcined kaolin with low thermal expansion. Basic bricks – magnesite, chromium – magnesite, magnesite-calcium, carbon, zirconium etc.
Unshaped refractories – monolithic refractories, mortars, heat resistant concrete – MCC (medium content of Al-cement), LCC (low content of Al-cement), ULCC (ultra-low content of Al-cement), NCC (non-cement content). Utilization is possible max. to 2000 °C depending on cement content, aggregate etc.

Refractory materials – oxides, non-oxides, others.

Raw materials - fire clays, quartzite – production of silica refractory.

Requirements: mechanical stability and corrosion resistance at high temperature (materials for inner walls of furnaces and melters), high thermal resistivity (materials for outer walls of furnaces and melters) and sufficiently high thermal shock resistance (required for all materials).