

1. Introduction to building materials engineering. Fundamentals of building materials engineering

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1.1. Chemical bonds

The behavior of materials under various types of loads can be explained in terms of atomic and defect structure of material. In many materials, the atoms can be grouped into unit cells or building blocks, often called crystals. However, there are many materials in which no clear grouping of atoms into unit cells or crystals can be identified. Atoms in such amorphous materials are apparently randomly distributed, and it is difficult to discern clear groups of atoms in such materials. Nevertheless, in amorphous and crystalline materials, mechanical behavior can only be understood if we appreciate the fact that the atoms within a solid are held together by forces that are often referred to as chemical bonds.

Two main types of chemical bonds, often occur together in solids, are known to exist (Tab.1.1):

- primary bonds: strong bonds with ionic, covalent, or metallic character;
- secondary bonds: weaker bonds (second attraction forces and hydrogen bonds).

Table 1.1. Characteristics of basic bonds

Bond type	Principle	Remarks
Primary bonds		
Ionic bonds	a result of strong electrostatic Coulomb attractive forces between positively and negatively charged ions; the ions may be formed by the donation of electrons by a cation to an anion (both ions achieve more stable electronic structures)	<ul style="list-style-type: none"> - Typical bond strengths: 40 and 200 kcal/mol; ionic bonds are nonsaturating and nondirectional; - high melting points since a greater level of thermal agitation is needed to shear the ions from the ionically bonded structures; - relatively difficult to break during slip processes that after control plastic behavior (irreversible deformation); relatively brittle since they can only undergo limited plasticity; - examples of ionically bonded solids include sodium chloride and other alkali halides, metal oxides, and hydrated carbonates.
Covalent bonds	between atoms with nearly complete outer shells. The atoms typically achieve a more stable electronic structure (lower energy state) by sharing electrons in outer shells to form structures with completely filled outer shells	<ul style="list-style-type: none"> - bond strengths between 30 and 300 kcal/mol may result in molecular, linear or three-dimensional structures, eg. polymers. - due to electron sharing, covalent bonds are directional in character. - plasticity in covalently bonded materials is associated with the sliding of chains consisting of covalently bonded atoms (such as those in polymers) or covalently bonded layers (such as those in graphite) over each other; - plastic deformation of three-dimensional covalently bonded structures is difficult because of the inherent resistance of such structures to deformation.
Metallic bonds	bonds can be understood as the overall effect of multiple electrostatic attractions between positively charged metallic ions and "gas" of delocalized electrons (electron cloud) that surround the positively charged	<ul style="list-style-type: none"> - the electrostatic forces between the positively charged ions and the sea of electrons are very strong - the high strengths of metallically bonded materials; - bonds are nonsaturating and nondirectional in character; - hence, line defects within metallically bonded lattices can move at relatively low stresses (below those

	ions	required to cause atomic separation) by slip processes at relatively low stress levels
Secondary bonds		
Secondary attraction forces		–
Hydrogen bonds	the attractive interaction of a hydrogen atom with an electronegative atom, such as nitrogen, oxygen or fluorine, that comes from another molecule or chemical group. The hydrogen must be covalently bonded to another electronegative atom to create the bond.	<ul style="list-style-type: none"> – bond (5 to 30 kJ/mole) is stronger than a van der Waals interaction, but weaker than covalent or ionic bonds; – this type of bond occurs in both inorganic molecules such as water and organic molecules. It also plays an important role in the structure of polymers, both synthetic and natural; –

1.2. Structures of solids

The bonded atoms in a solid typically remain in their lowest energy configurations. In several solids no short- or long-range order is observed (amorphous solids). Amorphous materials may be metals, ceramics, or polymers. Many are metastable, i.e., they might evolve into more ordered structures on subsequent thermal exposure; usually the rate of structural evolution is very slow due to slow kinetics.

Metals and ceramics

Metals are usually solid elements in the first three groups of the periodic table. Ceramics are compounds formed between metals and nonmetals. Ceramics may have ionic, covalent, or mixed ionic and covalent bonds. The relatively high compressive strengths of most ceramics may also be attributed largely to strong ionic and/or covalent bonds; ceramics are brittle due to their inability to accommodate strains in the presence of crack tips.

Metals and ceramics usually have long-range, ordered, crystalline structures. However, amorphous structures may also form under certain processing conditions. In the case of crystalline metallic and ceramic materials, the atoms within each crystal all have the same orientation. A crystalline lattice, consisting of regular repeated units in a regular lattice, is observed.

The arrangement of atoms may therefore be described by a three dimensional grid. The most common crystalline lattices in metallic materials are the body-centered cubic, face-centered cubic, hexagonal closed-packed and the simple cubic structures.

Polymers

The building blocks of polymers are called mers. These are organic molecules, each with hydrogen atoms and other elements clustered around one or two carbon atoms. Polymers are covalently bonded chain structures that consist of hundreds of mers that are linked together via addition or condensation chemical reactions. Most polymeric structures are based on mers with covalently bonded carbon-carbon (C-C) bonds. Typical chains contain between 100 and 1000 mers per chain. Also, most of the basic properties of polymers improve with increasing average number of mers per chain. Polymer chains may also be cross-linked by sulfur atoms (vulcanization).

Most polymeric structures are amorphous, i.e., there is no apparent long-or short-range order to the spatial arrangement of the polymer chains. However, evidence of short- and long-range order has been observed in some polymers. Such crystallinity in polymers is due primarily to the formation of chain folds, observed typically in linear polymers (thermoplastics) since such linear structures are amenable to folding of chains. More rigid three-dimensional thermoset structures are very difficult to fold into crystallites (crystallinity is typically not observed).

Long-chain polymeric materials exhibit a transition from rigid glasslike behavior to a viscous flow behavior above a temperature that is generally referred to as the glass transition temperature, T_g . This transition temperature is usually associated with change in coefficient of thermal expansion. The three-dimensional structures of thermosets (rigid network polymers) generally disintegrate at elevated temperatures - thermosets cannot be reused after temperature excursions above the critical temperature levels required for structural disintegration. Linear polymers (thermoplastics) do not disintegrate so readily at elevated temperatures, although they may soften considerably above T_g . They can thus be re-used after several elevated-temperature exposures.

1.3. Classification of the building material

A term of “building materials” covers wide range of various materials used in building industry for overground, ground and underground structures. Concrete and cement based materials, tiles and stones and timber are basic construction materials in EU.

Taken into account internal microstructures building materials and compounds belong to two main groups: homogenous (one phase), and non-homogenous (multi-phase). The most ordered structures have metals and alloys. They crystallize in three main crystal types: bcc, fcc and hcp. However, it should be pointed out that most metals are used in polycrystalline form – their microstructure contains many grains oriented in different way depends on the plastic and heat treatment. The many mechanical properties depends on the grain size, eg. Hall-Petch relationship.

Recently, the most construction materials belongs to the composites. The definitions and technical issues related to the composites are presented on slides 11-18. One of the most rapidly growing types of composites are polymers. Various plastic types are commonly used in building industry. A new area of polymer composites application is repair and strengthening of concrete structures (slides 19-22). They are considered as interesting, innovative materials, eg. for replacement of steel bars in concrete structures (slides 23,24) or light transmitting concrete (slides 25-27). It can be expected that field of application of polymers will grow up and new polymer types will be applied, eg. mineral polymers (slides 28,29).

The basic problem in fast incorporation of a new material solution are law regulations. The main issues in this area are discussed on slides 31-38.

Proper selection of building materials based on the selection of material properties suitable for given application. The overview of technical properties are presented on slides 40 – 109.