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PREFACE

Dear Friends and Colleagues!

The textbook *Dental Materials Science* is intended for students pursuing a degree in Dentistry and has been developed to summarize the latest data in materials science. The team of authors has made an effort to present the material in a detailed and accessible manner, drawing on practical, scientific and educational experience. The textbook consists of three chapters. At the end of each, review questions are provided to assess material comprehension. The structure of the textbook is classical, designed with consideration for scientific, educational and clinical principles. The introduction describes the basic properties of materials and methods of their study in materials science. The chapter «Materials used in prosthetic dentistry» presents the characteristics of structural and auxiliary materials. The chapter «Materials for Conservative Dentistry» describes all classes of materials used for direct restoration and root canal obturation. The chapter «Materials for Surgical Dentistry» presents the characteristics of suture materials and implant materials. The textbook is intended for dental students studying Dental Materials Science according to the Federal State Educational Standard. The team of authors will appreciate and consider all recommendations for improving the book.

Authors

Chapter 1

MATERIALS USED IN PROSTHETIC DENTISTRY

Materials used in prosthetic dentistry must meet the following requirements: be biocompatible, resist all possible impacts of the oral environment, ensure a strong and constant bonding to hard dental tissues, fully reproduce their appearance, exhibit a complex of physicommechanical properties consistent with the properties of the natural tissues to be restored, and promote treatment and regeneration. All materials are divided into two groups: main and auxiliary. *Main* materials are used to produce all types of prosthetic structures: single crowns, dental bridges, removable prostheses, splints, post and cores, inlays, veneers. These include metal alloys, plastics, and ceramics. *Auxiliary* materials are used at various stages of the prostheses production. These include impression materials, casting and modelling materials, packing, sanding, polishing heads and pastes, cements. The main and auxiliary materials are presented in **Table 1.1**.

Table 1.1. Main and auxiliary materials used in prosthetic dentistry

Dental materials						
Main			Auxiliary			
Metals	Polymers	Ceramic	Polymers	Low melting-point metals	Wax	Gypsum

The technology of production of dental prostheses includes clinical and laboratory stages (**Table 1.2**).

Dental prosthesis production process begins with taking an impression by a prosthodontist. Based on the obtained impression, diagnostic and working models are made of gypsum. A dental technician in the laboratory makes a prosthesis using a working model.

At the initial stages, the prosthesis is made of modeling materials, with wax being the primary option. Then the wax is replaced with a structural material, plastic or metal alloy. Replacement is carried out after the production of a master cast, for which medical gypsum or molding materials are used. After replacing the

Table 1.2. Stages of dental prostheses production

Stage of production of an dental prosthesis		Materials used
Clinical stages	Preparation of teeth, taking impressions	Impression materials
	Try-in	Polishing heads and pastes
	Fixing the prosthesis	Cements and adhesive systems
Laboratory steps	Model making	Gypsum
	Fabrication of a wax duplicate denture	Waxes
	Replacing the wax with a construction material	Packing masses, metals, plastics
	Treatment of metal frames or finished removable prostheses	Polishing heads and pastes
	Metal frame coating	Metals, ceramics, plastics
	Final polishing and sanding	Polishing heads and pastes

wax in the denture model with the structural material, the finished prosthesis is removed from the mold, cleaned of the remaining molding mass, and polished (**Fig. 1.1**).

Fabrication of full metal dental prostheses

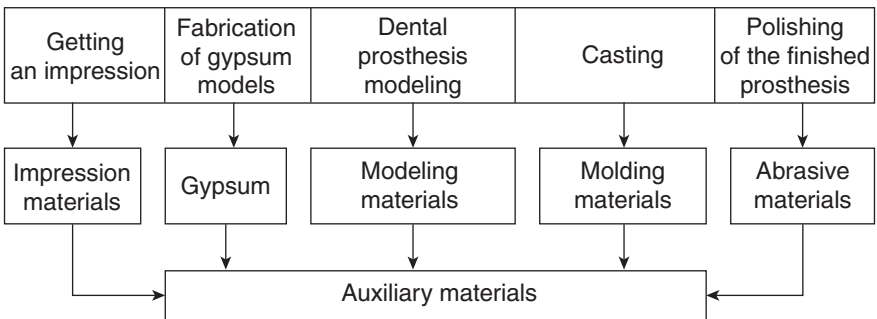


Fig. 1.1. Stages of production of dental prostheses and auxiliary materials for each stage

Each material has certain properties. Metals and their alloys are used in prosthetic dentistry when the prosthesis must withstand significant mechanical loads (**Fig. 1.2**).

Ceramic has a light color and translucency. Therefore, it can be used to create esthetic dentures that reproduce the appearance of natural teeth (**Fig. 1.3**).

Dental polymers in prosthetic dentistry are used for production of fixed appliances, removable prostheses, as well as auxiliary materials. In dentistry, chemically different materials are often combined.

IMPRESSION MATERIALS

An *impression* is a negative imprint of the hard and soft tissues of the mouth, obtained using impression materials (**Fig. 1.4**).

Based on the impression, a gypsum model is made, which is a positive imprint of the hard and soft tissues of the mouth.

The following requirements are applied to the impression materials: biological inertness, absence of unpleasant taste and odor, possibility of disinfection, plasticity, minimal shrinkage of the material, accurate reproduction of the relief and microrelief of the oral tissues, strength, sufficient working time, and a short hardening time of the material.

Impression materials are classified by the chemical nature of their components, physical condition after setting, conditions of use, and



Fig. 1.2. Metal alloys for the production of dental prostheses



Fig. 1.3. Ceramic blocks for production of all-ceramic dental prostheses



Fig. 1.4. Alginate impression

possibility of reuse. There are solid and elastic impression materials. Solid impression materials are divided into irreversible (gypsum, zinc oxide-eugenol) and reversible (thermoplastic compounds). Elastic impression materials are divided into hydrocolloids (reversible, irreversible) and elastomers (thiokol, polyether, silicone) (**Table 1.3**).

Table 1.3. Classification of impression materials by physical state after setting and chemical composition

Impression materials								
Solid			Elastic					
Irreversible		Reversible	Hydrocolloid		Elastomers			
Gypsum	Zinc oxide eugenol	Thermo-plastic compounds	Reversible	Irreversible	Thiokol	Polyether	Silicone	
							Type A — addition	Type C — polycondensation

Solid impression materials

Currently, gypsum is rarely used to make impressions. Characteristics of materials of this group are presented in the «Gypsum» section.

Zinc-oxide-eugenol impression materials are used to obtain impressions of the jaws without teeth (in production of complete removable dental prostheses), to obtain a thin-layer impression on an individual impression tray made of a thermoplastic compound or acrylate, or for bite registration. Currently, the use of zinc-oxide-eugenol materials has significantly decreased. It is available as two pastes. One paste is called the base and the second one is a catalyst. The base paste contains zinc oxide, oil and hydrated resin. The catalyst contains 12–15% eugenol, resin and a filler such as kaolin. The pastes are colored in contrasting colors, which makes it easier to control homogeneity when mixing them. There are slow and quick-setting pastes. When mixing the base and catalyst pastes, zinc oxide interacts with eugenol to form a solid product containing in its structure a matrix (organic salt of zinc eugenolate) and a dispersed phase (residual zinc oxide). To reduce the irritating effect of eugenol, rosin and balsam are added to the pastes. A schematic representation of the setting reaction of zinc-oxide-eugenol impression materials is shown in **Fig. 1.5**.

The advantage of zinc-oxide-eugenol materials is the accuracy of the soft tissue impression reproduction, due to the low viscosity of the material at the initial stage and, therefore, its high flowability. Zinc-oxide-eugenol materials harden quickly in the mouth. These materials are stable after setting, they reproduce surface details well, without shrinking, and have a low cost. The layers

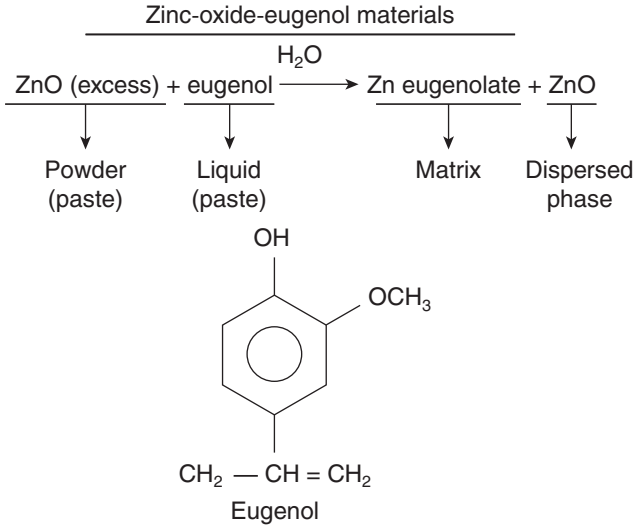


Fig. 1.5. A schematic representation of the setting reaction of zinc-oxide-eugenol impression materials

of this material are well bonded. They also bond well with thermoplastic impression materials.

The disadvantages of these materials include their ability to irritate soft tissues, contaminate skin, clothing, and tools, as well as the instability of setting time with fluctuations in temperature and humidity.

There are impression materials with similar properties that do not contain eugenol. Non-eugenol pastes contain carboxylic acids instead of eugenol, for example, lauric or ortho-ethoxybenzoic acids; they do not cause the burning that occurs in some patients upon contact with eugenol.

Thermoplastic compounds

Impression compounds are thermoplastic masses containing natural resins that add thermoplastic properties to these materials: wax that adds thermoplasticity, stearic acid (plasticizer), fillers (diatomaceous earth and talc) and inorganic pigments (**Fig. 1.6**).

There are two types of impression compounds. Type I is designed to produce impressions, and type II to produce impression trays (**Fig. 1.7**). Impression compounds pre-heated to 45 °C are introduced into the mouth. After cooling to 35–37 °C, they acquire sufficient hardness and rigidity. Therefore, the mechanism of hardening of these putties is a reversible physical process, not a chemical reaction.

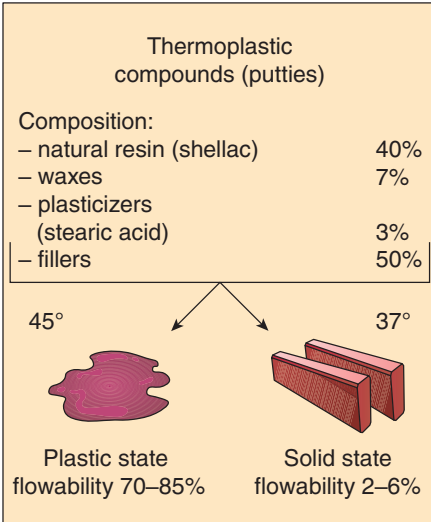


Fig. 1.6. Composition and forms of thermoplastic compounds



Fig. 1.7. Partial impression made of a thermoplastic material

Elastic impression materials

Elastic impression materials include hydrocolloids and elastomers. *Hydrocolloid materials* are divided into reversible (agar) and irreversible (alginate).

The main component of *agar hydrocolloid material* is agar, extracted from seaweed. By chemical composition, agar is a polysaccharide (sulfuric ether of linear galactose polymer). The agar impression material contains 12–15% agar (as a gel-forming component), 0.2% borax (increases strength), 1–2% potassium sulfate (improves the surface quality of gypsum models), 0.1% alkyl benzoate (as a stabilizer), dyes and flavors, and up to 85% water. Hydrocolloid agar materials have high elasticity. Recovery after deformation can be up to 98.8%. They have sufficient flexibility with a relative deformation of up to 11.0%. They show higher strength with rapid application of stress, so it is recommended to remove the impression from the mouth with a quick movement, a jerk.

Special equipment is needed to work with agar materials: a three-section bath for heating the gel and an impression tray with water cooling. Currently, dental clinics use elastomers instead of agar hydrocolloid impression materials. Agar materials are more often used as duplicate masses.

Agar impression materials are non-toxic, hydrophilic, and resistant to moisture (allowing the making of impressions from surfaces with blood and liquids). Hydrocolloid impressions can be easily separated from gypsum models; they do not leave stains on the surrounding surfaces and do not have an unpleasant odor.

Hydrocolloid impressions cannot be stored; it is essential to promptly create a gypsum model upon obtaining the impression.

Alginate impression materials are manufactured as a powder, the main components of which are sodium or potassium alginate (12–15%) and calcium sulfate dihydrate (8–12%). The composition includes diatomaceous earth as a hardener (70%) and sodium phosphate (2%) as a setting reaction inhibitor. To improve the surface quality of gypsum models, potassium sulfate or alkaline zinc fluorides (10%) are added to the powder. To improve organoleptic characteristics, flavors (traces) are added.

When mixing the impression alginate material, the powder is mixed with water. The process of their combination consists of two main chemical reactions (Fig. 1.8).

Polymerization reactions

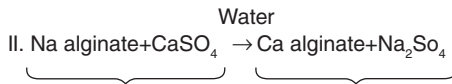
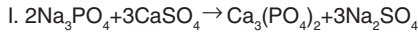


Fig. 1.8. Main components of the composition and setting reaction of alginate impression materials

First reaction: sodium phosphate interacts with calcium sulfate to ensure sufficient working time. Second reaction: calcium ions replace sodium or potassium ions in two molecules, forming a calcium alginate cross-linked complex or polymer.

Alginate impression materials (Fig. 1.9) are used in the production of partial and complete removable dental prostheses, as well as in orthodontics.

There are many types of *elastomeric impression materials* with different chemical compositions and properties. Synthetic polymers are used to produce elastomeric impression materials. Synthetic polymers consist of large coiled molecules, weakly bound to each other (weak intermolecular forces) in the initial state of the impression material. After

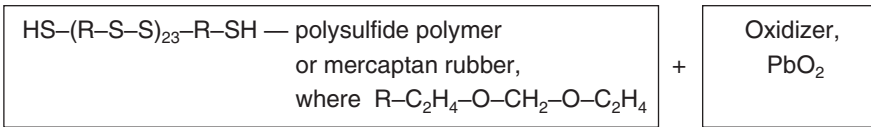


Fig. 1.9. Alginate impression from the upper jaw in complete absence of teeth

setting, the material becomes hard without loss of elasticity, which allows it to return to its original size and shape even upon significant deformation. They are divided into thiokol (polysulfide), polyether, and silicone materials.

Due to their high accuracy, *thiokol (polysulfide)* materials are used to obtain impressions for production of dental bridges and crowns. They are available as two pastes (base and catalyst) having different colors that are mixed immediately before receiving an impression. The main paste contains polysulfide or mercaptan rubber, and the catalyst contains an oxidizer, most often lead oxide (**Fig. 1.10**). Thiokol (polysulfide) elastomer impressions have high flexibility and strength. The elastic impression is easily removed from the mouth. However, their elasticity is lower than that of all other elastomers.

Polysulfide impression materials



Base paste

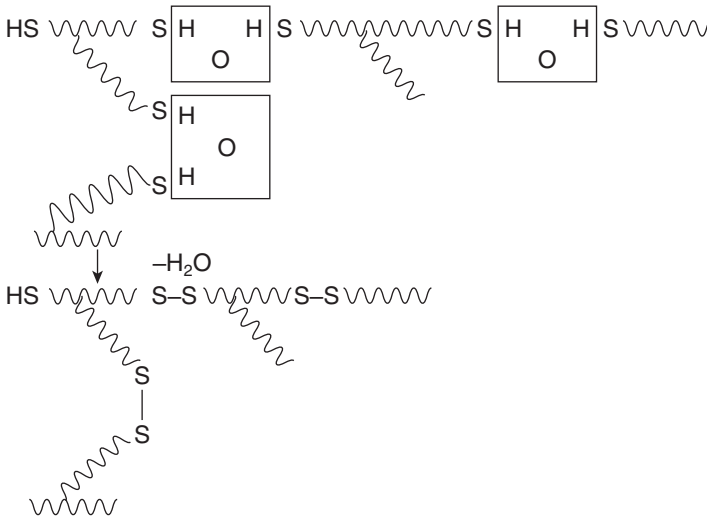


Fig. 1.10. Schematic representation of the setting process of polysulfide impression materials

Elastomeric impression materials based on polyethers

Polyether materials are available as a set of two pastes: a base and a catalyst. The base paste contains low molecular weight polyether with terminal ethylenimine

groups, as well as fillers such as colloidal silica and plasticizers. The catalyst paste contains an aromatic sulfonic acid ester. When mixing the base paste with the catalyst, ionic (cationic) polymerization occurs. It starts with the formation of the primary alkyl radical, the opening of the ethylenimine ring with subsequent growth of macromolecular chains and their crosslinking (**Fig. 1.11**). Polyether materials are used to obtain accurate impressions.

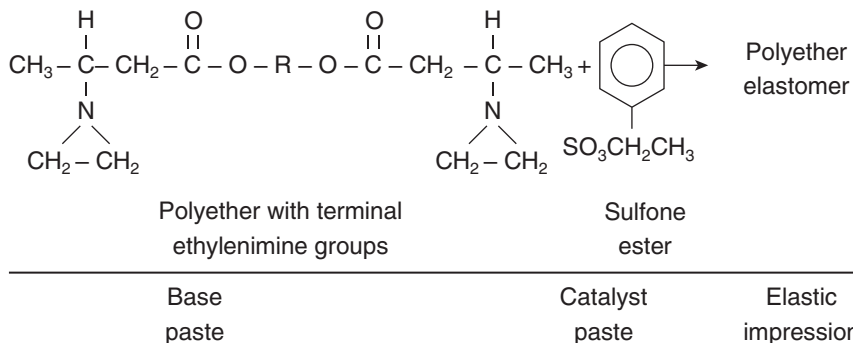


Fig. 1.11. Schematic representation of the setting mechanism of a polyether impression material

Low, medium and high viscosity polyether materials are manufactured. Polyether materials are extremely accurate, their shrinkage is 0.3% in 24 hours.

The advantage of polyether elastomeric materials is their higher accuracy in comparison with polysulfides and condensation silicones. They reproduce well the microrelief on the impression itself and the model cast made using it. When stored under appropriate conditions, the dimensions of a polyester impression remain stable for a week. The disadvantages include high rigidity after setting.

Silicone impression materials

Silicone impression materials are divided into two subgroups depending on the polymerization reaction: addition silicones (A-silicones) and condensation silicones (C-silicones¹).

Addition silicones (A-silicones) polymerize via the classical polymerization reaction — a polyaddition reaction without splitting off by-products. The polymerization reaction of A-silicones is based on polymerization between divinyl polysiloxane and polymethylhydrosiloxane with a platinum salt as a catalyst. They are often referred to as polyvinyl siloxane or vinyl polysiloxane. Like other elastomers, these materials are produced in the form of two different color pastes, which allows to control the quality of their mixing (**Fig. 1.12**).

¹ From English — condensation polymerization.



Fig. 1.12. A-silicone impression material. Base layer

The base paste contains polymethylhydrosiloxane as well as divinyl polysiloxane. The catalyst paste contains divinyl polysiloxane and a platinum salt. Both pastes contain fillers (**Fig. 1.13**).

To avoid polymerization reaction by products, correct proportions of divinyl polysiloxane and polymethylhydrosiloxane should be used, and impurities should be avoided. Residual polymethylhydrosiloxane in the material can lead to a secondary reaction with each other or with the moist environment of the mouth to form gaseous hydrogen, a by-product of the reaction that does not affect the stability of the impression size. Palladium is used as a hydrogen absorber. An A-silicone impression should not be cast immediately, if an epoxy resin is planned to be used as a model material.

Condensation silicones (C-silicones) polymerize via a polycondensation reaction, which results in release of a by-product during the formation of the polymer. *Silicone* polycondensation (or condensation, type C) materials are used to obtain impressions in the production of dental crowns and bridges. It is available as two pastes or as a base paste + catalyst liquid kit (**Fig. 1.14**). Silicone condensation materials have high elasticity.

The base paste consists of polydimethylsiloxane with an α - ω -hydroxyl end (see **Fig. 1.10**). The setting of this material involves a polymerization reaction of trifunctional and tetrafunctional alkyl silicates with tin octoate as a catalyst. The material is polymerized by crosslinking between the terminal groups of silicone polymers and alkyl silicate to form a three-dimensional grid (**Fig. 1.15**). Ethanol is a by-product of the reaction. Its evaporation causes shrinkage that occurs of the material when it hardens.

Condensation silicones have an increased hydrophobicity, therefore, to obtain an impression, it is necessary to maintain maximum surface dryness. The disadvantages of these materials include their inability to maintain high accuracy during storage due to release of by-products during the polycondensation reaction.

Silicone materials allow using a multi-step impression technique: the base of a two-step impression is made with a high-viscosity material, and the correction

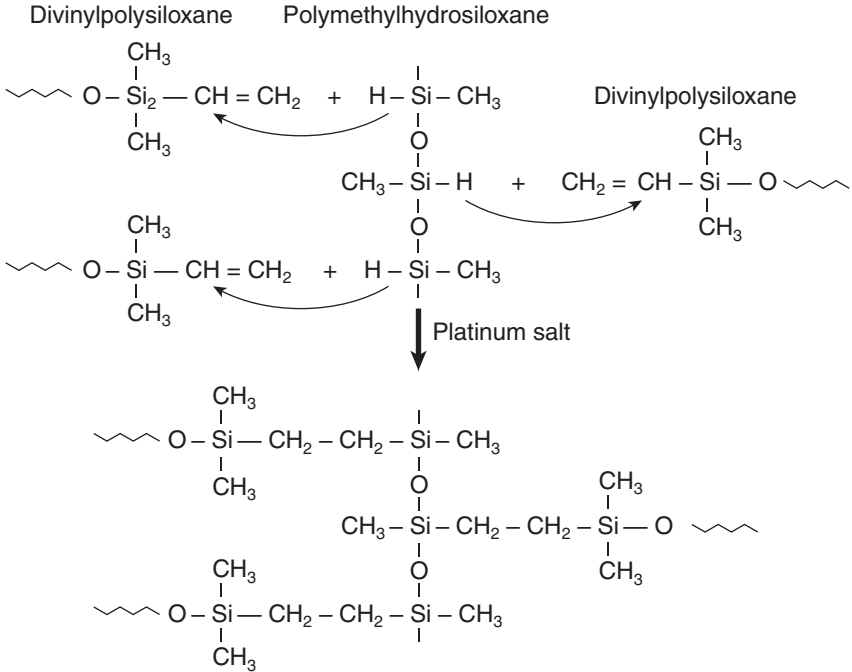


Fig. 1.13. A schematic representation of the setting mechanism for type A silicone impression materials

is performed using a low-viscosity material. This technique increases the accuracy of a silicone impression (**Fig. 1.16**).

The accuracy of addition silicones exceeds that of polycondensation silicones. This advantage is due to the transition from the polycondensation reaction to the polyaddition reaction, which occurs without splitting off by-products. Due to their high accuracy, these materials allow excellent results in making impressions for the production of dental crowns, bridges and partial removable prostheses. They have the required density after setting.



Fig. 1.14. C-silicone impression material. Base layer

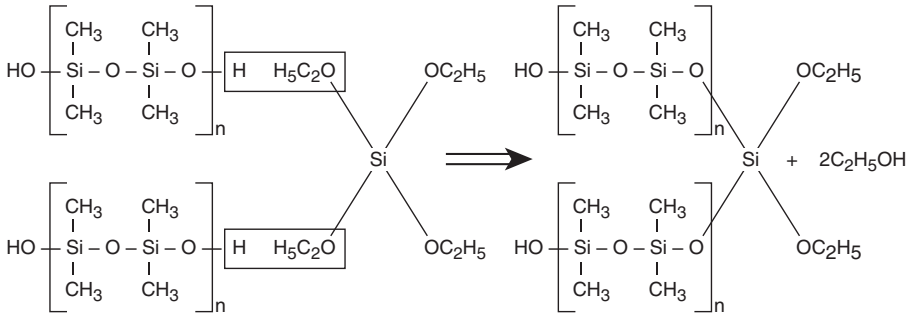


Fig. 1.15. A schematic representation of the setting process for type C silicone impression materials

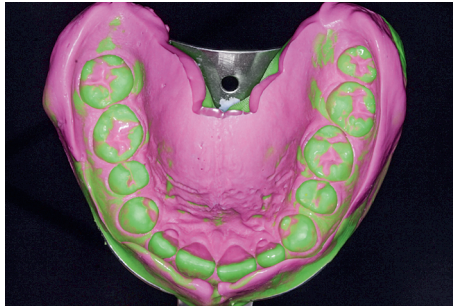


Fig. 1.16. Two-step silicone impression

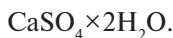
Questions for this section

1. Describe the classification and general characteristics of auxiliary materials.
2. What are the main properties of the materials used to take impressions?
3. Which components of zinc oxide-eugenol impression materials provide their setting?
4. List the advantages and disadvantages of zinc-oxide-eugenol impression materials.
5. What are the main components of agar hydrocolloid impression materials?
6. What are silicone impression materials?
7. What is the purpose of the main components that make up the powder of alginate impression material?
8. What factors affect the setting time of alginates?
9. Why are alginate impression materials classified as irreversible hydrocolloids?
10. What have you learnt about the setting process and the main properties of polysulfide impression materials?

11. What have you learnt about the setting process and the main properties of polycondensation silicone impression materials?
12. What have you learnt about the setting process and the main properties of addition silicone impression materials?
13. How do the ratio of a base and catalyst paste and temperature affect the working and setting times of elastomer impression materials?
14. Compare the elasticity of silicone, polysulfide and polyether materials.
15. What are the advantages of polyether elastomer materials?

GYPSUM: ITS PHYSICOCHEMICAL PROPERTIES AND COMPOSITION

Gypsum is a common sedimentary mineral, formed when sulfate salts precipitate from solutions enriched with them in lakes and lagoons. Gypsum in its pure form is very rare. Permanent impurities include carbonates, quartz, pyrite, and clay substances, giving gypsum different colors. There are also gypsum deposits that result from the weathering of rocks. In nature, gypsum appears as a white, gray or yellowish mineral, the chemical formula of which is a calcium sulfate dihydrate:



Gypsum formula

The term «gypsum» means various modifications of calcium sulfate (aqueous or anhydrous).

Gypsum was one of the first impression materials widely used in both dental and clinical practice. As an impression material, gypsum has been used since 1840. It has the ability to accurately reproduce the shape and size of oral tissues and dental structures. It is used in several stages of the dental prostheses production, both clinical and laboratory: to obtain impressions, make models (**Fig. 1.17**), face masks, molding masses, soldering. Dental gypsum is obtained by heating, or thermal treatment, of natural gypsum. Depending on the thermal treatment conditions, its various modifications (α - and β -) are obtained. When heated to 124 °C at 1.3 atm for 6 h, powdered calcium sulfate dihydrate turns into semi-aqueous calcium sulfate or calcium sulfate hemihydrate (α -modification of gypsum). It is characterized by high strength, density (2.72–2.73 g/cm³), water absorption (40–45%). Gypsum density is 2.2–2.4 g/cm³, Brinell hardness is 1.5–2 kg/mm². Crystals of gypsum α -modification are denser and have a prismatic shape.

This substance is considered the main gypsum product used to produce all types of dental gypsum.

Gypsum β -modifications are obtained by heating to 165–170 °C at atmospheric pressure for 10–12 h. β -modification crystals are characterized by porosity,