Abstract: This paper presents an analysis of non-rigid functional dental materials currently available to produce prosthodontics. Non-rigid dental functional impression materials are used for their flow and flexibility. They need to flow readily into minute features of cavity preparations to accurately capture grooves, cervical margin details and pinholes.The material must have a low enough viscosity to be able to be flow into the the tiniest pinhole.

According to Statista Research Service, 40.99 million Americans wear dentures. This number is likely to increase as the population ages. This is the driving force in materials science and engineering research for better functional dental impression materials. According to Ivanhoe, et al. approximately 57% of individuals over 65 years of age wear dentures. [1]

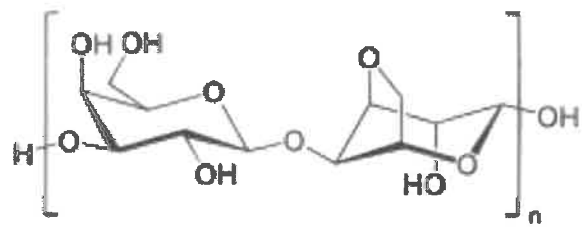
In this paper four criteria are used to evaluate currently available functional dental impression compounds:

1. Impression Fidelity
2. Ease of Working
3. Mechanical Stability
4. Setting Time

Two physical models were constructed to duplicate the palatoglossal arch, the palatoglossus muscle, the hard and soft palates (various complex shapes mimicking the maxillary bones of the hard palate), palatine tonsils, the alveolar ridge, the palatopharyngeal arch, and the palatopharyngeus muscle. In addition, complex shapes were incorporated into the two models, such as pin holes, torus palatines shapes, etc.

The first first non-rigid material examined was the reversible hydrocolloid, agar. WiroGel M, WiroGel C agar-agar, and AEP Colloid's agar-agar were evaluated.

Agar is a long chain polymeric polycarbohydrate composed of monosaccharide units bound together by glycosidic linkages. Two polysaccharides consisting of agarose (up to 70%) and agaropectin construct agar's structure.



The Structure of an Agarose Polymer

Agar exhibits a hysteresis loop, solidifying at 32-40° C (90-104° F), and melting at 85° C (185° F). The polymer has high accuracy as an impression material, it is hydrophilic, and reusable. Special equipment is required to use agar, such as: a water bath, rim lock trays with coiled edges to allow cold water to circulate while the agar is setting from 85° C (185° F) in the patient's mouth. For the record, the boiling point of water at sea level is 100° C (212° F).

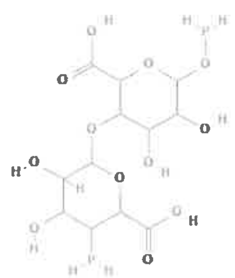
Besides a rather large initial capital outlay, using agar as an impression material involves time consuming and complex procedural steps. The accuracy of an impression depends on casting very quickly.

Agar, even when 0.1% of alkyl benzoate (C12-C15) is added as a preservative, has a short shelf life of six months to two years, according to Cabri.org, (M/1998/2.03).

The non-reversible hydrocolloid alginate was next evaluated. The following powdered alginate products were tested:

1. Hygedent, Practicon 7085610 Cavex Color Change
2. Zhermack Hydrogum 5 Extra Fast (C302070)
3. Vivid Jel All Purpose Fast Set

Alginate is an anionic polysaccharide consisting of two copolymers, guluronic acid and mannuronic acid, which impart strength and flexibility, when reacted (i.e., polymerized).



Alginate Molecular Structure

Dental alginate contains sodium alginic acid (IUPAC name: sodium 3,4,5,6-tetrahydroxyoxane-2-carboxylate) and potassium alginic acid (IUPAC name: potassium 3,4,5,6-tetrahydroxyoxane-2-carboxylate), both of which share the parent compound is hexuronic acid (IUPAC name: 3,4,5,6-tetrahydroxyoxane-2-carboxylic acid).

Alginic acid (a.k.a.: agin) is a major component of a number of biofilms, especially biofilms produced by ***Pseudomonas aeruginosa***, a Gram-negative Gamma-Proteobacteria. ***Pseudomonas aeruginosa*** is a common hospital acquired infection.

Alginate, if sodium phosphate is added to retard the exothermal reaction, has a mixing time of 45 to 60 seconds, and a working time of 45 seconds for the fast set version, which contains less sodium phosphate or 75 seconds for the regular set. Setting time is a function of water temperature used, which determines the kinetic pathway taken. For warm water the setting time is approximately 60 seconds, and can be up to 4 1/2 minutes if cold water is used.

The disadvantages this author found while working with alginate are as follows:

1. It is very easy to entrain air (i.e., bubbles).
2. Very poor shear strength. Alginate tears easily.
3. Virtually no dimensional stability. If unsupported, alginate will distort.
4. A minimum of 3 mm thickness for impressions is required, which makes alginate useless for impressions taken between teeth.

Non-aqueous elastomeric dental impression compounds were next evaluated.

The first class examined were the polysulfides. Polysulfides contain chains of sulfur atoms and fall into two main classes: organic and anionic. In coordination chemistry, polysulfides are ligands that bind to a central metal atom forming an organo-metallic compounds. Ligands are Lewis bases. Polysulfides can undergo a condensation polymerization reaction which releases water forming condensates. Please see Appendix 1 for a schematic illustration of synthesis of metal organic framework functionalized with polysulfide.

Lead and or copper is often added to dental polysulfide functional impressional materials. The National Toxicology Program [2012] concludes that there is sufficient evidence for adverse health effects in children and adults at for lead levels with BLL <5 μg/dL [CDC 2012].

The following polysulfide compounds were investigated:

1. Coe-Flex Lead Free Regular Body Standard
2. Coe-Flex Regular Body Fast Set
3. Kept 60102 Permiastic.

The mixing time was approximately five minutes, with a settling time of ten minutes or more.

The following problems were found with polysulfides as an impression material:

1. Lack of fidelity. Polysulfides do not replicate the finest details.
2. Polysulfides do not flow.
3. Difficult to mix.
4. Long setting times.
5. Moisture was a problem. Polysulfides are hydrophobic which produces poor wetability, and difficult casting.
6. Stability issues. Polysulfide impression compounds distort on setting due to a condensation polymerization reaction. This can worsen with a delay in casting.
7. Polysulfide dental impression material can contain toxic heavy metals.

The next class of synthetic elastomer evaluated were polyethers. Polyethers are a class of organic compounds that contain an ether group and an oxygen group connected to two aryl or alkyl groups. Polyethers generally contain either linkages in their main chain.

Polyethers used in dentistry are supplied as a base and an activator paste, both of the same viscosity (i.e., a mono-phase impression material). The activator paste contains an aromatic sulphonate ester which acts as the cross-linking initiator. There are no reaction by-products, as with polysulfides, so the cast is dimensionally stable. In addition, polyethers are hydrophilic, so good wetability and easy of casting can be had.The working time for polyethers is between two minutes and 20 minutes, with a setting time of approximately five minutes.

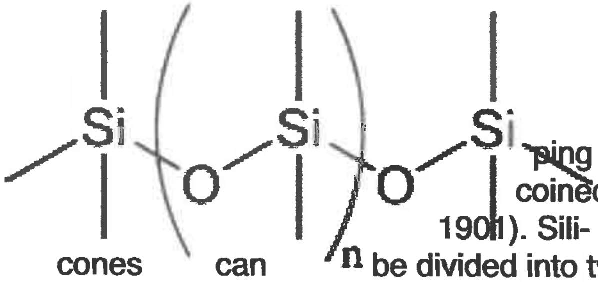
Three dental polyethers were examined:

1. 3M Impregum Pinta Medium Body
2. 3M ESPE Impregum Pinta Soft
3. EXA'lence Heavy Body vinyl polyether.

The disadvantages found with polyethers as functional impressional materials are:

1. The flow characteristics are the poorest of any of the elastomeric materials.
2. Flexibility (i.e., elasticity) is the lowest of any of the elastomeric compounds. Polyethers are too stiff, and can crack when being removed from a stock tray.
3. Fidelity is poor.
4. Rigid when set.
5. Low to moderate shear strength.
6. Short working and setting times.
7. Hydrophilic, which means polysulfides can adsorb moisture. This can have an adverse effect on the cast.

The next class of elastomeric compounds evaluated were polymerized siloxanes (i.e., silicones, the term which F. S. Kip-



ping coined in 1901). Silicones can be divided into two categories: condensation cure and addition silicones.

Chemical Structure of Silicone

Condensation reaction formed silicones are mostly used in construction sealants and caulks. Dental and medical silicones formed by condensation reactions differ from the silicones available at Home Depot or Lowe's, in that they are Class VI, medical grade silicone that is tested for biocompatibility. The reaction method also differs in that a platinum catalyst, that include Pt (0) complexes, Pt (II) complexes and Pt (IV) complexes (3M Innovative Properties, Co. patent number CN104254559 (A)). Tin can also be used as a catalyst.

The condensation cure system(s) comprise two or more silanol functional polyorganosiloxanes.
This condensation reaction forms a three dimensional polymer network, while expelling ethyl alcohol (EtOH). The release of EtOH retards the exothermic polymerization reaction, and induces pronounced shrinkage.

The working time varies from 2 minutes to 20 minutes, with a setting time of approximately 9 minutes.

Five dental impression condensation reacted silicones were assessed:

1. Zhermack Zetalabor Condensation Silicone
2. Coltene Speedex Putty Condensation Silicone
3. Stomaflex
4. Optosil-Xantopren
5. Lusisoft Molloplast-B

The disadvantages of condensation reacted silicones are:

1. Hydrophobic, so wetability is poor and casting is difficult.
2. Lack of flow, so lack of fidelity.
3. Unreliable dimensional stability and shrinkage due to the release of EtOH.
4. Expensive
5. Due to poor dimensional stability, it is difficult to accurately proportion components causing highly variable results.
6. Platinum catalyst reacts with other elastomeric materials and polymers (e.g., gloves, dams, GIC, composites).

The platinum-catalyzed hydrosilation reaction is extensively used today to produce both condensation and addition silicones. A platinum-catalyzed hydrosilation reaction occurs when a silicon-hydrogen (Si-H) bond is added across an unsaturated carbon-carbon double bond (C=C) of an olefin, resulting in the formation of a silicon-carbon (Si-C) bond. The next group of polymerized siloxanes impression materials reviewed were the addition reaction silicones.

Dental addition reacted silicones (i.e., PVS or VPS) are also often platinum catalyzed, but they produce no by-products, as do condensation reacted silicones. This allows for greater dimensional stability and accuracy. In addition, impressions can remain unchanged for months, if not years. Dental addition silicones can be used for one or two stage impressions. The working time for these silicones is between 2 to 15 minutes, with an average setting time of 5 minutes.

Five addition reacted silicones were tested:

1. Elements Light Body Regular Set
2. Plastcareusa Light Body
3. Plastcareusa Heavy Body
4. Defend Super Hydrophilic Vinyl Silicone High Performance
5. Elkem VPS.

The disadvantages of addition reacted silicones are as follows:

1. Poor shear strength
2. Hydrophobic, which will affect wetability leading to poor casting.
3. Platinum catalyst reacts with other elastomeric materials and polymers (e.g., gloves, dams, GIC, composites).
4. Expensive
5. Lack of flow, so there is a lack of fidelity.

Plasticized functional dental were reviewed next. A plasticizer is a chemical added to increase plasticity and to decrease viscosity. Plasticizers affect the elastic modulus, as a function of temperature and the concentration of plasticizer. When a plasticizer is added to a polymer, regardless of the plasticizer's concentration, the polymer's glass transition temperature will decrease. This is explained by the Flory-Fox equation first proposed in 1950 by Paul J. Flory and Thomas G. Fox. The Flory-Fox equation relates molecular weight to the glass transition temperature of a polymer system.

The 'gold standard' for plasticized dental impression compounds was Hydro-Cast, which was created in the early 1920's, but was recently removed from the market.

Hydro-Cast evolved many times since the 1920's, but every version contained low-molecular weight phthalates derived from C3-C6 alcohols. Phthalates are toxic and have been banned from use in medical, dental and veterinary applications. A study in the peer-reviewed journal ***Environmental Pollution*** published October 12, 2021estimated that phthalates may contribute to 91,000–107,000 premature deaths each year among people aged 55–64 in the United States.

Hydro-Cast's plasticizer was mixed with the polymer provided in the kit, according to directions, and then tested.

After testing the aforementioned dental impression materials, the first noticeable effect of Hydro-Cast was its ability to flow into the smallest features. The fidelity to record the finest details was impressive.

The only disadvantage found was Hydro-Cast's toxicity.

A new entry to the market is Flow-Cast, which is a safer alternative to Hydro-Cast.

Flow-Cast uses a proprietary ester based plasticizer, which was mixed with the polymer powder provided in the kit, according to directions, then tested.

Remarkably, Flow-Cast flowed into the smallest pin holes better than Hydro-Cast, and had a higher shear modulus than Hydro-Cast. The fidelity was the best of any dental functional impression materials evaluated in this paper.

Summary: This paper presented an analysis of non-rigid functional dental materials currently available to produce prosthodontics. Four criteria were used to evaluate the commercially available functional dental impression compounds:

1. Impression Fidelity
2. Ease of Working
3. Mechanical Stability
4. Setting Time

Based on these criteria, Flow-Cast was superior to all of the dental functional impression materials evaluated in this paper. Appendix 2 contains application photos of Flow-Cast.

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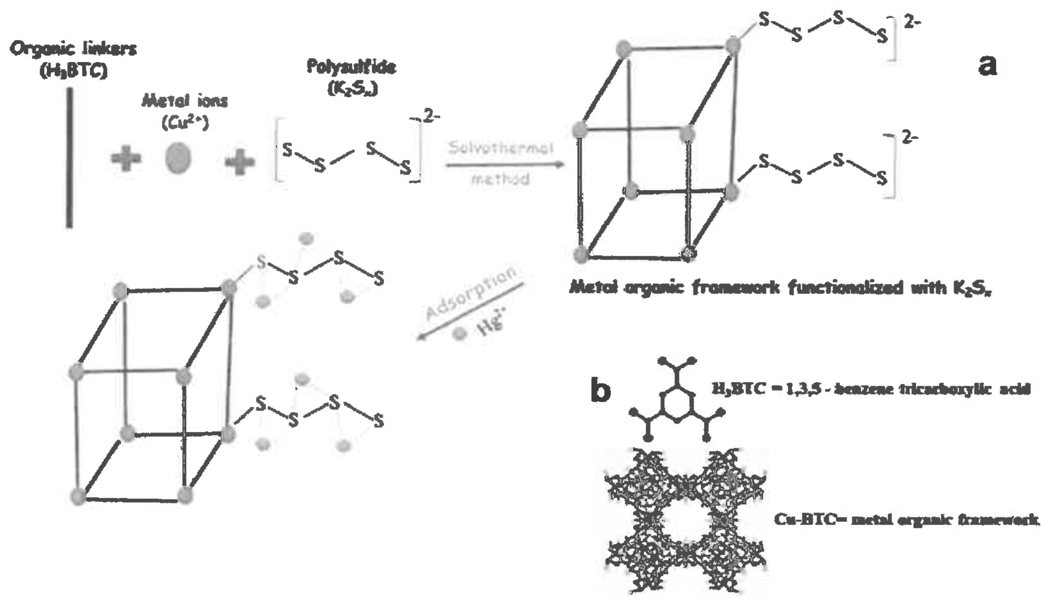
APPENDIX 1



Schematic Illustration of Synthesis of Metal Organic Framework Functionalized with Polysulfide [2]

APPENDIX 2