IMPRESSIONS AND IMPRESSION MATERIALS IN CONSERVATIVE DENTISTRY

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INTRODUCTION

Impressions and Impression Materials form a large part of the manipulative needs of Conservative Dentistry, in the fabrication of inlays, splints, crowns and bridges.

While the history of Dentistry in this field is of recent origin, there has been a great impetus to clinical work of this nature by increased knowledge of the physical properties of the agents used, and in their method of use. Great accuracy may be attained in the construction of inlays, crowns and bridges at the chairside, by the direct method, but this work can be both fatiguing and time consuming. Improvements in impression materials, of a more elastic nature, have led to much, if not most, of this work being carried out in the laboratory, by a more indirect method.

In 1756, Philip Pfaff, a German, was credited with being the first to use sectional wax impressions of the mouth to prepare plaster models. This was the period that both wax and plaster were common dental materials, but it was not until 1840 that wax was used in England for impressions, together with plaster models and metal dies. Plaster was used for mouth impressions in 1844. Some thirteen years later, in 1857, Stänt developed impression compound, and it was used as an impression material in 1874.

It was considerably later that the agar-agar compounds, or reversible hydrocolloids, were suggested by Alphonse Poller in
1925. It was in this year that he was granted a British patent on this material. He sold the patent rights for its dental use to the De Trey Brothers of Zurich, Switzerland, who marketed a modification under the trade name of "Dentocoll". After American patents were granted, many materials were developed of a similar nature, the most essential ingredient appearing to be agar-agar. Sears in 1937 adapted this material in a technique for use in crown and bridgework, while a specification for this material was drawn up by Paffenbargr 127 in 1940.

Alginate was introduced just before World War II, and interest in this material was intensified when supplies of agar were cut off during the war years. As alginate was improved, various authors suggested its use in inlay, crown and bridge procedures. When agar became available again, while these two materials were used in conservative dentistry, drawbacks were encountered that limited their practical usage.

In 1953, Patrick, in the United States of America, during research for an anti-freeze liquid, discovered "Thiokol". This was a chemical synthetic with rubber like properties, and was found capable of being used as an impression paste. Silicone elastomers were introduced about the mid-fifties and came into use as elastic impression materials.

There has been much research and improvement of these materials since their inception and early use. Drawbacks in their physical properties have been improved, as far as possible, and while no one material is ideal as an impression material, scope is offered
in the selection of the appropriate impression material for each individual case.

This critical review covers some of the impressions and impression materials used to produce patterns, dies and models for this phase of conservative dentistry. An attempt is made to evaluate their properties, indications for use and contra-indications in the use of each material.

Since their physical properties are directly related to their manipulation, and also have a bearing on their dimensional stability; these properties are reviewed. The advantages and disadvantages in the use of each, and indications for techniques are mentioned. There has been an attempt to correlate properties in a comparison of those which are of particular interest to the operator, viz. accuracy, reproductibility, ease of manipulation and die materials.

Die and cast materials are briefly reviewed, since some reference in comparison evaluation is made of methods of preparing dies and casts, but there is no attempt to fully cover the structure, chemistry and properties of all die and cast materials.
CHAPTER 1

IMPRESSION TECHNIQUES

Impression materials have been classified into three broad groups:

(i) Rigid substances, or those which set to a rigid consistency. Plaster is in this group.

(ii) Thermoplastic materials, or those which become plastic at higher temperatures and resume their original form when the temperature is lowered again. Impression compound and impression waxes are in this group.

(iii) Elastic materials, or those which remain in an elastic or flexible state after the impression material is removed from the mouth. Agar, alginate, thiokol and silicone are in this group.

The line of demarcation cannot be a strict one, for the action of agar is such that it obeys some of the definition of a thermoplastic material in that it is softened by heat, but strictly does not return to its original form. Rigid materials may be capable of recording tooth or tissue details accurately, but they cannot be removed from the mouth over undercuts without fracture. With the thermoplastic materials, distortion inevitably occurs if they are removed over undercuts, and thus minute details become lost. Elastic materials, therefore, are the only satisfactory materials to record both fine details, and to be removed from the mouth over undercuts without fracture or distortion.

The elastic materials can be further divided into two groups:
(a) **Colloids**

(b) **Elastomers.**

Such restorations as inlays, crowns and bridge units are formed by a gold casting process which utilizes the lost wax pattern technique\(^{131}\). A pattern of wax is first constructed which duplicates the size, shape and contour of the desired gold casting.

Thus wax is used in a great proportion of the clinical side of conservative Dentistry, and is the means by which restorations of a cast nature are fabricated. It may be used as an Inlay wax which can be adapted in two ways: (1) directly, or (2) indirectly. It may also be used as an indirect wax impression.

(1) **The Direct Technique** is one in which the inlay wax is adapted directly into the prepared cavity, cavities, preparation or preparations in the mouth.

(2) **The Indirect Technique** is one in which after a die, model or cast has been made, the inlay wax is adapted to the preparation or preparations duplicated there from the mouth.

(3) **The Indirect Wax Impression** is taken over the preparation or preparations in the mouth, and is an impression from which a die or cast is fabricated.

(1) **Direct Wax Patterns:**

Inlay pattern wax used directly must possess properties which contribute to the accuracy and fine detail of the wax pattern. The wax should be an accurate reproduction in form of the missing tooth structure\(^{177}\). Since in this method the pattern is fashioned on the tooth\(^{78}\), the casting can be no more accurate than the wax
pattern\textsuperscript{177}. A wax which has the ability to function well in the
gold casting technique must possess certain physical properties, such
as softening temperature, resistance to flow, thermal expansion, and
others which are extremely critical in their limitations\textsuperscript{131}.

a. Advantages:

The direct wax pattern technique possesses the following
advantages:

(i) Time saving in that further steps of indirect technique eliminated.
(ii) Mouth used as an articulator regarding occlusion\textsuperscript{82}.
(iii) Inaccuracies and wax variables which could develop in further
steps, eliminated\textsuperscript{16,82,92,196}.
(iv) Reduced armamentarium\textsuperscript{82}.

b. Disadvantages:

The following disadvantages apply to this technique:

(i) A number of preparations can be time consuming.
(ii) Difficulty of correct interproximal contact areas.
(iii) Difficulties of inaccessible cavities, large patterns which
may move\textsuperscript{92}, three or more surfaces\textsuperscript{196}.
(iv) Difficulty of complicated preparations with fine margins\textsuperscript{196}.
(v) Extra appointment needed for patient\textsuperscript{82}.
(vi) Possible errors of direct inlay wax and its manipulation\textsuperscript{177}.

(2) Indirect Wax Patterns:

Wax patterns can be formed by the indirect technique in
that they are fashioned on a die\textsuperscript{78}. The manipulation of such de-
mands that the pattern should be well adapted to the prepared cavity,
properly carved and the distortion factors minimised. Pattern wax for this technique possesses many similar properties to waxes used in the direct technique. Perhaps the greatest difference is that a wax with a property of lower solidification temperature can be employed.

a. **Advantages:**

   This technique possesses the following advantages:-
   
   (i) Saves chairside time by utilizing laboratory techniques.
   (ii) Restorations can be polished ready for cementation.
   (iii) Better marginal adaptation in difficulty cavity preparations.

b. **Disadvantages:**

   These could be the disadvantages of this technique:-
   
   (i) The possibility of a cumulation of errors developing during additional steps.
   (ii) The possibility of inadequate marginal exposure of preparations failing to record.
   (iii) Inaccuracies of impression causing errors.
   (iv) The problem of occlusal relationship being correct.

(3) **Indirect Wax Impressions:**

   In this form, wax is used not as a material to produce a wax pattern, but is an impression recording material in itself. The inlay wax is often confined in a copper band, with an occlusal stop of impression compound. For further refining of detail, the wax can be relined with a second impression inside the first.

a. **Advantages:**

   The following could be the advantages of this technique:-
(i) Simple armamentarium.

(ii) Accuracy of fine detail of the preparation.

(iii) Gingival margin detail without tissue retraction.

(iv) Freedom from air bubbles.

(v) The possibility of further correction of an incomplete impression.

(vi) Can be electro-plated for a metallic die.

b. Disadvantages:

The following may be disadvantages of this technique:

(i) Wax distortion in the form of flow is possible.

(ii) Undercuts present may be disguised by distortion of the impression.

(iii) Wax variables can cause inaccuracies.

(iv) Difficulty of complete heating of the wax.
CHAPTER 2

A. INLAY WAX

GENERAL PROPERTIES

(i) Desirable Properties:

Skinner and Phillips\textsuperscript{177} give the following as desirable properties of inlay waxes.

(1) The wax should be sufficiently plastic at a temperature slightly above that of the tooth so that it can be forced into the prepared cavity to reproduce every minute detail.

(2) It should not, when heated, become flaky or exhibit laminations when it is bent or formed.

(3) It should remain of a smooth texture at all times.

(4) It should be capable of being carved to the thinnest margin without distorting, flaking, or chipping.

(5) The colour of the wax should be in sharp contrast to that of the mouth tissues or die material to aid visibility during carving.

(6) When used directly, pattern wax should not change in dimension greatly when removed from mouth to room temperature - there should be a low coefficient of expansion / contraction.

(7) It should vaporize completely when being "burned out" from investment mould, leaving 0.10% or less of the original weight of the pattern.

The American Dental Association Specification No. 4 for pattern wax may be summarised as below, and the Federation Dentaire Internationale\textsuperscript{55} is similar.
<table>
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<th>COLOUR</th>
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<th>FLOW</th>
<th>THERMAL EXPANSION</th>
<th>WORKING TEMPERATURE</th>
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<td>Contrast with hard and soft tissues</td>
<td>Soften without flaking.</td>
<td>99.5°F.</td>
<td>Provide curve showing thermal expansion from room to softening temperature</td>
<td>Provide wax temperature for most satisfactory use in taking direct impressions</td>
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<td></td>
<td>No appreciable flaking or chipping when trimmed to a fine margin at room temperature.</td>
<td>Not more than 1% [100.4°F.]</td>
<td>Not more than 5% [107.6°F.]</td>
<td>Not less than 5% [109°F.]</td>
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In the Australian Standard Specification for Dental Inlay Casting Wax No. T14² - the classification has been divided into two types:

Type A: Suitable for general use

Type B: Suitable for indirect technique only.

(ii) Actual Properties:

(1) The softening temperature may be many degrees above that of the tooth for complete softening - 122°F. or more as against the 98°F. for the tooth.

(2) Laminations do at times form, and in practical usage, flakiness can appear on the surfaces.

(3) Most waxes have smooth textures.

(4) Flaking and chipping may occur on very fine sections.

(5) The colour, ranging from greens through to black, does not at all times contrast sufficiently with the tooth structure.
(6) Dimensional changes on removal of a direct wax pattern are possible with some waxes.

(7) Most waxes burn out without a heavy residue.

(iii) **Physical Properties:**

(a) **Composition**

The inlay waxes are a finely blended balance of waxes occurring naturally and some created synthetically. Whilst the exact composition of proprietary waxes is a commercial secret\(^{171}\), they are basically paraffin wax, with carnauba, candelilla, beeswax, dammar resin, and colouring agents added. A blend of waxes proposed by R. L. Coleman in 1928\(^{131}\) possesses properties that closely resemble the commercially available inlay pattern waxes. This experimental wax contained 60% paraffin wax, 25% carnauba, 10% ceresin, and 5% beeswax\(^{131}\). By altering the proportions of the different ingredients, the working characteristics are altered, so that a wax can be soft or hard, or intermediate stages between.

(b) **Structure**

In the structure of waxes, while they have many of the properties of a semi-crystalline material, it would be more appropriate to consider them as an amorphous substance of the nature of a super-cooled liquid\(^{171}\). A typical time temperature cooling curve for an inlay wax shows a plateau which in its nature is similar to a metallic solid solution. There seems to be evidence from this of the presence of space lattices in the loosely-knit molecular structure, and the molecules can rearrange themselves under the effect of
heating and subsequent cooling.

![Time-temperature cooling curve for an inlay wax.](image)

(c) **Flow**

The property of flow or marked plasticity is one in which there is a gradual but permanent molecular movement due to either heat or a load.

In spite of the evidence for this semi-crystalline structure, the inlay waxes exhibit a property of flow which in some respects resemble that of a truly amorphous substance or super cooled liquid. Either the liquid or the solid properties may predominate, depending upon the temperature of the wax, but even at room temperature the liquid property of flow is present along with a certain
degree of rigidity.

This property may be easily demonstrated. A stick of wax will snap easily if bent suddenly between the fingers at room temperature. If suspended at its ends only in a horizontal position, it will slowly bow or bend under its own weight, thus exhibiting the property of flow.

The practical significance of flow lies in the construction of the wax pattern. When sufficiently plastic at temperatures tolerable to the mouth, it is flowed or forced into the prepared cavity to impress every minute detail. In this phase the predominance of the liquid property is highly desirable. When cooled and shaped, it must be withdrawn without distortion or flow, and in this phase, the solid property is more essential. Since waxes cannot be maintained at temperatures below mouth temperature whilst in the mouth, the waxes must exhibit a minimum of flow at mouth temperature.

This property is strictly controlled under the American Dental Association No. 4, and the Australian Standard Specification A.S. No. T.14.

From Anderson.

Flow curves of three inlay waxes.
(d) **Thermal Expansion and Contraction**

While the thermal conductivity of waxes is low, and time is required to heat them uniformly throughout, and to cool them to mouth or room temperature, they have a higher linear thermal coefficient of expansion than any other material used in Dentistry\textsuperscript{131,171}.

Smyd\textsuperscript{181} reports that some inlay waxes may expand as much as 1.3\% in the 25°F. range between mouth temperature and room temperature. Skinner and Phillips\textsuperscript{177} noted that wax may change nearly as much as 0.7\% with an increase of temperature of 20°C. (36°F.), but the amount of thermal change may be affected by the previous treatment of the wax. When a wax has been cooled under pressure, and then re-heated, the expansion rate increases sharply above a temperature of approximately 37°C. (99°F.). The temperature at which the change of rate occurs is known as the transition temperature or transition point\textsuperscript{177}, and is thought to be due to some constituents of the wax probably changing crystalline form at this temperature, and the wax becoming more plastic\textsuperscript{177}. Not all waxes exhibit transition temperatures.

Since with most waxes, and particularly with hard waxes, the rate of expansion increases sharply from just below mouth temperature to just above working temperature\textsuperscript{131}, the thermal expansion curve of wax is not a straight line\textsuperscript{2}. It has been reported by Hollenback\textsuperscript{78} that the behaviour of pattern wax when exposed to thermal influence cannot be completely predetermined, as the thermal coefficient of some waxes is changed considerably by manipulative procedures.
(e) **Internal Stresses and Strains**

These factors, which so often give rise to wax distortion or warpage, are the results of manipulation of wax when the temperature is below the transition temperature, and there is disturbance of the molecular arrangement.

Internal stresses and strains are induced by (1) natural tendency of the wax to contract upon cooling, (2) changes in shape of the wax during moulding, and (3) manipulative variables such as carving, pooling and removal. With the inlay waxes, very little stress relief occurs between room temperature and $37^\circ C$. over short periods of time. But if the stressed wax is left at room temperature for any length of time, relief of stress will occur by the gradual movement of molecules and the subsequent distortion of the wax. So all waxes must be manipulated while fully softened in order to reduce the amount of stress.

From Skinner and Phillips.

Thermal expansion of an inlay wax. Curve A represents the thermal expansion when the wax was held under pressure while it was cooled from a liquid state. When the same wax was allowed to cool without pressure and again heated, Curve B resulted.
(f) **Wax Distortion and Variables**

"Probably distortion is the most serious problem faced during the forming and removal of the pattern from the mouth or die. Such distortion arises from thermal changes and from the release of the internal stress always present in the pattern. These stresses are induced from (1) natural tendency of the wax to contract upon cooling, (2) changes in shape of the wax during moulding, and (3) manipulative variables such as carving, pooling and removal. The amount of residual stress and resulting distortion will thus be governed by the method of forming the pattern, its handling, and the length of time and temperature at which it is stored."\textsuperscript{177}

**Theory of Wax Distortion**

Wax pattern distortion is a typical example of relaxation, to which the theory of relaxation applies precisely\textsuperscript{177}.

E. W. Skinner\textsuperscript{97} has postulated that "an inlay wax cannot be treated as an amorphous structure, but must rather be treated as one that is partially crystalline and partially amorphous. When the wax is heated above the arrest point, the thrust of the crystalline growth induces stresses, which may be absorbed temporarily by the amorphous phase. During their release by temperature change, the distortion will be outward, as originally occurred."

On the other hand, if the manipulation is carried out at the lower temperature, the crystalline phase will not be greatly changed. The residual elastic stresses introduced into the amorphous phase by the confinement across the occlusal portion of the
pattern will naturally cause any distortion to occur inward. However, since the rigidity of the crystalline phase is greater than that of the amorphous phase, the latter is neither so sensitive to temperature changes, nor of such magnitude as the former distortion, which occurs as the result of the solidification of the crystalline phase.\textsuperscript{96}

Types of Wax Distortion

It would seem that, apart from distortion by fracture, three types of distortion of a wax pattern are possible.

(1) Expansion Distortion of the Wax Pattern.
(2) Contraction Distortion of the Wax Pattern.
(3) Distortion of the Wax Pattern by Flow.

(1) Expansion Distortion of the Wax Pattern

A distortion in which the movement of the wax is outward at the margins and the casting at the margins does not fit the preparation. This has been described as being "short at the Gingival"\textsuperscript{171}. In many cases, very slight distortions may not be recognised as such in the clinical fit of a casting.

This distortion is more frequently caused by variations in temperature in heating above 130°F.\textsuperscript{97}. It can also be due to incorrect manipulation in which the "elastic memory" or residual stress of wax tends to revert it to its original shape and form, particularly where the wax has not been melted\textsuperscript{182}. In single sprue placement in a MOD wax pattern, Lasater\textsuperscript{97} claims the occlusal portion moves first on removal, pulling the gingival margins away, and that
they flare. Karloff\textsuperscript{87} considers that this form of distortion is possible in withdrawal of wax patterns over undercuts, as does Markley\textsuperscript{113}. Van Aken\textsuperscript{197} in reporting of a definite interaction between the investment and the wax pattern, foresees this distortion with patterns of thin occlusal portions of 1 mm. or less. Prolonged storage, in excess of 45 minutes\textsuperscript{139}, of patterns before investment can also cause this form of distortion\textsuperscript{177}. Setting and hygroscopic expansion of the mould during the initial set of the investment can form this type of distortion\textsuperscript{113}.

Distortion of this nature can best be controlled by correct heating of the pattern wax, in a manner which thoroughly softens the plastic mass. The temperature should be kept to specified softening temperatures, with pressure maintained until the wax has completely cooled to mouth temperature. Correct removal of wax patterns, so that pressure is not applied unevenly, is essential. Undercuts would need to be blocked out in the preparation.

(2) \textbf{Contraction Distortion of Wax Patterns}

This type of distortion is the most frequently encountered. The casting does not seat properly on the preparation, but bears heavily on axial walls.

Heating and manipulation are main factors in this type of distortion. Variations in temperature in heating, which is below 130\textdegree F., can cause a distortion which is inward\textsuperscript{97}. Patterns formed without pressure, even with melted wax, will distort with a contraction, since tensile stresses induced in manipulation would
tend to be relieved\textsuperscript{177}. Symd\textsuperscript{181}, with claims of "elastic memory" for wax, finds that patterns if worked or changed in shape without melting, tend to revert to their original shape or form, and hence distort. Charbeneau and Peyton\textsuperscript{26} find that undercuts from rotating instruments can cause failure of the casting to seat fully. Any storage of pattern can definitely cause this form of distortion \textsuperscript{82,177}, especially with raised temperatures during storage.

This type of distortion is best controlled by correct heating and manipulation. Manipulation should be with pressure, slow cooling and thorough softening of the wax at the specified softening temperatures. Storage of patterns is again contra-indicated; or if impossible to invest immediately, storage in a refrigerator is very necessary\textsuperscript{177}.

From Fusayama\textsuperscript{59}.

Distortion of the wax pattern and the mould during setting of the investment.
(3) **Distortion of the Wax Pattern by Flow**

This distortion of wax patterns, which may take different forms, is by the flow of the wax upon its removal from the tooth\(^{177}\).

This distortion is brought about by storage of the wax pattern, and is a product of the temperature of the medium of storage, and the time\(^{131}\).

The control of this type of distortion is immediate, or as soon as possible, investment of the wax pattern\(^{82,131,177}\).

Markley\(^{113}\) insists "Wax variables are probably the greatest obstacles to accurate reproduction of cast restorations. Many of these are inherent, and inevitable, but they may be minimised to a high degree by full knowledge of their existence".

He claims wax may contribute to the inaccuracy of restorations in seven different ways:-

1. By distortion caused in the removal of the pattern from the mouth or die
2. By the high coefficient of thermal expansion of wax
3. By the tendency of wax to warp from internal strain and elastic memory
4. By the resistance of wax patterns to the combined hygroscopic and setting expansion of the investment mould as it sets
5. By the use of excessive lubricant
6. By the interference with accuracy and the surface character of the mould by wax residues
7. By injury to the mould resulting from the method of wax elimination."
B. THE DIRECT PATTERN

Technique:

Heating the Wax

There are many ways in which the wax for a wax pattern can be heated, and of these the simplest is by softening the inlay wax over a flame\textsuperscript{78}, or by "dry heat"\textsuperscript{177}. Overheating of the wax is to be avoided because of possible tissue damage and discomfort to the patient, as well as the difficulty encountered in compression of overheated wax\textsuperscript{131}. Baum\textsuperscript{78} believes that heating over an open flame, by softening the stick of wax into a "beaver tail" shape, is best, while others\textsuperscript{2, 131} disagree, claiming that there is volatization of some of the ingredients of the wax. Skinner and Phillips\textsuperscript{177} consider that wax can be softened well above the flame in this dry heat softening, but states that the use of a water bath is contra-indicated, the water leaching out some of the lower melting constituents, the loss of which may cause flaking.

The suggestion by some\textsuperscript{2, 131, 177} for the use of a thermostatically controlled "wax annealer" to maintain the wax at 122\degree F. for fifteen minutes before use\textsuperscript{97, 139} is by far the best method suggested in the reviewer's opinion. This produces also a relatively stress-free wax at the proper consistency for fine detail impressions\textsuperscript{131}.

Inserting the Wax

One of the controls in preventing distortion is pressure in confining the wax\textsuperscript{78, 97, 131, 177}. This is also necessary to force
the wax into adaptation to the cavity, and can be best brought about by restricting the wax in the cavity with some form of matrix. Many types of matrices are in use, and range from the micro-thin steel band adjustable types, to copper bands\(^{62,184}\), and even to steel reinforced with modelling compound pads\(^{16}\). Celluloid strips and celluloid bands have a place, but constriction with pressure to stop the softened wax from spreading from the preparation is the most important consideration.

There are conflicting thoughts whether matrices should be close or loose fitting\(^{71}\), but the greater weight of opinion seems to favour a contoured tightly fitting matrix which is freed on margins away from the preparation\(^{113,196}\), and well below the occlusion. Pressure must be maintained\(^{32,36,109}\), whether by instrument, operator's finger\(^{177}\), or occlusal pressure from the opposing dentition\(^{113,196}\). Hollenback\(^{78}\) prefers to tighten the matrix after the wax is inserted, and claims this gives greater adaptation to the walls of the preparation. Markley\(^{113}\) suggests that the patient be pre-instructed, and then allowed to make lateral and protrusive mandibular movements, which are recorded on the wax surface.

Schell\(^{162}\) suggests three techniques for inserting the wax:

1. Warming a medium hard inlay wax either in dry heat or warm water, forcing the wax into the cavity with or without the aid of a matrix, rebasing the cervical aspect and slightly rewarming the impression, then forcing it back into the cavity and holding it under pressure until cold.
(2) Liquid wax method: melting hard inlay wax into the matrix, and while wax is in a semi-liquid state, forcing it to place and holding it under pressure until it is cooled. 

(3) Placing a matrix around the tooth and forcing wax into the cavity by aid of a syringe, holding it under pressure until it is cooled.

He found that these three techniques gave shrinkage factors varying from 0.4% to 1.6%.

The first method suggested by Scheu must surely induce far greater stresses in that fresh softened wax is added in rebasing to a wax at mouth temperature. Slight rewarming would not release these residual strains, and surely must produce distortion. The lack of a matrix would negate the holding of the pattern under pressure until it cooled.

The use of a syringe to introduce the wax is one which is not employed to any extent at present, but would suggest difficulties. Surely there must be some degree of air bubbles introduced, and the pressure applied would not obliterate these.

**Cooling the Wax**

The wax must be cooled before carving and adapting can be commenced, to a temperature which Nilson calls an "adaptation temperature". While it has been suggested that the wax be cooled by decreasing temperatures of water (an annealing effect), all authors are agreed that the pattern should not be chilled suddenly, and certainly not with iced water.
Hollenback\textsuperscript{78} suggests that while pressure is maintained, the pattern can be cooled by blasts of compressed air.

The effect of hastening the cooling is to sharply increase the contraction which takes place in the wax cooling from working temperature to mouth temperature. This also causes compression stresses which are maintained with little chance of release. To the reviewer, the most important part of cooling is to maintain pressure on the wax mass, and to allow the wax to attain mouth temperature without trying to speed the cooling process in any way.

\textbf{Carving the Pattern:}

Since wax lends itself to easy building and sculpturing, the pattern can be carved to faithfully reproduce the dental anatomy, unless dictated otherwise by the occlusion. Some believe that carving should be completed with unheated sharp instruments\textsuperscript{2}, others that blunt instruments are of more use\textsuperscript{105,113}, and yet others that as little carving and pooling as possible should be undertaken\textsuperscript{177}. A slightly warmed instrument is regarded by some authors\textsuperscript{78,131} as best, for they claim this brings the wax to its proper working temperature, and less stress will be induced in those areas. Hollenback\textsuperscript{78} suggests that after carving with sharp instruments, the gingival margins be trimmed, and for this purpose the pattern is removed from the tooth before being replaced.

Additions of any great size to the wax pattern are contraindicated\textsuperscript{2,131}, especially toward gingival margins\textsuperscript{78}. Small additions can usually be luted on without inducing too much strain.
Markley\textsuperscript{113} considers that when undercuts are present, soft wax should be luted to the hard wax, for he claims that the soft wax will bend rather than fracture, and will not distort the pattern. Surely this is a rather hazardous procedure, since luting on soft wax could possibly introduce strains into the already more solid wax, as well as tend to cause the pattern not to fit at other margins. A cement lining into the undercut would perhaps be a more positive approach. Hollenback\textsuperscript{78} recommends the addition of further wax to give good marginal adaptation, but stresses that the addition of wax to any part of the gingival third of a wax pattern is usually unsuccessful. Both Bassett\textsuperscript{10} and Hollenback\textsuperscript{78} recommend the luting of wax onto contact points after removal. Markley\textsuperscript{113} and Byrnes\textsuperscript{24} believe they should be soldered on later.

The reviewer considers there are inherent dangers of inducing distortions in pattern carving with blunt burnishers which push and move the wax. Sharp instruments, requiring less pressure should produce less strain. The luting of wax onto contact points for better reproduction is hazardous in that further heated wax is applied, and may induce strain patterns. It is considered that greater control of these variables is obtained in soldering on contact points after the casting has been made.

Removing the Wax Pattern:

Before the sprue for casting procedure can be attached to the pattern, the pattern should, in complicated preparations, be removed from the preparation\textsuperscript{2}. While earlier authors suggested
removal by means of a sharp explorer or similar instrument\textsuperscript{2,177},
the possibility of distortion because of rocking of the pattern in
the preparation is ever present\textsuperscript{35}. Anderson\textsuperscript{2} prefers using a
metal sprue former attached to the pattern, while Hollenback\textsuperscript{77}
suggests drilling a hole with a round bur the diameter of the sprue
pin and two millimetres deep. The pin is warmed and placed in
the hole and the wax chilled. He also recommends\textsuperscript{78} removing
the pattern with the aid of a thin strip of copper, one or two
millimetres wide, and three-quarters of an inch long cut from a
copper band, bent to a V shape, and heated luted to the pattern\textsuperscript{78}.
Markley\textsuperscript{113} favours luting a \[\text{I}\] shaped staple of high carat 22
gauge gold wire to the pattern and removing the pattern by means
of dental floss looped through the staple.

Black\textsuperscript{16} suggests the use of hollow wire sprue formers
so that lessened heat for attachment is required. Markley\textsuperscript{113}
favours this for Class V inlay pattern positions, suggesting one-
eighth inch diameter stainless steel.

\textbf{Spruing:}

One of the most important steps in securing a good cast-
ing is the attachment of the correct sprue or sprues in the correct
position. The diameter, the length and the position of the sprue
are vital factors. Shell\textsuperscript{196} has stated that: "The point of
attachment of the sprue to the casting is always a critical area.
Very often the point of attachment is so located that the metal
must change its direction of flow very rapidly as it flows from the
sprue and enters the casting cavity. A change of direction is not desirable and should be eliminated when feasible."

While in the past thick sprues or reservoirs have been considered essential, Ryge et al.\textsuperscript{154} investigated the effects of spruing on the porosity of castings in relation to sprue diameter and length. They classified all porosities in gold castings under two general groups:

(1) \textbf{External} and

(2) \textbf{Internal}.

Myers and Pfeiffer\textsuperscript{124} correlated the cross sectional areas of the sprue against the time required to cast. A preference by Shooshan\textsuperscript{167} for the vacuum elimination of wax, permitting low temperature furnace burnouts, can help in checking porosities.

Of interest with the denser casting investments required with some casting procedures are the vents and blind sprues used to obviate back pressure porosities. Such are not required with the cristobalite type investment. Both Lucca\textsuperscript{105} and Blanchard\textsuperscript{17} discuss these, in which a 16 gauge wax rod is carried to within $\frac{1}{2}$ to one-eighth inch clearance from the casting. This permits the mould gasses to escape more quickly when the molten metal shoots down the sprue channel.

Thayer et al.\textsuperscript{190} has suggested a one sprue design for one piece fixed partial dentures. This procedure emphasises the use of blind venting, and is considered by the reviewer to offer very great scope for these castings.
Spruing and Positioning of the Pattern. From Ney.\textsuperscript{125}

\textbf{Left.} Incorrect spruing: thin sprue freezes before the casting, causing "shrink-spot" porosity.

\textbf{Right.} Correct spruing for air-pressure castings; by adding a reservoir to the thin sprue, the "shrink-spot" porosity is concentrated outside the inlay.

\textbf{Left.} Incorrect positioning; pattern too far from end of ring, resulting in casting with rounded margins.

\textbf{Right.} Correct positioning and spruing for centrifugal casting; pattern placed $\frac{1}{4}$" from bottom of ring for sharp margins; thick sprue used to prevent porosity in the casting.

\textbf{Fig. 336. Special type of spruing.} (From Crown and Bridge Construction Using Hydrocolloid Impressions, ed. 2, New York, 1954, J. F. Jelenko & Co., Inc.)

\textbf{Fig. 337. Special type of venting which is a remedy for the situation in which gases pass too slowly from the mold cavity of a full crown.} (From Crown and Bridge Construction Using Hydrocolloid Impressions, New York, 1954, J. F. Jelenko & Co., Inc., p. 45.)

Special Spruing. From Lucia.\textsuperscript{105}

\begin{itemize}
  \item [(b)] \textbf{Dimensional Changes}
\end{itemize}

The high coefficient of expansion of pattern waxes,\textsuperscript{131} together with their rather low thermal conductivity,\textsuperscript{131} means that induced stresses are always and unavoidably present in wax patterns.\textsuperscript{177}

The decrease in temperature of the wax from working temperature to mouth temperature results in a contraction. This
contraction, to some degree, is compensated for when the pattern is formed under pressure until the decrease to mouth temperature is completed.\textsuperscript{131}

Smyd\textsuperscript{181} has reported that directly affecting accuracy are (i) wax shrinkage, (ii) elastic memory, (iii) compressibility, and (iv) tensility. Of these the first two are the most important, and have a direct bearing on the direct inlay wax pattern. Compressibility can create another difference in that biting pressure creates stresses which can cause expansion on removal from the cavity.

Lasater\textsuperscript{97} is of the opinion that variations in temperature in heating result in different types of distortion. High temperature heating (above 130\degree F.), patterns distort outward; at low temperature heating (below 130\degree F.) patterns distort inward. Thus the shrinkage factor in a wax pattern may be as high as 0.4\%.

In addition, other dimensional changes can occur from the release of internal stress present in the wax pattern.\textsuperscript{177} These stresses are induced by (i) natural tendency of the wax to contract upon cooling, (ii) changes in shape of wax during moulding, and (iii) manipulative variables such as carving, pooling, and removal.

In removal and handling of the wax pattern, a further temperature change producing distortion can occur if the pattern is touched by the fingers or hands.\textsuperscript{177}
Discussion:

It would seem that both a contraction of a wax pattern on removal from a cavity, as well as inherent stresses, are unavoidable \(^97,131,177,181\). While contraction is usually of the order of 0.4%, it can at times be as high as 1.3\(^\%\)\(^181\). It has been found by many authors that the relaxation that takes place is a product of both the temperature and the time of storage. The higher the temperature, the less is the time required for relaxation of stress \(^177\). With this possibility of distortion always present, investing of the wax pattern as soon as possible becomes necessary. As has been suggested, if this is impossible, storage in a refrigerator is the best medium to maintain wax patterns without distortion \(^131,177\).

It has been suggested \(^78,113\) that the effects of thermal expansion and contraction can be overcome completely by investing the pattern at the same temperature at which it was formed. It would seem that this could be markedly successful if the investment ring were positioned in such a manner that the water bath did not cause hygroscopic expansion of the investment. Since the thermal expansion of wax patterns has been largely discarded today \(^196\), the temperature to which the investment would need to be brought must be very carefully selected and maintained in this technique.
C. THE INDIRECT PATTERN

This procedure of securing a wax pattern, by far the most frequently used in crown and bridgework, is that in which, after an impression is made of a preparation, a die or cast is formed, and the wax pattern fabricated directly on the die or cast.

Many of the wax distortions and variables are applicable to this procedure. Hollenback\(^78\) holds that the fundamental requirements are:

1. Good marginal adaptation.
2. Proper axial contours and contact relationship.
3. Proper occlusal relationship.

Technique:

The forming of the wax pattern on the die permits a change in the type of wax and in certain manipulative procedures which are necessary for the direct wax pattern technique. The property of flow, revised by Stanford et al.\(^183,185\), and accepted by the Federation Dentaire Internationale\(^55\), as well as the Australian Standards Specification A.S. No. 14\(^3\), becomes less critical. This permits the use of lower temperature manipulation.

(1) Die Surfaces and Lubrication

Dies used in the indirect pattern technique may range from stone, plaster, amalgam, silico-phosphate cement, electro-deposited silver or copper to casting investment\(^131\). The selection of one of these is determined by the particular impression material used, and by the purpose for which the die or cast is to be used\(^131\).
Because of incompatibility with some materials, and other technique problems, certain impression materials limit the type of casts or dies that can be made from them\textsuperscript{131}. Most frequently used are the stone dies, electro-deposited silver or copper, and amalgam dies, and each has its advantages and disadvantages.

The properties of stone for dies has been investigated by many researchers\textsuperscript{132,141,175}. Peyton et al\textsuperscript{132} found that neither oil nor water immersion improved their hardness, nor their abrasive hardness values. Phillips and Ito\textsuperscript{141} believe that vacuuming the stone before pouring into the impression gave somewhat denser surfaces. They found also that with certain impression materials, immersion in 2\% potassium sulphate solution for ten to fifteen minutes gave much denser surfaces to the stone casts. With some impression materials, storing the poured impression in 100\% relative humidity while setting gave better stone surfaces, and avoided dimensional changes\textsuperscript{141}. Skinner and Gordon\textsuperscript{175} found that the surface hardness of the stone was definitely improved by the use of a hardening solution with some impression materials.

When adapting wax to a stone or metal die, some form of lubrication is necessary to allow separation of the wax and die\textsuperscript{168}, and there are many preparations used for this purpose. Oils, liquid soap, detergents, and a number of commercial preparations\textsuperscript{131} can be used - one in particular is most popular (Kerr's "Microfilm"). Since some oils are wax solvents, their use, unless incorporated in the stone die or cast by vacuum pressure, as suggested by Tylman and Tylman\textsuperscript{196}, is rather contra-indicated\textsuperscript{131}. 
(2) Heating the Wax:

While regular inlay wax can be used in this procedure\textsuperscript{82}, greater choice is often made of softer waxes\textsuperscript{109,181}, which are frequently used in the molten state\textsuperscript{145}. Lasater\textsuperscript{97} treated the heating of wax four ways, and formed the opinion that the least distortion resulted from those in which the temperature had been kept at the lowest possible working temperature. The four methods he tried were:

1. Heated over an open Bunsen flame, manipulated by fingers and placed in a matrix.

2. Wax completely fused and poured into the matrix on a prepared tooth.

3. Heated at a predetermined temperature in an enclosed dry electric oven.

4. Wax submitted to decreasing temperature in a water bath.

These findings were in direct contrast to Phillips and Biggs\textsuperscript{139}, who discovered that the higher the temperature at which the wax was manipulated, the fewer were the internal strains, and the less the resultant distortion upon storage. Mahler and Miller\textsuperscript{109} noticed that distortion was greatest in the areas not confined by the die preparation, while soft waxes produced less change than hard waxes, and small additions less change than large additions.

(3) Adapting the Wax:

Symd\textsuperscript{182} reports that "the more closely the die temperature approaches the melting temperature of the pattern wax, the
freer the resulting pattern will be of strains".

The three most popular methods of adaptation are:-

(1) Flowing of small melted increments from a spatula to build up the desired contour$^{78,131,177}$.

(2) By adapting a plastic mass of wax by the compression method$^{78,131}$.

(3) By dipping the die preparation firstly into molten wax$^{82,131,177,196}$.

Hollenback$^{78}$ has stressed that each small increment must be covered and held by the thumb and finger while cooling, thus providing a positive pressure to give a denser casting with better surface adaptation.

Fusayama$^{59}$ has compared the results of three moulding techniques:-

(1) The "press-moulding technique" in which softened wax was moulded in the mould by a heavy finger pressure.

(2) The "pour and press moulding technique" in which fluid was poured into the mould and held by a heavy finger pressure before hardening.

(3) The "pour-moulding technique" in which fluid wax was poured into the mould and no pressure was applied.

His findings were that, while the shrinkage of inlay wax on a room temperature die could not be overcome by pressure, the "press-moulding technique" produced the most accurate patterns. This seems to be in direct conflict with authors$^{78,131}$ who agree that the "pour and press moulding technique" gives the better
results, and produce the more accurate castings.

Smyd\textsuperscript{181} believes that soft waxes should be used for the indirect techniques, because pattern forming can be done at temperatures approximating the melting point of these waxes, thus minimising the effect of temperature gradients.

A swager, whether of the water or clay variety, is recommended by several authors\textsuperscript{78,109,113}. Markley\textsuperscript{113} feels that the wax should be flowed onto a warm die, which conditions can be obtained by a thermostatically controlled heating pad under a warm light. There is more difficulty encountered in working on a metal die\textsuperscript{78,131}, even with these advantages, since the wax tends to cool rapidly, and to pull away from the margins.

(4) **Cooling the Wax**:

The same guiding principles apply to the cooling of the wax in this technique as in the direct pattern technique, in that the wax pattern should not be chilled too rapidly because this will increase strains and distortions\textsuperscript{105}. Pressure also must be maintained, even with a finger\textsuperscript{82}, until the wax is cool. It should be realised that with Smyd's\textsuperscript{182} principle that the more closely the die temperature approaches the melting temperature of the pattern wax, the freer the resulting pattern will be of strains, the die temperature would be raised by fabrication on a thermostatically controlled heating pad and under a warm light.

(5) **Carving the Wax Pattern**:

With stone dies, most authors\textsuperscript{82,131} consider that blunt, but warmed, carvers are essential to prevent marking or chipping of
the margins of the preparation. With metal dies, particularly when they are not warmed, the wax can cool rapidly, and pull away from the margins, and these then need repairing, with additions to be made to them. Should the pattern be stored on either type of die, the margins must be checked and reperfected.

Hollenback suggests polishing the wax pattern with a soft cloth or a flexible cuttlefish disk rotating slowly in a handpiece, and this will both polish and burnish the margins.

One contentious point regarding the indirect wax pattern is the precise finishing line of the casting, and there have been methods suggested to overcome this difficulty. Hollenback suggests outlining the margins on the die with the side of a soft lead pencil. Smith suggests a groove 0.33 mms. below the margin of the preparation and this gives a definite finishing line as well as acting as a guide in carving the wax pattern. While this method no doubt helps in seating the casting on the die, and in finishing the margin of the restoration, the reviewer wonders how this line can be measured with such exactness - is it perhaps measured with a micrometer?

Johnston et al recommend this technique, with a measurement of about 0.3 mms. below the margin of the preparation.

(6) Removing the Wax Pattern:

With the indirect technique, and without directional pressures blocking it, removal of the pattern can be made by means of the sprue, since on individual dies all points are accessible. Johnston et al suggest the placement of a very small semi-circular
mound of wax to receive the sprue pin. They do suggest that spruing is best made off the die. Others suggest the attachment of the sprue to the pattern on the die, and with a hollow sprue pin. 

**Dimensional Changes:**

Any wax pattern contains a certain amount of internal stress due to carving, moulding of the wax, spot heating, or the natural tendency of wax to contract on cooling. It is due to the basic physical nature of wax that distortion of the wax pattern is a continual hazard.

The stress induced in the pattern can be reduced by avoiding undue patching and pooling of the wax, and by forming the pattern at as high a temperature as possible. This is possible with the indirect pattern technique, since the molten wax can be poured into the preparation, or the preparation may be dipped into the molten wax.

Skinner and Phillips report that the residual stress is less in the poured type pattern, since there is no tendency, because of molecular rearrangement, for the wax to return to its original form as in a plastic or moulded pattern. Thus the poured pattern will distort less on storage, and small additions of wax in building a pattern on a die will produce less distortion than the use of large additions. In addition, the softer waxes distort less.

It is apparent, then, that the pattern formed on a die in an indirect technique is superior in terms of reduced residual
stress, and exhibits less distortion if stored\textsuperscript{177}. Dimensional changes can still take place, particularly if a wax pattern is stored on a die, for the margins would need to be rechecked and reperfected\textsuperscript{113}. It would still be good procedure to invest every wax pattern as soon after it is made as possible\textsuperscript{78}.

**Discussion:**

It would seem that wax contraction on cooling, and residual stress on moulding are always present in fabricated indirect wax patterns. These factors are, by the available means of manipulation, not as great as with the direct wax pattern, and control is easier by the reason that margins can be reperfected before the pattern is removed from the die.

There are those who consider, from their experiments\textsuperscript{78,105}, that wax is a relatively stable material, and that provided certain manipulative principles are obeyed, distortion can be controlled, and accuracy assured. Dimensional changes that take place are of such extreme smallness as to clinically be insignificant\textsuperscript{105}. From their experiments, improper adaptation or the use of too much lubricant were contributing factors to distortions. They found that wax could not be adapted to carve surfaces closer than 15 microns, but explained that the reasons for such were obscure\textsuperscript{105}.

Even with the evidence of these experiments, it would appear to be sound procedure to invest every wax pattern as soon as possible after fabrication. If not possible, storage in a refrigerator, where relaxation of stress would be much delayed,
would be desirable. Investment of the wax pattern at the temperature at which the pattern was formed, would lessen the cooling contraction. Should any delay in investing occur, it would seem advisable to check and reperfect margins.

D. WAX SUBSTITUTES: ACRYLIC RESIN

To overcome some of the wax variables, and to guard against the possible contractions and expansions with temperature differences, some investigators have used auto-polymerizing acrylic resin as a direct inlay/crown pattern material.

Saunders\textsuperscript{157} claims for this technique that it can completely eliminate the use of inlay wax, since he found that it can be used for all types of preparations, from full crowns to pin ledge preparations.

a. Advantages\textsuperscript{157}:

1. Non adhesive without the use of adhesives.
2. Vaporize at 480\degree F., with no residue.
3. Greater tensile strength than wax.
4. Difficult preparations can be formed directly in the mouth.
5. No intermediate steps.
6. Occlusion and contact points are established easily.
7. Margins can be thinned down.
8. Spruing is easier, and to the thickest part of the pattern.
b. Disadvantages:

1. Shrinkage factor of up to 6% possible\(^{154}\).

2. Incomplete vaporization at temperatures compatible\(^{153}\) with normal casting practice\(^{108}\).

3. Castings not smooth\(^{108}\).

4. No accurately fitting castings\(^{108}\).

5. Necessity of adding 10% to 20% of wax to the pattern\(^{152}\).

6. Necessity to avoid sharp angles in the pattern\(^{152}\).

c. Technique:

Saunders\(^{154}\) used two methods of securing a direct pattern in acrylic resin:

1. A "pressure" form of a "dough" mix which is held under pressure to reduce as much as possible the anticipated 6% shrinkage.

2. A "non-pressure" or "brush-on" technique in which the shrinkage factor can be more controlled by "layer building" of the pattern.

As explained by Saunders, the pattern after formation can be removed, polished, have wax contact points and occlusion added, and be returned to the preparation. Roydhouse and Barr\(^{152}\) modified this technique by the addition of wax of from 10% to 20% of the volume of the pattern, and the avoidance of sharp angles in the pattern.

d. Discussion:

While this technique may be of help with a preparation which offers difficulties with a direct wax pattern, its general
use would seem to be contra-indicated, since it does not entirely eliminate the use of wax. There would not be many preparations which an elastic impression would fail to reproduce accurately. The necessity for an accurate acrylic resin pattern to have 10% to 20% of the volume of wax added means greater care in balancing these proportions out. To the reviewer, perhaps the greatest disadvantage is the need to avoid sharp angles, which often form an integral part of retention in the preparation.

There is a definite need for these materials in restorative dentistry, in that they can, from copper band or elastic impressions, form direct crown patterns on teeth, to be cast in gold, or cemented as temporary coverage. Resin transfer copings can be formed in this same cold cure acrylic resin, and in form, the patterns so formed are sufficiently accurate.
CHAPTER 3

MODELLING COMPOUND

Modelling compound is one of the thermoplastic impression materials\textsuperscript{177}. It is still widely used in indirect inlay procedures\textsuperscript{131}, and jacket crown impressions, where no undercuts can cause distortion on removal. In addition, where the die needs to be of a metallic nature, either electro-deposited copper or silver, or of an amalgam die, compound / copper tube impressions are used extensively\textsuperscript{128,177}.

There are two types: Tray Compound and Impression Compound - the impression compound being used in these techniques.

Composition:

The composition of modern commercial impression compounds is a trade secret\textsuperscript{131}. They are essentially a mixture of thermoplastic resins and waxes, a filler and a colouring agent. By varying the proportions of the various ingredients, compounds of different physical properties can be made.

Peyton et al\textsuperscript{131} give the following composition as a typical impression compound.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosin</td>
<td>30</td>
</tr>
<tr>
<td>Copal resin</td>
<td>30</td>
</tr>
<tr>
<td>Carnauba wax</td>
<td>10</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>5</td>
</tr>
<tr>
<td>Talc</td>
<td>75</td>
</tr>
<tr>
<td>Colouring agent</td>
<td>appropriate amount.</td>
</tr>
</tbody>
</table>
Desirable Requisites:

Desirable requisites for an impression compound are:

1. It should be free of poisonous or irritating ingredients.
2. It should harden at, or slightly above, mouth temperature.
3. It should be plastic at a temperature which is acceptable regarding comfort to the patient.
4. It should harden uniformly when cooled, without any warpage or distortion.
5. When soft, it should possess a consistency able to reproduce all details - be cohesive but not adhesive.
6. On withdrawal, there should be no fracture or deformation.
7. The surface should possess a smooth, glossy appearance after flaming.
8. After solidification, it should be able to be trimmed with a sharp knife without flaking or chipping.
9. No dimensional changes should occur during or after its removal from the mouth.

A. Physical Properties

1. Thermal Conductivity:

The thermal conductivity of impression compounds is low. Softening usually takes place rapidly on the outside, but slowly on the inside. This property has an important bearing both on the softening of the material before taking the impression, and on cooling the impression material in place. Time is required to allow complete hardening, for premature removal may result in a serious distortion.
2. Softening and Flow:

These properties are rigidly controlled by Specification. Compounds should soften at a temperature point just above mouth temperature, and in this state exhibit adequate flow in order to adapt closely to the tissues and register surface detail\textsuperscript{131}. The American Dental Association Specification No. 3 for impression compounds specify that the flow at 37°C will not be more than 6%\textsuperscript{131}, and at 45°C not more than 85%, and not less than 80%\textsuperscript{177}.

3. Thermal Contraction:

The linear thermal coefficient of expansion of impression compound is considerable in comparison to many other substances\textsuperscript{177}. In cooling from mouth to room temperature (37°C to 25°C) the average linear thermal contraction may vary
between 0.3% and 0.4%\textsuperscript{177}, but varies with the particular compound selected. This property is inherent in the material\textsuperscript{131}.

4. **Accuracy and Dimensional Stability:**

Accuracy with the impression compounds can best be obtained by careful preparation and handling of the material\textsuperscript{131}. Softening of the material by a method which will not adversely affect its physical properties by overheating or prolonged heating\textsuperscript{131}. Adequate flow must be developed during softening to allow close adaptation and a minimum of internal stresses. The copper band must be strong, rigid and stable, without flexibility\textsuperscript{131}.

Dimensional stability is best secured by making the cast or die as soon as possible\textsuperscript{131}. This prompt pouring of the impression prevents possible warpage, due to the release of stresses. It cannot control the thermal contraction which occurs on cooling from mouth to room temperature\textsuperscript{131}.

5. **Distortion:**

Early fabrication of the die or cast can control the relaxation due to the release of internal stresses, but not thermal contraction\textsuperscript{177}. A premature removal of the impression before thorough cooling can cause an early relaxation. If the impression is disturbed before or during the fusion range temperature, which is above the actual hardening temperature, distortion can follow\textsuperscript{177}.
B. Techniques

After the preparation or preparations have been completed, a copper band of suitable size is selected and an identifying hole placed on the buccal or lingual aspect. A modified Backhaus towel clamp can be used for this. The band is then annealed, festooned, and contoured at the gingival end. For the purpose of checking on contouring and festooning, it is fitted to the preparation filled with soft wax, and this helps in assessing defects of the preparation. After correction to festooned and contoured edges of the copper band, it is, after burnout of the wax, filled with heated impression compound. The copper band is then reseated on the preparation and the impression taken. Tylman and Tylman suggest leaving the incisal end open until the gingival edge is in position, then resealing the incisal end. The band is then carried further gingivally with pressure on the compound at the incisal end. It has been stressed that there should be no rocking of the band during removal.

Miller suggests removal by a quick, direct thrust with a modified Backhaus towel clamp.

Wiland gives a description of the accurate contouring of a copper band, with special equipment to assess the diameter required, depth of gingival crevice, and a further differential marking device to accurately transfer the amount of the band necessary when contouring it. By these means, the band is fully contoured before being observed on the tooth. The tube is usually festooned, and the internal surface of the
band roughened to allow the compound to be better retained. There is a volume of opinion to indicate that the band must be annealed\textsuperscript{11,22,82,104,115,180}, but there is a feeling by some that annealing can add to possible distortion\textsuperscript{98}.

The reviewer considers that annealing does allow the band to have better adaption to the tooth preparation.

Identification of buccal and lingual surfaces is secured by either marking the band in these areas\textsuperscript{21}, or by punching holes on either surface by means of a rubber dam punch\textsuperscript{115}, or a Backhaus towel clamp\textsuperscript{115}. Bands preferred are of the 36 gauge B. & S.\textsuperscript{196}, rather than the heavier gauges. Two wings are sometimes bent over to rest on the adjoining margins of adjacent teeth to prevent gingival trauma by the gingival margin of the band\textsuperscript{196}. Removal by ligature wire or dental floss passed through holes through the occlusal end is of help\textsuperscript{1}.

Techniques have been suggested in the literature by which the actual preparation for copper plating of impressions for metallic dies is started in the patient's mouth. By these means, the copper band - compound impressions are ligatured with 24 gauge dead soft brass wire in a continuous fashion, extending beyond the last copper band so as to make contact with the anode\textsuperscript{100,101}. A plaster impression, which can be removed from a lubricated stock tray, is then taken over the prepared bands and wire.

To the reviewer, this would seem to introduce possible errors in that any movement of the wire ligatures could disturb
the correct setting of the bands, and if only one was disturbed, this shortening of steps in the technique would defeat its own purpose.

Bluff suggests less gingival compression by placing the occlusal end of the copper band on a tapering fulcrum stick, and thus permitting excess to force out the occlusal end. The reviewer considers that this must surely defeat the object of slight gingival retraction, with the possibility of an entrapment at the gingival end. The hole punched in the buccal aspect of the band would function better for excess than the fulcrum stick.

Bevan and Smith observed that a low flow property is required, and suggest that the compound be softened without kneading.

**Advantages:**

Miller suggests the following advantages of the copper band - impression compound technique:

1. Ease and simplicity of the procedure.
2. Rapid technique - the impression is removed after the compound is chilled (30 to 60 seconds).
3. Availability of materials.
4. Inexpensive armamentarium.
5. Gingival retraction is fool-proof (built-in),
6. Dependable.
7. Impression will not distort if stored and not plated immediately.
8. Because of the brittleness of the compound, it will break if pulled over an undercut (built-in safety factor).

Discussion:

To the reviewer, to describe the technique as being an easy and simple procedure is to minimise the necessity of the exactness of the fit of the copper tube at the gingival margin. For a band to be non-traumatic to viable tissue in this vulnerable area, great care and careful attention to pressure must be observed. While the impression taking in itself is rapid, preparation of the band can be time-consuming. Gingival retraction, despite pressure from the impression compound, is not fool-proof, for often full gingival margin detail may not register. The claim of being dependable is to assume that the band has not moved during the impression taking, and that complete chilling of the compound has taken place. There must be internal stresses recorded in the compound impression, and to claim that the impression can be stored, without specifying for how long, is to assume that relaxation of the compound confined in the band will not take place. This relaxation could possibly take place, with disastrous result in the form of distortion. Miller's "built-in safety factor" regarding the brittleness of the compound disregards the 6% flow property which is present at mouth temperature. This could affect the accuracy of the impression.
Disadvantages:

Axman gives the following disadvantages for this technique:

1. The gingival tissue may be distorted and compressed to the tooth.
2. The gingival fibres of the periodontal membrane may be damaged.
3. The tube can be moved during the final impression.
4. Often the tube does not give a true reproduction of the prepared abutment in the gingival area.
5. Time and effort are required to contour the tube.
6. Difficulty may be encountered in seating tubes accurately with multi-abutted preparations.

Discussion:

While a poorly prepared band can traumatize gingival tissue, care taken with this part of the technique, and in the testing of the fit of the tube with soft wax, trauma to gingival tissue should be minimal. Multi-abutted preparations do present difficulties in seating copper bands, but the reviewer considers any preparations which are adjacent to be rather contraindicated for copper band - impression compound recording. The greatest danger, not mentioned in the above disadvantages, is perhaps the difficulty of heat control of the impression compound. Both pulp and tissue trauma can occur if the compound has been excessively heated. There is difficulty in controlling
heat to the same degree throughout the length of the tube. Seltzer and Bender\textsuperscript{163} consider that if the compound is too hot, not only pulpal trauma is possible, but that microorganisms may be freed through dentinal tubules into the pulp chamber.
CHAPTER 4
HYDROCOLLOID IMPRESSION MATERIALS

The hydrocolloid impression materials were first developed from the discovery by Poller of agar hydrocolloid in 1925, and later improved. They form part of the emulsion phase of colloids, from which a jelly or "gel" can be obtained.

Colloidal Gels:

Since some hydrocolloid sols possess the property of changing to a "gel" under certain conditions, differentiation is made between those that by cooling the sol form a gel, and those in which the change is usually brought about by a chemical reaction.

In those in which gelation is brought about by cooling the sol, the gel is reversible in nature provided that it can be returned to the sol condition when the temperature is increased. Irreversible hydrocolloids are characterised by the fact that while the sol can be changed to a gel, the gel cannot be reversed to the sol by any simple means.

Structure of the Gel:

The property of a gel which sustains a shearing stress without flow, indicates the presence of some continuous mechanical network or structure. Such a network is visualised as composed of minute, submicroscopic fibres formed by the colloidal particles of the dispersed phase. The fibres form a network of spaces or "micelles" in which the water is held by absorption. The fibres become entangled to form a
"brush heap" structure. This is a characteristic of impression hydrocolloid materials. In the reversible type of hydrocolloid the fibres are held together by secondary valence bonds; in irreversible hydrocolloids, by primary valence bonds.

With the reversible hydrocolloids, when the temperature is raised, the chains and micelles break up, chiefly because of increased thermal agitation of the molecules. As the temperature increases, the micelles disunite and the viscosity greatly diminishes as the gel changes to the fluid sol.

When the temperature decreases, the micelles gain more cohesive force, and finally maintain a definite "brush heap" structure. The temperature at which rigidity is attained is known as the "gelation temperature". This is not the same as the freezing point, since the gel becomes more rigid as the temperature decreases below the gelation point.

Gel Strength:

The strength of a gel is fundamentally related to the "brush heap" density, and the concentration of the dispersed phase. The strength of the gel can be increased by the addition of certain modifiers such as chemicals and fillers. The fillers usually become caught up in the micelle network to render the brush heap more rigid with less flexibility. The filler also increases the viscosity of the sol when reversible hydrocolloid is liquified.
A. Agar: or Reversible Hydrocolloid Impression Material:

1. Chemistry and Composition:

Apart from water, the main constituent is agar-agar, an organic hydrophilic colloid (polysaccharide), a sulphuric ester of a linear polymer of galactose[^177], with the generally accepted structural formula of:

![Chemical Formula Agar](image)

Chemical Formula Agar.

Agar-agar forms a colloidal sol with water, liquefying between 160°F. and 212°F., and setting to a gel again between 122°F. and 86°F., varying somewhat with the concentration of the gel[^131].

Borax is added to give body and strength, while potassium sulphate counteracts the retarding influence of the borax on the setting time of the stone casts.

[^177]: Skinner and Phillips[^177] give a possible composition of a reversible hydrocolloid impression material as follows:

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agar-agar</td>
<td>14.3</td>
</tr>
<tr>
<td>Borax</td>
<td>0.2</td>
</tr>
<tr>
<td>Potassium Sulphate</td>
<td>2.0</td>
</tr>
<tr>
<td>Water</td>
<td>83.5</td>
</tr>
</tbody>
</table>
Moffa\textsuperscript{118} agrees with this - Peyton et al\textsuperscript{131} give different percentages.

It is felt that the borax, by forming a borate, increases the strength of the gel by increasing the strength or density of the micelle framework in some manner\textsuperscript{177}. Since both borax and gel inhibit the setting of the plaster or stone, a disadvantage which can be overcome by either:

(1) Immersing the impression in a solution containing a setting accelerator for the plaster or stone; or

(2) Incorporating such accelerator or "plaster hardener" in the impression material.

The potassium sulphate is added for such a purpose.

2. Properties

Dimensional Change and Distortion:

Since gels are subject to changes in dimension by syneresis and imbibition, once an impression is removed from the mouth, and placed in air at room temperature, syneresis commences immediately, with resultant shrinkage of the gel\textsuperscript{177}. These changes have been studied by many authors\textsuperscript{10,69,174,176}, and all have emphasised the distortion which may result from varying water contents. When syneresis has occurred, and the impression is immersed again in water, the imbibition that follows is not uniform enough to return the impression to its original dimension\textsuperscript{177}, and so distortion results. Thus the impression must be exposed to the air for as short a time as possible, which means pouring in stone immediately if possible\textsuperscript{131}. 
Viscosity and Flow:

Viscosity of the impression material is of considerable importance, since it must be of sufficient viscosity not to flow out of the tray. It must have sufficient viscosity to flow through the perforations in the tray, but not to completely flow through those out of the impression tray. Furthermore, the viscosity must be such that the material will readily penetrate every detail of teeth and soft tissues bounded by the impression. Since agar alone is too fluid for this purpose, the viscosity is increased by fillers. The viscosity is influenced by temperature, and there is a sharp increase as the gelation temperature is approached.

Storage of Impressions and Fixing Solutions:

With agar impressions in particular, there is a majority of opinion favouring the need for the immediate pouring of the impression. Much research has been undertaken to find a suitable storage media when there is difficulty in pouring the impression immediately, and with the problem of how to maintain the equilibrium whilst the stone is setting. It is generally agreed that placing the impression in an atmosphere of 100% relative humidity will best maintain equilibrium both before and after pouring. Phillips and Ito, and others feel that placing the impression in a 2% solution of potassium sulphate will not only help to prevent dimensional changes, but will also improve the surface of the stone die/cast. Skinner and Gordon
tested other solutions for maintaining equilibrium, and found that unless impressions were thus treated, the surface hardness of the stone cast was definitely less.

Concerning these problems, the reviewer finds that while there has been speculation that an ideal osmotic pressure bath may yet be developed, the opinion of Swartz et al.\textsuperscript{189} in their theory that stress patterns are introduced into the impression during manipulation, and that with storage for any length of time, the release of these strains results in distortion, is correct, and that immediate pouring of hydrocolloid impressions is imperative.

Some manufacturers provide fixing or control solutions in which the impression is immersed before pouring. These solutions help the cast, in that they contain an accelerator for the setting of the stone or plaster, counteracting the imbibing effect of the hydrocolloid.\textsuperscript{69} While it is claimed they often have a salt concentration similar to the impression material, to prevent exchange of solute and liquid, and so maintain dimensional stability, James\textsuperscript{80(1)(ii)(iii)} found that equilibrium and balance were not maintained.

\begin{center}
\textbf{From Skinner and Phillips\textsuperscript{177}}
\end{center}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig7-5.png}
\caption{Percentage change in water content by weight of a reversible hydrocolloid impression material in various storage media.}
\end{figure}
Specification:

Specifications for the physical properties of agar impression material have been laid down by Paffenbarger\textsuperscript{127}, and later revised. Cresson\textsuperscript{39} believes that these should have application to the clinical use of these impression materials, for which the Commonwealth Bureau of Dental Standards\textsuperscript{28} did substitute a requirement for set after a given strain, instead of after a given stress, as does the Australian Standards Specification No.T.16\textsuperscript{5}.

Removal of Impressions:

Due to the elastic properties of agar materials in that they recover more completely from a sudden bend or deformation\textsuperscript{32}, than from a gradual application of stress, the removal technique for the impression becomes very critical. Distortion is very possible with teasing out of the impression by the handle, or removal by means of a rocking movement, so the impression must be removed by means of a sharp direct thrust or pull along a line of the long axes of the teeth\textsuperscript{127,135}.

There should be inspection of the impression to ascertain if there has been any separation of impression material from the tray, for if such has happened, the impression should be discarded\textsuperscript{177}.

Stone Surfaces:

Fixing solutions are necessary with some agar impression materials; some can be poured without fixing, but all need immersion in 2% potassium sulphate solution for true stone surface hardness\textsuperscript{135}. Faults reported with stone surfaces have been chalkiness, roughness,
irregularities, and the presence of bubbles. Some chalkiness can result from the mixing of incompatible hydrocolloid and stone, but is improved by immersion in 2% potassium sulphate solution. This gives a more resistant surface unaffected by subsequent syneresis from the hydrocolloid, the greatest problem then being the union of an incompatible hydrocolloid and stone. The solution should be carefully blown from the impression to prevent streaks and pitting, but the surface should not be desiccated or dehydrated, since this can cause dimensional changes, with the danger of the stone sticking to the impression, leaving a rough surface.

Reproduction by agar hydrocolloid is very good, but not all stones can reproduce the smallest indentations on the impression material. To obtain the best surfaces, Phillips and Ito suggest that, apart from the correct water/powder ratio, which has an important effect on surface density, the stone be vacuum mixed, and that there be mild vibration with an even flow of stone into the impression. Skinner and Gordon experimented with mixing some of the hardening solution with the stone, instead of water, but noted no increase in the surface hardness of the stone. Hall Best raised the important point that since colloid materials shrink during gelation, it is important to select a stone material which has the correct compensating expansion. Peyton et al. claim that neither water nor oil immersion improve the surface hardness of the stone cast.
Hysteresis:

One of the phenomena of the reversible hydrocolloid impression material is that of hysteresis. The gelation temperature of the hydrocolloid paste is lower than its liquefaction temperature. There is a range of temperature which provides a working range for the operator, and could well be from 50°C to 60°C, or from approximately 98°C to 40°C. This property of a range of temperature between gelation and liquefaction is known as hysteresis.

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**Diagram Illustrating**

**Range of Temperatures**

(“Hysteresis”)

| A - B | Range of Gelation Temperatures. |
| C - D | Range of Liquefaction Temperatures. |
| B - C | Minimal Working Range of Temperatures for Manipulation. |
Syneresis:

The greatest part of the volume of the gel is water, which is, under very favourable conditions, in a state of balance. If the water content of the gel is reduced, by evaporation from its surface, or by the exudation of a fluid, the gel will shrink, and this process is known as Syneresis\(^{177}\). This is one of the characteristic properties of a gel, and the exudate is not pure water. It may be acid or alkaline, but the process results in a shrinkage of the gel.

![Graph showing shrinkage of three hydrocolloids exposed to air over a period of 1 hr. and subsequent expansion when immersed in water. (Adapted from Skinner, E. W., Cooper, E. N., and Berk, F. E.: Reversible and Irreversible Hydrocolloid Impression Materials, J. A. D. A. 40: 196, 1950.)]

From Peyton et al\(^{131}\)

(page 167)

Imbibition:

Since the greatest volume of the gel is water, there can be different levels of this fluid. If the gel loses water by evaporation, or by syneresis, and is then placed in contact with water, sorption of the water will occur\(^{177}\). A swelling of the gel occurs during imbibition, until the original water content is restored. Gels appear to exhibit a "memory" in this respect; if a
certain amount of water is removed from a gel of a given concentration, imbibition will occur only to the extent that the lost water is restored.\textsuperscript{177}

![Graph showing dimensional change over time](image)

Fig. 7-4. Linear contraction in air (31 to 42 per cent relative humidity) and subsequent expansion in water of six reversible hydrocolloid impression materials.

From Skinner and Phillips

3. **Techniques:**

**Manipulation**

a. **Copper Band:**

Hydrocolloid reversible impression material has been used to record details of impression in copper bands and tubes.\textsuperscript{53,167} Because the resultant stone die is more fragile, and subject to damage during indirect wax pattern procedures, the use of hydrocolloid material in copper bands is not very well favoured.

b. **Tray Material:**

There are many ways in which this material can be handled, but for brevity, the most efficient, in the reviewer's opinion, is that of the heating, storing, and tempering water bath,\textsuperscript{177} which will be discussed.
Equipment incorporating three compartments, each thermostatically controlled, at different temperatures, is marketed, and in general use\textsuperscript{131,196}. These are essentially electrically heated compartments, which maintain constant temperature, for the purpose of boiling, tempering, and storing, the hydrocolloid, so that the impression material may be ready at any given period, and will overcome some of the hazards of material not thoroughly prepared. The compartment used for boiling is set at $212^\circ F$, and it is suggested that a minimum of eight minutes\textsuperscript{196} be allowed for this. Phillips\textsuperscript{135} suggests ten minutes. The storage compartment is kept at $145^\circ F$ to $150^\circ F$, until needed\textsuperscript{135}. After the impression material is removed from the storage bath, it is loaded into a tray and stored for tempering or conditioning in that respective compartment for a suitable time which varies with the temperature maintained: at $115^\circ F$, five to ten minutes, and at $102^\circ F$, two minutes\textsuperscript{196}. Phillips\textsuperscript{135} suggests seven to fifteen minutes at $115^\circ F$. While tempering cool the material to a temperature compatible with the oral tissues, it also develops more body in the material.

The agar hydrocolloid impression material having no adhesive property, the material must be confined or locked into a tray, by means of either a rim lock\textsuperscript{130}, or a perforated type\textsuperscript{2,171}, which should be water cooled\textsuperscript{196}. A bulk of impression material is required to allow sufficient strength to avoid rupturing on removal, at least one-eighth of an inch\textsuperscript{135}. The use of modelling compound to seal the post dam area, as well as reduce the palatal
vault\textsuperscript{85,86}, is suggested. It is necessary for the compound to be softened by chloroform\textsuperscript{85,86,89}, and even have wisps of cotton wool attached to it, for proper retention of the agar material. When the loaded tray is removed from the conditioning bath, the top layer of agar material, which has become water contaminated, is removed by scraping off with a knife to a depth of one-eighth of an inch\textsuperscript{145,196}.

After the tray has been inserted, water is passed through it to both cool it and to allow gelation to occur. There is a difference of opinion as to which temperature is required for this water, some authors preferring tap water of approximately 50° to 60°F.\textsuperscript{89,99,134,135,156,196}, while others suggest ice water\textsuperscript{145,192}, and one author suggests that either could be used\textsuperscript{10}. The tray is left in place until gelation has occurred, depending on the temperature and the thickness of the hydrocolloid.

The reviewer considers that ice water is contra-indicated for two reasons – firstly because of patient discomfort, and even possible tooth trauma, and secondly because of possible distortion, the agar hydrocolloid cooling rapidly on the tray and pulling away from the impressed area.

c. **Syringe Material:**

An agar impression material of a different viscosity is necessary for use in an injection syringe for inlay, crown and bridge impressions\textsuperscript{131}. The increased fluidity is achieved by increasing the water content.
For impressions of small cavities, and to prevent bubbles formed by trapped air, a syringe is employed to inject the material in such a way as to displace the air, and this is followed by a tray impression. The syringe tip is usually placed in the gingival area of a preparation, and the agar hydrocolloid flowed in front of the syringe to displace air which would otherwise be trapped. There are many types of syringes available, as well as different diameters of needles for the best injection of the agar hydrocolloid.

In using syringe material, there is no necessity for conditioning, for the loaded syringe can be taken from the storage compartment and injected immediately after wiping off the first cm. or two of hydrocolloid ejected. There is a drop of 8°F. in thirty seconds, on 19 and 22 gauge needles. Pruden suggests the use of 25 gauge needles.

Often difficulty can be experienced in recording slice preparations, pin holes or post holes. The nature of agar is such that thin sections are liable to rupture on withdrawal of the impression, and if the impression material ruptures, fine pin holes are not recorded. Where injection of unsupported agar is indicated, Pruden uses a 25 gauge needle on the hydrocolloid syringe for fine detail, and 21 gauge for interproximal tissue. Moffa uses 23 gauge and 19 gauge needles respectively.

The use of nylon bristles, tapering acrylic pins, plastic points, stainless steel wire, or platinum gold wire.
fitting the diameter of the pinholes is often better in recording these retention points. The miniature nylon bristles have ends balled over \(^{12}\), and the tapering acrylic and plastic points can be roughened for retention in the agar. With metal, it is better to bend the round wire over half or one millimetre above the tooth \(^{81}\), as this provides retention in the agar.

Johnston et al\(^{82}\) recommend that, where the agar hydrocolloid technique is to be used, pinholes be enlarged with a greater diameter and less depth. Where pinholes were to be made to a depth of 2 mms. with a No. 701 bur, they suggest these should be made to a depth of 1.5 mms. with a No. 702 bur, for better recording of the impression material.

4. **Accuracy**

The accuracy of the reversible hydrocolloid impression material is directly associated with the resultant product - the die, model or cast. The accuracy of such cast produced by the
indirect technique is primarily a function of the inherent accuracy of the impression material. This accuracy of reproduction is, however, dependent on the dimensional behaviour of the materials involved, and the surface condition of both the impression and cast. Surface accuracy does involve the accuracy of surface details, and is dependent on both the interfacial relationship between the impression material and the original object, and the compatibility of the impression material and the cast material.

Phillips stated that for accurate reproduction of cavity preparation, the following were necessary: (1) fluidity or flow (2) gelation time (3) strength of resistance to fracture (4) minimum permanent deformation (5) no deleterious action on stone. He believed agar impression material gave somewhat better surface and possibly sharper detail of cavity preparation than the irreversible hydrocolloid.

Ayers et al. found the reversible hydrocolloids excellent in their ability to reproduce the smaller indentations in accuracy tests with this material. They also noted that the ability of the impression material to register detail from the original die exceeded the reproduction capabilities of the gypsum cast materials.

Skinner and Hoblit, in investigating the accuracy of the hydrocolloid impression material, found the accuracy of such to be excellent. They stressed that in removal of such impressions over undercuts, stresses were formed in the impression material.
They considered such to be of no practical interest, and less than with any other impression material with the exception of thiokol impression material. They also outlined an accurate technique for use of irreversible and reversible hydrocolloid impression materials in combination.

Skinner et al.\textsuperscript{174} found that the reversible hydrocolloids were very accurate, with dimensional stability much improved from the earlier material of ten years previous.

5. Discussion

Agar hydrocolloid impression material is an elastic impression material which exhibits excellent accuracy and reproduction. Since correct preparation and manipulation of this material is imperative, the necessary equipment to prepare it becomes essential. This is evident in that the tempering of this material not only avoids trauma to the patient, but minimises the thermal contraction of the material during subsequent cooling in the tray\textsuperscript{127}. It also develops body to improve the impression with the material. Dimensional stability is not good under all conditions, but is said to be maintained in storage up to one hour at 100\% relative humidity. Others claim immediate, or within fifteen minutes pouring of the impression to be necessary. Since reproduction of detail is excellent, it has a definite and important use in conservative dentistry for reproduction of cavities, abutments and undercut areas.

Manipulation in preparing the material, loading the tray and removal of the impression from the mouth must follow a
standardised and sound procedure^{137}. Compatibility between the stone for dies and casts and the hydrocolloid is essential, with emphasis on the use of 2% potassium sulphate solution for fixing and hardening of the stone. There should be careful removal of any excess fixing solution. When pouring the stone, vibration and the rate of flow of the stone are important. The stone should be allowed to set for at least thirty minutes before separation, preferably in an atmosphere of 100% relative humidity.

6. **Tissue Retraction**

Since all the elastic impression materials are mucostatic^{118}, and do not displace tissue, it is essential that for detailed recording of margins, the gingival tissues do not obstruct the impression material.

Perdigon^{130} gives Pankey's four positions for gingival margins of cavity preparation, in relation to the gingiva, as follows:

**Class I**  
Gingival margin of cavity not below the gum line - an average of about 10% and no need for tissue displacement.

**Class 2**  
Gingival margin of cavity slightly below the gum line - about 75%, and need for slight gingival retention.

**Class 3**  
Gingival margin moderately deep under the gum tissue, but gum tissue healthy and there is no need for gingival removal.

**Class 4**  
Gingival margin deeply under gum line: usually tissue hypertrophied, bleeds easily and lacerated. Need for gingival removal.
Waerhaug\textsuperscript{198} maintains that restorations should be restricted to the gingival margin and claims subgingival restorations are among the major aetiologic factors in periodontitis. The other viewpoint, however, is that in caries susceptible patients the margins must be carried into the gingival sulcus\textsuperscript{95}. The retraction of this tissue is the most troublesome phase, for without adequate exposure of the gingival margin of the preparation, the entire procedure of the indirect technique must fail.

Gingival retraction has often been grouped under three broad headings:--

(1) Mechanical
(2) Medicinal means
(3) Surgical \textsuperscript{63},

but the reviewer prefers the Thompson\textsuperscript{192} classification, which is:--

(1) Conservative
(2) Radical.

Thompson\textsuperscript{192} defines the Conservative method as any procedure which does not cause sloughing or loss of tissue. These treatments may traumatize, but healing is complete within twenty-four hours. Radical methods constitute destruction or removal of tissue by means of surgical blade, electrical instruments, or chemical agents. In Conservative treatment, there may be two broad classifications:--

(i) Mechanical, and (ii) Medicinal.

Mechanical means are frequently used, particularly where an impression is to be taken at a later appointment.
Gutta percha dressings\textsuperscript{105,130}, base plate gutta percha, zinc oxide - eugenol dressings\textsuperscript{105} and any of the temporary cements exert pressure which will displace gingival tissue sufficiently to expose the gingival cavity margins\textsuperscript{105}. To the reviewer, gutta percha is rather contra-indicated, since it can not only cause possible pulp trauma, but may, at the least, increase the sensitivity of the tooth. Rubber dam\textsuperscript{65,196}, black thread\textsuperscript{155}, or even a simple cotton ligature secured with a drop of sticky wax is sufficient\textsuperscript{196}. Orthodontic rubber bands dipped in chloroform to retain their elasticity can be used\textsuperscript{65}, as well as thread packed in and secured with festooned or end crimped aluminium or copper shells (Pagenkopf's technique)\textsuperscript{155,196}. Temporary acrylic splints holding cotton cords impregnated with 8\% zinc chloride solution can be used\textsuperscript{20}. Tylman and Tylman\textsuperscript{196} suggest the use of rubber dam and clamps.

From Yoder and Thayer\textsuperscript{204}

"Retraction cord being placed in the gingival crevice".
Drugs used to retract tissue are many and varied both in strength and times of application. Most are applied on either unwaxed ligature cord or cotton fibres:-

(i) **Adrenaline** has been used in strength from 1 : 100, 10,86,130 to 1 : 1000,70, also 8%191.

(ii) **Alum** crystal form or 40% solution impregnated into cotton fibres192,203. Thompson191 suggests the addition then of one or two drops of epinephrine solution (2% or 8%) to the fibres for two minutes, as does Eberle37.

(iii) **Ferric sub sulphate** (Monsel's powder) is used as a styptic on the cord191,196,203.

(iv) **Tannic Acid**: Used in solution of 20% impregnating the retraction cord191,203.

(v) **Zinc chloride**: this drug varies greatly in the applied strength. Pfeiffer and Jeffreys133 suggest 5%, Kahn86, Perdigon130 and Thompson192 use 10%. Hampson70 advises 5% to 40%, while Woychesin203 experimented with 40%.

(vi) **"Gingi-Pak"**. (A cord impregnated with approximately 1 mg. racemic acid: epinephrine hydrochloride per inch) - used as a retraction cord in itself203.

In addition to the more popular agents, Woychesin203 has tested on laboratory animals, the following drugs:-

(1) **Cocaine 10% with epinephrine 1 : 1000**
(2) "Hemodent" gingival retraction cord: (a cord impregnated with "hemodent" - containing aluminium chloride, hydroxyquinoline sulphate, phenocainum chloride and ethyl benzoate).

(3) Negatan Solution: an aqueous solution containing in 100 gm. approximately 45 gm. of a condensation product obtained by reacting metacresol sulphonic acid with formaldehyde.

He reported, of the drugs tested, only two, Zinc Chloride and Negatan, were contra-indicated. 8% Zinc Chloride solution proved satisfactory when limited to two or three minutes. Both Tylman and Kendrick support the use of 8% zinc chloride solution, ferric subsulphate, tannic acid 20% and alum 40%. They also favour the use of 1 : 100 solution of adrenaline chloride and 8 : 100 solution of racemic - epinephrine. Thompson favours the use of alum, since he claims the action of racemic epinephrine solution will retard the setting of the stone, and care must be taken that all chemicals are washed away from the impression before the stone is poured.

In the last section, Class 4 of Pankey's classification, where radical treatment is necessary, the inflamed and pathological tissue must be removed. Although some authors suggest chemical destruction by 40% zinc chloride solution, the reviewer considers this as rather an uncertain method of treatment, with the destruction often greater than the anticipated need. Surgery in the form of
electro-cautery, as described and illustrated by La Forgia\textsuperscript{96}, or removal by surgical blade, is far more certain, and is particularly advisable on tissue distal to the lower third molar.

It is well to consider whether in efforts to secure an impression with well defined preparation margins, permanent trauma is not wrought on the tissues. Loe and Silness\textsuperscript{103} maintain that it is undesirable to extend fixed restorations below the gingival margin. They admit, however, that this procedure must often be done\textsuperscript{200}, with which Waerhaug\textsuperscript{198} agrees, and in their investigations found that the packing pressure of strong retraction agents should be reduced as much as possible, and that healing usually took place in some six to nine days. They condemn the use of 8\% zinc chloride solution, as does La Forgia\textsuperscript{95}.

Harrison\textsuperscript{72} suggests times of five to thirty minutes for untreated string, also string saturated with 1 : 1000 epinephrine solution; but recommends five to ten minutes only for 8\% epinephrine or 100\% alum solution.

The reviewer agrees with the concern regarding the use of more escharotic drugs, since only very isolated cases exist in which haemorrhagic lacerated tissues need firmer retraction control, and these are more amenable if temporarily dressed for impressions at a later date. Local anaesthesia will control some degree of haemorrhagic exudation well, and both the commercial products of "Gingi-Pak" and "Orostat" offer gingival retraction control in the majority of cases - an opinion supported by several authors\textsuperscript{82,105}. 
Tissue Retraction
La Forgia

FIG. 2—A. The strands for enlargement of the sulcus and arresting of hemorrhage and seepage are shown above the apical strands and the margin. B. The enlargement strands are removed allowing the apical strands to remain in position.

FIG. 3—A. The alum strands in position replacing the enlargement strands. B. All strands removed and the syringe tip in position to start injection of the impression material.
Tissue Retraction

La Forgia

Fig. 4.—Strands in position to partially arrest hemorrhage and seepage.

Fig. 5.—A U-shaped loop electrode in position to form a sulcus before preparing a subgingival shoulder.
B. Alginate: or Irreversible Hydrocolloid Impression Material

Irreversible hydrocolloid impression material, or alginate, has the same ultimate result as the reversible hydrocolloid material in that a gel is formed. This is brought about by a chemical reaction which is irreversible.

1. Chemistry and Composition:

The chief ingredient of the irreversible hydrocolloid impression material is one of the soluble alginates. An alginate is a salt of alginic acid which is extracted from marine kelp, and is generally conceded to be a linear polymer of the sodium salt of anhydro-beta-d-mannuronic acid with the following structural formula:\(^{177}\):

![Structural formula of alginate](image)

While alginic acid is insoluble in water, some of its salts are not, mainly the sodium, potassium, ammonium, and magnesium, and of these the sodium and potassium salts are used in dental impression materials. When the soluble alginate dissolves in water, it forms a viscous sol of relatively low concentration. The soluble sol of alginate is changed by a chemical reaction into an insoluble gel form. Usually this takes place by a reaction of the soluble
alginate with calcium sulphate to produce insoluble calcium alginate\textsuperscript{177}. To give sufficient "working-time" to take a dental impression, the reaction must be delayed. This is brought about by the introduction of a third soluble salt with which the calcium sulphate will react in preference to the sodium or potassium alginate. So the reaction is prevented or delayed while any of the added salt remains.

For example, if suitable amounts of calcium sulphate, potassium alginate and trisodium phosphate are mixed together in proper proportions in water, they react as follows:

\[ 2\text{Na}_3\text{PO}_4 + 3\text{CaSO}_4 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + 3\text{Na}_2\text{SO}_4. \]

When the supply of trisodium phosphate is exhausted, the calcium ions begin to react with the potassium alginate to produce calcium alginate

\[ \text{Kn Alg} + \frac{n}{2} \text{Ca SO}_4 \rightarrow \frac{n}{2} \text{K}_2 \text{SO}_4 + \text{Ca} \frac{n}{2} \text{Alg}. \]

Two possible compositions of an alginate impression material are given:

<table>
<thead>
<tr>
<th>Skinner and Phillips\textsuperscript{177} (percentage by weight)</th>
<th>Peyton et al\textsuperscript{131}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium alginate</td>
<td>12 per cent</td>
</tr>
<tr>
<td>Diatomaceous earth</td>
<td>70 &quot; &quot;</td>
</tr>
<tr>
<td>Calcium sulphate</td>
<td>12 $\frac{n}{2}$ &quot; &quot;</td>
</tr>
<tr>
<td>(anhydrate)</td>
<td></td>
</tr>
<tr>
<td>Trisodium Phosphate</td>
<td>2 &quot; &quot;</td>
</tr>
</tbody>
</table>

Potassium alginate

Calcium sulphate

Sodium phosphate

Modifiers (zinc sulphate fluorides, silicates or borates)

Diatomaceous earth

The two compositions given are for a typical alginate impression material, but commercial formulae are closely guarded
secrets. The diatomaceous earth is a filler which gives body and consistency to the mixed impression material\textsuperscript{131}. Modifiers such as sodium silico-fluoride (Na\textsubscript{3}Si F\textsubscript{6}), or potassium silico-fluoride give models poured into the impression material a denser surface, by counterbalancing the retardation of setting of the stone in hydrocolloid materials\textsuperscript{177}.

2. Properties

Dimensional Changes and Stability:

These materials show very similar dimensional stability to agar, as they are subject to the actions of syneresis and imbibition. At first there is a slight initial expansion which can probably be attributed to a continued imbibition of the residual free water by the gel after the initial gelation\textsuperscript{177}, but is then followed by a contraction. Some materials do not lose water by evaporation or by syneresis as readily as the reversible hydrocolloids, since their contraction in air is not as great\textsuperscript{177}. Imbibition of water is more erratic\textsuperscript{177}, and the relaxation of stress in the impression is accompanied by dimensional changes\textsuperscript{177}. While the golden rule is still to pour immediately\textsuperscript{25,47,174}, some alginites exhibit excellent dimensional stability when stored in an atmosphere of 100% relative humidity\textsuperscript{177}. Morrant and Elphicke\textsuperscript{119} claim there was no appreciable change in alginate impressions when stored in liquid petrolatum (paraffin) for 48 hours.

Storage and Shelf Life:

During storage, if any moisture comes in contact with the dry powder, the two chemical reactions, which bring about
gelation, react, and a lumpy mass results\(^2\). The powder is either dispersed in metal foil packets, or in tins with lids\(^{177}\). Great care should be taken with the sealing of the tins after use, and frequently a longer setting time is experienced with the last few mixes of powder\(^2\). This may be due to settling of the retarder particles, or moisture contamination\(^2\). The tin should be shaken before use\(^2\).

The alginate impression materials deteriorate rapidly at elevated temperatures\(^{177}\). At 37\(^\circ\)C., for prolonged periods, they polymerize slowly, but at 50\(^\circ\) to 60\(^\circ\)C., deterioration is more rapid, and the material shows poor strength and a variable setting time\(^2\). The volume measuring of powder instead of weighing has been criticised as not being completely accurate\(^{202}\).

The Australian Standard Specification A.S. No. T.15\(^4\) for alginate states that when stored in the original container, it shall retain the properties detailed for a period of not less than one year after the date of manufacture.

**Strength and Elasticity:**

The strength of the alginate hydrocolloid is adequate if they are correctly manipulated. This means the recommended ratios of powder and water\(^{48}\), correct spatulation and sufficient time to fully gelate in the mouth. The strength of the alginate gel increases for several minutes after the initial gelation\(^{177}\). Skinner and Phillips\(^{177}\) claim that it may be greater than the crushing strength of the reversible hydrocolloid impression material,
which should be at least 2,000 grams per square centimetre. Anderson\(^2\) has described them as having a consistency similar to set very weak plaster, in which there is elasticity due to the structure of the gel. The surface layer of each particle of powder changes to calcium alginate, and the centre remains soft. The rigidity is due to the attachment of calcium atoms between molecules of adjacent fibres as well as the molecules of the same fibres. The Australian Standard Specification A.S. No. T.15\(^4\) specifies that the alginate shall exhibit an ultimate compressive strength of 5,000 grams per square centimetre. Skinner and Pomes\(^{178}\) found that if the alginate is insufficiently mixed, the strength of the gel is reduced 50%.

Peyton et al\(^{131}\) report: "the elastic impression products are sufficiently elastic or flexible for all clinical uses, even though they have a tendency to tear or rupture more readily than the agar hydrocolloids." In this manner, the accuracy of the material is bound up with the elasticity, and several authors\(^{159,172,178}\) have reported on its accuracy, supported by Fusayama\(^{58}\). Inaccuracies also develop if the impression is held in the mouth too long after gelation\(^{143}\).

**Impression Removal:**

Al hydrocolloids will stand a sudden abrupt deformation better than a prolonged deformation, without distortion. For this reason, the impression must be removed in a direction parallel to the long axes of the teeth, with a sharp tug or thrust\(^{47}\).
Lucca\textsuperscript{105} suggests pressure be exerted on the periphery, since teasing or rocking the impression out will again, as with agar, cause distortion.

**Stone Surfaces and Reproduction:**

With earlier alginites, friable chalky surfaces were found on stone dies and models due to the retarding action of the alginate on the stone\textsuperscript{131}. To counteract this, control solutions were used, and after immersion, the accelerator allowed the correct setting of the stone. Fixers are still needed with some alginate impression materials, for the density and stone surface hardness can still vary due to pH changes and chemical reactions taking place at the alginate - stone interface\textsuperscript{142}. Phillips and Price\textsuperscript{142} found that, with some alginites, placing the poured cast in tap water during the set of the stone produced an inferior surface. It may well have introduced hygroscopic setting expansion to the cast.

Ayers et al\textsuperscript{7} claim that the alginites' ability to reproduce all indentations present in the test model was poor, a view shared by Dell et al\textsuperscript{44}. This is in direct contrast to Fusayama and Hosada\textsuperscript{60}, who found that a line of ten microns width could be reproduced, and this was rivalled only by the thiokol impression material. Fusayama\textsuperscript{58}, because of reproduction by the alginate impression material, has advocated its use in crown and bridge procedures.
3. Technique

Manipulation:

a. Copper Band:

The reviewer can find no references in the literature to the use of alginate impression material in copper bands. The nature of the material and its fragility and weakness in thin sections would mean its contra-indication in this procedure.

b. Tray Material:

The alginate powder is proportioned with a measured amount of water, and these are mixed with a spatula in a rubber plaster bowl with vigorous and thorough spatulation. Phillips and Price found that using plastic bowls and spatulas did not produce superior stone surfaces on casts. Not only are the proportioning ratios critical, but so is the mixing time as laid down by the manufacturer, usually timed at one minute's spatulation. Both overmixing and undermixing are detrimental to the strength of the set poured cast. Poor mixing gives a lumpy mix, which sets unevenly, and distorts upon removal from the mouth. Wilson and Smith report inferior properties of thin mixing proportions, and also criticise the volume measuring instead of weighing of the powder.

The adhesive properties of the alginate hydrocolloid are poor, especially in smooth impression trays unless they are specially treated, so perforated stock metal trays are the trays of choice. Jordan disagrees, claiming the impression material is not, by these trays, forced into intimate contact with the preparations.
made trays, into which holes are drilled to enable the alginate to lock into place by forcing through the holes, and setting on the outside surface, can be used. The size, position, and number of holes are important, and, in the reviewer's opinion, many alginate impressions undergo distortion because the incorrect perforated tray is selected. Other trays used are often non-perforated - smooth stock trays where either sticky wax, with or without cotton wisps, is softened on the contact area of the tray, or an adhesive, such as adhesive plaster, is applied. If the sticky wax is hot when the alginate is loaded, and softened sticky wax forms the best adhesion, the rate of gelation of the alginate is speeded up due to the heat exchange. The lining of trays with adhesive tape is quite retentive for alginate impression material, and the reviewer has found this method to be particularly useful.

After spatulation at 200 to 250 r.p.m., the tray is loaded and conveyed to the mouth, where it is positioned and held lightly until gelation has occurred. This first manifests itself by a lack of tackiness in the setting mass, and the tray should be allowed to remain in place for two more minutes. Due to the body temperature constant of the mouth, the alginate gels at the tissue surface first, and the thicker portions last. When the teeth are dried, there is a tendency for the alginate to stick to the teeth; this condition can be corrected by the use of mouth washes using salivary inhibitors and astringents, as suggested by Hedegard and Nyquist.
A relining or double technique has been suggested by Saizar in which the first alginate impression is trimmed away around teeth to be impressed, and a second alginate impression taken with the first for pressure. With this technique, the reviewer considers that stresses would be introduced, and possible inaccuracies and distortions formed.

c. Syringe Material:

Skinner and Carlisle concede that alginate accuracy is slightly better than agar. This led to the use of alginate in the Sear’s Hydrocolloid Impression Technique, in which syringe and tray material are used in combination. Articles by Fusayama, Pfeffer and Jeffreys, and Skinner and Carlisle illustrate this technique which poses problems because of the short working time of the alginate before gelation. Caul claims that a 10 C. (18 F.) decrease in temperature approximately doubles the gelation time, and this factor is made use of when using the syringe technique. The gelation time is increased to from six to eight minutes by pre-storing the mixing bowl, syringe, and spatula in a refrigerator, the use of ice water for mixing, and, with one author, the addition of more water (an extra 6 ccs. in 50 ccs.) to decrease the viscosity. The alginate is loaded into a Luer-type syringe with 18 gauge needle, and a removable or sliding cover for quick loading of the alginate. Fusayama uses water at room temperature, or an ideal 68°F., and he believes the water should be warmed in cooler temperatures. He also suggests a special loose
joint on the tray to prevent strain on the alginate. Injection of the alginate is carried out at the gingival areas which have usually been retracted, and then, as soon as possible, the tray is inserted over the injected alginate. The greatest difficulty is lack of union between the two masses.

Slice preparations, pin holes and post holes pose the same problems as with agar: how to record them. The weakness of the material indicates that it should be supported, and for this reason wherever possible metal or plastic pins or posts of similar diameter to the retentive area, and roughened for retention in the alginate, give the best results. They can be inserted after injection of the alginate into these holes, but the reviewer considers that this delay, slight as it may be, in this technique, can possibly cause non-union between the two masses. In addition, the timing of this operation would appear to pose the greatest problem, and while success has been achieved by some with it, the reviewer agrees with Sullivan, who considers that it should be used only in very short spans.

4. Accuracy

Many authors agree that agar and alginate hydrocolloid impression materials are equally accurate in impression taking, but others disagree, claiming that the alginate is inferior.

Again, the accuracy of the irreversible hydrocolloid material is directly associated with the model, die or cast. Skinner and Phillips have reported that this accuracy of reproduction is
dependent not only on the dimensional behaviour of the materials involved, but also on the surface condition of both the impression and model. Being an elastic impression material, the removal of the impression from an irregular and undercut object can be done without permanent distortion. Thus when a cast is poured in an impression taken with such a material, it possesses a high degree of accuracy. Hollenback reports of the alginate material, that although their over-all accuracy was high, in the reproduction of fine detail they were not equal to reversible hydrocolloid. Ayers et al. found that the ability of the alginate to reproduce smaller indentations was poor. Skinner and Hoblit found the irreversible hydrocolloid impressions equal in accuracy to those obtained with the reversible hydrocolloid. They also reported that all the impression materials exhibited distortions after removal, but they considered the distortions generally to be small in comparison to the errors inherent in most other impression techniques. Fusayama noted the accuracy of the alginate material to be excellent, and suggested its use in indirect inlay and crown techniques. Fusayama and Hosada found the reproductibility of the alginate impression material to be as good as the mercaptan rubber base material, and a line of ten microns could be reproduced.

Phillips and Ito discovered that deviation from the proper water/powder ratio not only altered the setting expansion of the stone, but also influenced the surface density of the cast. Skinner and Pomes found the dimensional stability to be as fully
adequate as that of the agar impression material, but suggested immediate pouring of the cast.

5. **Discussion**

It would seem, then that if strict control is exercised over the correct water / powder ratio, correct spatulation time, and sufficient time to fully gelate in the mouth, accuracy is improved\(^{177}\). The potassium sulphate solution needs to be carefully blown from the impression, the stone mixed under vacuum, and then evenly flowed into the impression with mild vibration, and allowed to set fully in 100% relative humidity\(^{141}\). The stone die, cast, or model should then be fully accurate, with the exception perhaps of very fine detail.

It would seem that the use of a metallic fixing solution, preferably 2% potassium sulphate solution is necessary for stone surfaces and their density. The dimensional stability, claimed to be as good as\(^{178}\), and in some respects better than the agar hydrocolloid, is susceptible to the actions of syneresis and imbibition. While with some alginate materials storage in 100% relative humidity can maintain this stability, the possibility of release of stresses would suggest the immediate pouring of the impression to be advisable. While setting, storage in 100% relative humidity should lessen relaxation of stresses risks.

Because of the strong conflict between authors regarding accuracy and reproductibility, each operator must assess this material in the light of what he expects from it. On the one hand, the findings of Caul\(^{25}\), Fusayama and Hosada\(^{60}\), Paffenbarger and Stanford\(^{128}\),
and Skinner, Cooper and Beck\textsuperscript{174} indicate that accuracy is of a particularly high standard. Ayers, Phillips, Dell, and Henry\textsuperscript{7}, Donnison and Docking\textsuperscript{48} find the recording of fine detail to be poor and disappointing, and from perusal of the literature, the quality of the material is probably the greatest factor in this technique, as suggested by Fusayama and Hosada\textsuperscript{60}.

For inlays, the use of a syringe and tray technique would require meticulous timing, with the possibility ever present of non-union between the injected syringe material and the tray material. Crowns and bridge impressions could fare similarly. Sullivan\textsuperscript{188} has suggested that if this material is used for these impressions, very short spans only should be attempted.
CHAPTER 5

ELASTOMERS

The mercapton polysulphide and silicone rubbers are essentially liquid polymers which can be converted to rubber-like solids at room temperature by being mixed with a suitable catalyst 131. These materials are technically elastomers, and are hydrophobic in nature. The liquid polymer is usually mixed with fillers to form a paste, and polymerization takes place after mixing the polymer with the catalyst by a condensation reaction 177.

A. Thiokol or Mercaptan Polysulphide Rubber

1. Origin:

These materials were originally developed for a variety of industrial uses, and were called Thiokol rubbers, the name of the manufacturing producer. From their original development, they have been modified and adapted for dental use 131.

2. Composition and Chemistry:

The impression materials are dispensed in two pastes, one white and one brown. The white paste, which is the liquid polymer, is formed by the addition of fillers to the liquid polymer; the fillers usually are zinc oxide and calcium sulphate, with oleic acid added as a retarder. The brown paste, which derives its colour from the lead peroxide content, contains also sulphur.

Pearson 129 gives the following analysis for the base and the accelerator (catalyst):-
<table>
<thead>
<tr>
<th>Base</th>
<th>Percent</th>
<th>Accelerator</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polysulphide rubber</td>
<td>79.72</td>
<td>Lead peroxide</td>
<td>77.65</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>4.89</td>
<td>Sulphur</td>
<td>3.52</td>
</tr>
<tr>
<td>Calcium sulphate</td>
<td>15.39</td>
<td>Castor oil</td>
<td>16.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other substances</td>
<td>1.99</td>
</tr>
</tbody>
</table>

The chemical formula of the polysulphide rubber is:

\[ \text{HS}(\text{R-S-S})_{23}\text{-R-SH} \]

where \( R \) is assumed to be:

\[ \text{C}_2\text{H}_4\text{-O-CH}_2\text{-O-C}_2\text{H}_4. \]

When the lead peroxide and sulphur react with this, the reaction is as follows:

\[
2\text{HS-}(\text{R-S-S})_{23}\text{-R-SH}+\text{PbO}_2 \rightarrow -\text{S}(\text{R-S-S})_{23}\text{-S-R-Pb-S-R(S-S-R)}_{23}\text{-S+2H}_2\text{O} \]

then

\[
-\text{S}(\text{R-S-S})_{23}\text{-R-S-Pb-S-R(S-S-R)}_{23}\text{-S+S } \rightarrow -\text{S}(\text{R-S-S})_{23}\text{-R-S-S-R(S-S-R)}\text{-S+PbS}. \]

3. Properties:

**Dimensional Changes and Stability:**

It has been shown that a shrinkage takes place during and following the setting of the mercaptan impression materials. Some of this is due to thermal contraction from temperatures developed during polymerization, and the loss of water produced by the setting reaction. The actual dimensional change is related to the thickness of the impression material, and its retention in the tray. Since they are hydrophobic in nature, as against the hydrophilic nature of colloids, there is no danger from syneresis or imbibition.
Dimensional stability is generally considered to be very good\textsuperscript{54,92,129,173,187}, although not quite so good as was first assessed. Other authors consider there are dimensional changes in stability even after thirty minutes\textsuperscript{13,133,160}. Schnell and Phillips\textsuperscript{160} reported that distortion at any time interval was less than with the reversible hydrocolloids.

**Shelf Life and Storage:**

Skinner and Cooper\textsuperscript{173} who stated that any product, the use of which involves a chemical reaction, can be suspected of possessing a shelf life, reported no significant change in setting time during a period of five months.

Most investigators\textsuperscript{129,173} have found that there is no difference with regard to the various storage media: air, water, or 100\% relative humidity. Where acrylic resin stops or trays are used, storage in water is contra-indicated, because of absorption of water by the resin and consequent distortion\textsuperscript{177}.

**Elasticity:**

This was found to be excellent when tested under the American Dental Association Specification No. 11 for reversible hydrocolloids. Skinner and Cooper\textsuperscript{173} confirmed this, Fairhurst et al\textsuperscript{54} complained that, although they found excellent elastic properties, times for setting as specified by the manufacturer did not give satisfactory elastic properties.

**Strength:**

This is far greater than agar\textsuperscript{123}, and thin sections will
not break when the impression is removed from the mouth, even when teased out. Eberle\textsuperscript{57} claims that the tear, elongation and compression strength is many times that of colloids.

**Viscosity and Flow:**

The early thiokols were of one consistency, but with needs of syringe and gingival retraction requirements, products with different viscosities were developed. There is now a thin bodied (syringe) material, a regular, and a heavy bodied thiokol. While the true test for viscosity for impression material is that the material will not drip out of an inverted impression tray, to leave the material to develop "body" is to risk developing polymerization, with possible distortion of the impression\textsuperscript{150}. Clark and Phillips\textsuperscript{27} found that flow was not greatly influenced by the time interval between spatulation and the application of the load.

**Surface Reproductions:**

Thiokols give dense smooth surfaces on stone dies / casts, with fine detail reproduced\textsuperscript{7,9,51,67,123,129}. This could be due to greatly lessened water content compared to the colloids\textsuperscript{51}. Ayers et al\textsuperscript{7} found there was an inability of all stones to reproduce all the indentations present in the impression, but claimed the rubber base materials were excellent in their reproduction of surface details. Sturdevant\textsuperscript{186} found the surface of their stone dies superior to those from reversible hydrocolloid.

**Toxicity:**

Although the accelerator paste used to complete
polymerization contains lead peroxide in an approximate 78% content, there does not appear to be any danger of patient absorption of this drug systemically\(^{129}\), for the lead peroxide does not dissolve in the saliva, and the impression period of approximately six minutes is too short. Their use as temporary relining impression materials is contra-indicated\(^{170}\).

**Working and Setting Time:**

This period of time covers the polymerization time from commencement of spatulation to removal of the impression from the mouth\(^{170}\). Working time includes not only spatulation time, when the material loses plasticity and becomes more viscous, but time taken to load the tray and to insert it into place in the mouth, for if not seated within the working time, strains will be introduced which later produce distortion. The setting time is influenced by many factors: humidity, temperature, accelerator/base proportioning, time of spatulation, accelerators and retarders. Both temperature and humidity accelerate the setting time, as does a drop or two of water\(^{2,177}\), while drops of either oleic or stearic acid act as retarders\(^{2,54,177}\).

It has been shown that despite suggestions that the accelerator paste be varied to produce shorter or longer working times\(^{67,169}\), this practice is contra-indicated, since it leads only to poor elastic properties, with a tacky weak impression\(^{54,173}\).

Altering the accelerator paste balance does not necessarily affect the setting time\(^{173}\), which can be accelerated or slowed
down by heating or chilling the mixing slab. Some investigators claim the manufacturers did not give the correct manipulative times for the early thiokol impression materials.  

It is generally agreed that an average of ten minutes of working and setting time is required for complete polymerization, although elastic properties continue to develop for some time after the tray is removed from the mouth. La Forgia suggests eight minutes, while Myers and Stockman consider six minutes to be better.

The reviewer considers that ten minutes, allowing four minutes for spatulation and working time, and six minutes for setting time, is quite adequate, and this time appears generally to be completely satisfactory.

From Myers and Peyton

**Effect of Room Temperature on Initial Set.**

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Fig. 1—Effect of room temperature on initial set.
Mixing:

Many investigators\textsuperscript{51,76,122,166} consider the procedure of choice is the double-mix technique utilizing a syringe, and an individual contoured tray, and for this two mixing pads are necessary. Equal lengths of base and accelerator materials of both syringe and tray thiokol are placed on the pads (Hollenback\textsuperscript{78} criticises this method of proportioning), spatulas are wiped into the accelerator pastes, and these are drawn into the base materials, and thoroughly incorporated\textsuperscript{90}.

From Yoder and Thayer\textsuperscript{204}

Thiokol impression materials ready for mixing.

The syringe material being required first, spatulation commences with this thiokol material\textsuperscript{90,196}, and if possible the tray material is mixed by a second assistant. Sturdevant\textsuperscript{189} suggests mixing the tray material first. Spatulation takes from 45 to 60 seconds, and the syringe and tray are then loaded. Injection is then commenced at the gingival margin, forcing the light bodied thiokol ahead of the syringe as it is carried from preparation to preparation.
In the reviewer's experience, the most advantageous position to commence is at the most distal portion of the preparation, and there will be excess passing onto the occlusal area. This injection phase, apart from the bubble occlusion, is non-critical, in that the tray material when placed into position plunges the syringe material into more intimate contact with the teeth. The tray is held with light pressure for sufficient time to complete polymerization. A test portion can be injected onto teeth not in the impressed area, to test for recovery after pressure, to assess polymerization. A technique in which thiokol rubber impressions are recorded on thin elastic metal strips for interproximal recording has been suggested by Gregg.

One commercial product ("Neoplex" - Surgident Limited) goes through a non-tacky stage about two and a half minutes after spatulation, and can be handled by means of moistened fingers, and be forced into place with fingers or instruments. This, while
being useful with non sealed copper band impressions, is not, in the
reviewer's opinion, as useful with bridge impressions, since air
bubbles can still form, and if used as a single mix technique, the
dimensional stability of the double mix factor is lost. It can be
of advantage, however, when using this material in a double mix
technique, to press the material more firmly into the tray, trying
to displace occluded bubbles.

The reviewer considers that Hudson's\textsuperscript{79} suggestion of
stainless steel mixing pads to be most helpful. These, of four
inches square, or five inches by six inches, are in a practical usage
far heavier than the paper pads, and provide a firmer base for mixing
as against the nine inches by twelve inches paper pads suggested by
La Forgia\textsuperscript{94}. Control of the polymerization rate by means of heat-
ing / chilling of the steel pad is an additional advantage.

4. Technique

Manipulation:

a. Copper Band:

Paramount among the requisite treatment of the band for
thiokol impressions is that the band must not be annealed, otherwise
distortion must follow\textsuperscript{18,67,79}. Lucca\textsuperscript{104}, while pressing that the
band should not be annealed, claims, however, that if un-annealed,
the band may distort due to its elasticity\textsuperscript{22}. The bands are fas-
tooned and contoured as they are for compound impressions\textsuperscript{22,82,196}.
While Sturdevant\textsuperscript{186} advocates the use of copper bands of 30 gauge and
work hardened, others suggest the use of stiffer bands\textsuperscript{67}. The
danger with finer gauge bands is that when being withdrawn, they may distort from either internal or external pressures. For this purpose, Hirshberg\textsuperscript{75} uses two bands, one two sizes larger than the other.

Roughening of the internal surface of the band forms some retention for the rubber base impression material, but it is considered that with this retention alone the impression material may pull away from the wall of the band and cause a distortion which is not discernible at that time\textsuperscript{67}. While perforations do allow the pressure of the impression material to diminish, added retention can be provided in this manner\textsuperscript{18}. The occlusal end of the band should be sealed\textsuperscript{67,129,169}, with either modelling compound\textsuperscript{18}, or auto-polymerizing acrylic resin\textsuperscript{38}, and it is better retained if the occlusal end is either ragged\textsuperscript{38} or notched to aid locking of the compound or acrylic resin\textsuperscript{38,196}. Brecker\textsuperscript{2} uses soldered reinforcement rings and copper bands in this technique; Azaria\textsuperscript{8} a piece of tin sheet soldered to the occlusal end, while Morris\textsuperscript{120} suggests a washer soldered to the band. Retention can be further helped by crimping in the gingival end slightly, as suggested by Silver\textsuperscript{169}. Adhesive cements painted on the internal wall do undoubtedly provide the best retention\textsuperscript{67,173}, but in the reviewer's opinion, this can be added to by both roughening the internal surface, placing two or three perforations on both buccal and lingual surfaces, thus supporting the tube at its weakest points.

It is important that the band be centred\textsuperscript{38} on the prepared tooth, so that there is a similar amount of material on all
sides \(^{50,67}\), for without this there is a tendency to distort - a thickness of two to three millimetres of rubber base \(^{54}\) being the ideal \(^{173}\). Kinghorn and Allan \(^{92}\) believe that bands confine the rubber base material too much, and do not leave it free to negotiate undercuts.

The double mix technique of syringe and heavy or regular bodied thiokol material with copper bands is preferred by many authors \(^{122,160,164}\), but since the rubber base may even be applied to the gingival tissue by means of a plastic instrument \(^{18,88}\), a single mix can also give a very satisfactory impression, or be relined with a further impression. The reviewer prefers for this type of impression a specific rubber base material ("Neoplex" - Surgident Limited) whose non-tacky stage after approximately two and a half minutes permits it to be packed in by instruments or finger pressure, thus obviating a good deal of bubble formation.

After removal of the copper band impressions, dies can be poured in stone \(^{18,38}\), or silver plated \(^{18,21}\), from which transfer acrylic or metal copings \(^{21}\) can be seated on the original preparations, to be removed in a second impression \(^{57,82,115,196,199}\), either of plaster \(^{18,38}\), or rubber base \(^{38}\). Others feel that a rubber base impression taken over a copper band in place will fill the requirements of a master impression \(^{67}\). The reviewer considers the use of transfer copings preferable, for not only is this a check on the details of the copper band impression, but it also allows more contact point detail to be recorded.
b. **Tray Material:**

Earlier trays for the thiokol material were usually of the perforated metal type, but other trays and techniques were tried - these are:-

(i) Perforated metal stock tray$^{49,123}$

(ii) Stock metal tray with compound liner and stops$^{31,92,170}$

(iii) Plaster impression in a metal tray$^{66}$

(iv) Perforated shellac base plate tray$^{196}$

(v) Trays made from polystyrene resin$^{187}$.

Subsequent investigations$^{9,51,122,166}$ proved that best impression results are obtained with individual contoured acrylic resin trays which can be either perforated, or used with an adhesive 9,76; a butyl rubber cement$^{177}$. Davis$^{43}$ suggests with acrylic resin adapting the tray directly to the area to be impressed in the patient's mouth, but the reviewer considers that, due to the exothermic reaction of acrylic resin, damage can inadvertently occur with tooth trauma. Duxbury$^{49}$ favours either the cold cure acrylic resin tray, or one made from L shaped perforated metal, with which both Myers et al$^{123}$ and Skinner and Cooper$^{173}$ agree. Shippee 164 believes perforated metal trays lose compression through the perforations, and do not give a satisfactory impression.

Whichever tray is used, it must be close fitting with a space of three to four millimetres between tray and tooth$^{54,166,173}$, since the amount of shrinkage after polymerization is in direct ratio to the mass of material$^{78}$. Hollenback$^{78}$ states definitely that a minimal amount of impression material must be used for
maximum accuracy. Where undercuts of a severe degree are present, the tray should be relieved in those areas, to allow withdrawal without distortion.

The cold cure acrylic resin tray\textsuperscript{9,49,51,54,79}, now the most popular for inlay crown and bridge impressions, is usually fabricated over a study model\textsuperscript{54}, where the necessary space for the impression is formed by either a layer of wax or asbestos tape\textsuperscript{196}, after a separating medium is laid down. The reviewer favours the use of heavy tin foil or asbestos for this purpose. Stops are made by removing wax or asbestos over adjacent teeth\textsuperscript{90}, not part of the preparations; the acrylic resin is mixed, laid down and a handle from excess resin fashioned for attachment. Holes may be drilled for mechanical retention, or adhesive painted on and allowed to dry\textsuperscript{51,54,79}. The reviewer considers the use of asbestos very satisfactory, in that a slightly rougher tray surface is formed, but believes that even with adhesive, holes drilled will provide added retention.

The use of compound in trays with rubber-base "washes"\textsuperscript{9}, is rather uncertain\textsuperscript{31,67}, in that distortion of the compound could cause distortion and failure if any length of time elapsed before pouring the model. The rubber base material, because of plasticisers, can cause softening of the compound\textsuperscript{67}, and distortion is due to elastic memory. It is considered that, if not subjected to great temperature changes, the impression can be allowed to stand for longer periods before distortion\textsuperscript{67,129,170,173,187}. 
From Yoder and Thayer\textsuperscript{204}

Steps in fabricating contoured individual acrylic resin tray.

1.

2.

3.
c. Syringe Material:

The greatest single problem in earlier use of the rubber base material with the single mix technique was the entrapment of air bubbles. While spatulas and plastic instruments were suggested, to carry the impression material to the preparations, the tackiness and high viscosity made this a difficult operation, and especially subgingivally. This led to modification of the
impression material, the light bodied or syringe material being then developed, while the heavy bodied or tray material exerted the necessary pressure to maintain the light bodied material in close contact with all surfaces.⁷⁹

There have been gradual improvements in the syringes used, from the earlier modified hypodermic syringes⁴³,⁹² to those designed and built by manufacturers⁵¹, with advantages of plastic separable nozzles and easily cleaned plastic barrels which allow the operator to see any bubble occlusion⁹⁰. Filling the syringe has been by various methods: Sturdevant¹⁸⁷ suggests the use of a paper funnel, from which the impression material is squeezed into the barrel. One company (Kerr Manufacturing Company Limited) recommends the barrel be filled by drawing up the material previously transferred to a Dappen glass, while some aspirate directly from the mixed mass. The reviewer favours the simplicity and ease of the syringe developed by Eberle⁵¹ who designed a sliding sleeve for easy loading. It must be considered that with any technique there is a danger of air occlusion, which can only be minimised by careful manipulation.

The problem of fine slice preparations, which present difficulties with agar impression material, and the long bevels suggested by Rosner¹⁴⁸ are easily recorded by the strength and inherent toughness of the thiokol material⁵¹. Again, the toughness and elastic properties of thiokol is helpful in impressing the parallel or new parallel walls of preparations, with the possibility of undercuts, suggested by Kaufman et al.⁸⁸.
Pin holes are recorded successfully by injecting with very small aperture nozzles\textsuperscript{116} on the syringes, directly into the holes. Miniature pin holes\textsuperscript{12,161} are often too small to achieve full length thiokol recording of their depth. Here better results are achieved if they have nylon bristles\textsuperscript{165,166}, or tapered acrylic pins\textsuperscript{82} inserted before the impression is taken, and the thiokol material can be injected around them. It is well to remember to allow sufficient length of nylon\textsuperscript{82}, with turned over ball ends\textsuperscript{125}, or acrylic pins to project far enough for positional locking in the impression material, and to coat each pin with adhesive cement to secure bonding in the thiokol impression. Should there be any possibility of movement of the pins, the acrylic locking plate suggested by Kortsch\textsuperscript{93}, and by Eisenbrand\textsuperscript{52}, will stabilize the pins for the impression taking.

Post holes can also be recorded by injecting directly, but these are often better recorded when supported by placing plastic points or platinum gold wire\textsuperscript{81} coated with adhesive in the holes after injection. Lister\textsuperscript{102} prepares the iridio platinum wire secured with cork. For the purpose of impressing the full depth, Hailey\textsuperscript{67} has suggested the use of motor driven root canal reverse spirals, in a pumping action on the thiokol, but with the tackiness and increased time to complete this operation, the working time of the impression could become rather critical, in the reviewer’s opinion.
From Lucia\textsuperscript{105}
Loading the syringe with rubber-base material from a Dappen glass.

From Yoder and Thayer\textsuperscript{204}
Thiokol injection into depth of gingival crevice.

From Johnston, Phillips and Dykema\textsuperscript{82}
Plastic pins with rubber-base impressions.
d. **Reline Technique:**

A method which makes use of both light and heavy bodied material without the use of a syringe is the Reline Technique\(^{122}\). An impression with heavy bodied material in an acrylic tray is taken. When polymerization is complete, the interproximal rubber area and areas adjacent to the preparations are removed. Care must be taken to cut adequate spillways, so that excess thiokol may escape, and not form inaccuracies in the impression. A light bodied material is applied to the teeth with a plastic, or similar instrument, or placed in the tray itself which is reseated and held lightly until set. Shippee\(^{164}\) is of the opinion that these impressions are not accurate, and Hudson\(^{79}\) believes compressive strains are introduced. To secure adherence of the second layer of thiokol to the first polymerized layer, Skinner and Cooper\(^{173}\) suggest wiping the first layer with a mild grease solvent, such as carbon tetrachloride, to eliminate greasy plasticisers.

Schell and Phillips\(^{160}\) have listed the advantages of the double mix syringe technique as follows:

1. increased initial accuracy.
2. reduced distortion during storage.
3. bulk of material less critical.
4. bubbles minimal.
5. compared to hydrocolloid: (i) less variation in results, (ii) less distortion on storage, (iii) initial accuracy more than comparable.
The reviewer considers that the reline technique is not as stable as the double mix syringe technique.

5. **Accuracy**

Accuracy with mercaptan polysulphide rubber impression material is free of two problems, of the colloids, which pose difficulties - syneresis and imbibition\textsuperscript{177}. However, dimensional stability which was thought at first to be excellent, is now understood to be influenced by continued polymerization and, it is thought, by contraction by stress relaxation\textsuperscript{177}. Impression materials confined in a tray do not contract as much as free impression materials\textsuperscript{177}. Since compatibility with gypsum products is satisfactory, stone surfaces are very good. Ayers et al\textsuperscript{7} found the mercaptan rubber impression materials excellent in their ability to reproduce the smallest test indentations\textsuperscript{44}. Bailey\textsuperscript{9} claims that their accuracy is comparable to that of the hydrocolloids. He also found that exceptionally smooth dies can be poured from them. Eberle\textsuperscript{51} speaks of the sharper unwrinkled impressions producing casts of harder surfaces with sharper marginal detail. Hailey\textsuperscript{67} has noted the ability of thiokol to reproduce minute details, and large undercuts. Pearson\textsuperscript{129} found that the thiokol rubber base material gave a sharp tough elastic impression with smooth surfaces and great accuracy of reproduction. Sturdevant\textsuperscript{187} claimed the surface of dies from the thiokol impression material to be superior to dies from reversible hydrocolloid material. Fusayama and Hosada\textsuperscript{60} found that these impression materials could reproduce a ten micron line with accuracy.
6. Discussion

Careful and proper manipulation of the impression material, timed procedure for recording the impression, and pouring of the die, cast or model before dimensional stability, due to continued polymerization, is affected are necessary for accurate results. Selection of the correct impression tray, with full retention due to adhesive cement and possibly perforations, is also necessary. The impression material should be kept to uniform, comparatively thin layers for greater accuracy. Accuracy is improved, as well as dimensional stability, by the use of the double mix syringe technique. There is no deterioration of stone surface, nor smoothness, set in contact with the thiolok impression material. Elasticity of the impression material is excellent, and the strength is far greater than agar.

A conclusion can be made that the mercaptan rubber-base impression material should be correctly proportioned and mixed, and used with syringe and tray materials in an individual contoured acrylic resin tray. If surfaces to be impressed are dry, with gingival retraction of margins and adequate time for complete polymerization of the impression material, impressions of great accuracy with fine reproduction should be the result.
B. Silicone Rubber-Base Impression Material

The silicones are synthetic polymers which are widely used as oils, greases, resins and rubbers\textsuperscript{131}.

1. **Chemistry and Composition:**

The silicone rubber-base impression materials are elastomers, which are polymers of dimethyl-siloxane\textsuperscript{2}, formed from a polymer chain of silicone and oxygen\textsuperscript{131}. Dimethyl polysiloxane has the formula\textsuperscript{131}:-

\[
\text{CH}_3 - \left[ \begin{array}{c}
\text{Si} \\
\text{OSi} \\
\text{OSi} \\
\text{OSi}
\end{array} \right] \\
\text{CH}_3
\]

This is in many cases a liquid, but when compounded with inert fillers, a paste of suitable consistency is formed.

The curing or polymerization is effected with a type of organo-metal compound and some type of alkyl silicate\textsuperscript{177}. While some authors claim that this accelerator is composed of tin octoate (tin caprylate, Sn (CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{6} CO\textsubscript{2})\textsubscript{2}), and a type of ethyl silicate\textsuperscript{177} - others claim that the accelerator is a mixture of dibutyl tin dilaurate and tetramethyl oxysilicate\textsuperscript{2}. In some instances, when the paste and accelerator are mixed, hydrogen gas, with resultant problems, is evolved, and to minimise this, a hydrogen acceptor, such as an aldehyde or chromic oxide, or both, is incorporated\textsuperscript{177}.

2. **Properties:**

**Dimensional Changes and Stability**

Silicone impression materials shrink during polymerization, and this continues for many hours, after removal from the
mouth\textsuperscript{61}, despite the cross chain linkage of this elastomer. Earlier, hydrogen gas was evolved\textsuperscript{177}, making the early pouring of silicone impressions inadvisable\textsuperscript{30}. Later, it was considered that storage was contra-indicated, since with storage the ratio and degree of distortion became greater as the time increased\textsuperscript{61}. Investigators later confirmed the existence of this problem\textsuperscript{41}. They suggest immediate or within thirty minutes pouring of the impression.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{The relative distortion of impressions when stored at room temperature. The results on one typical Thiolal are also shown. The data have been corrected for any initial inaccuracy of the fit when poured immediately. These dimensional changes may be related to continued curing, release of stress, collapse of internal bubbles, or volatilization of some of the ingredients.}
\end{figure}

From Gilmore, Schnell, and Phillips\textsuperscript{61}.
"The relative distortion of impressions when stored at room temperature."

\section*{Setting Time:}

Earlier silicone impression materials had a rapid polymerization time of between two to three minutes\textsuperscript{131}, which was unaffected by heat or humidity\textsuperscript{117}, but was too short for many procedures, including the use of the syringe technique. While this rate could be altered by varying the ratio of catalyst to polymer, the polymerization time was often excessively delayed, with the material adhering to the teeth, and distorting upon removal\textsuperscript{121}. Custer et al\textsuperscript{41} report that with later silicones, the setting time can be accurately
controlled by varying the amount of catalyst, a view supported by others. For this reason there is a range of consistencies available for both tray and syringe material.

From Rubinstein

"Setting time of Silicone impression material in regard to amount of catalyst used."

From Myers and Peyton

Effect of catalyst concentration on the initial setting time.
Elastic Properties:

These are of the same order as the thiokol rubbers, especially when tested for percentage strain and percentage permanent deformation $^{131}$. It is claimed that they recover better than mercaptan rubber-base material after a deformation $^{30}$. There is a rather wider variation in some products, and Peyton et al. $^{131}$ formed the opinion that some are too flexible. Other investigators $^{54}$ reported the elastic properties excellent during storage for twenty-four hours; on present research, Custer et al. $^{41}$ found the elasticity became less as the setting time was increased.

From Rubinstein $^{205}$

Elasticity of silicone material according to proportion of catalyst in mixture.

Shelf Life:

This is perhaps the greatest disadvantage of this impression material. Earlier silicone impression materials had a very poor shelf life $^{61,117,121,177}$. This may have been due to the silicone gum part of the paste stiffening in the tube, as suggested by Skinner and Phillips $^{177}$. They also suggest that the tin octoate catalyst, which should not be stored at a temperature above 80°F. for
any extended period, could undergo deterioration. Custer et al\textsuperscript{41} claim that while this property has improved, there is still slight deterioration after some time. The reviewer maintains that this possibility in the past has made any stock of silicone impression material suspect, as being stored overlong.

**Reproduction:**

Reproduction of detail is excellent\textsuperscript{7,44}, and comparable to both agar reversible hydrocolloid, and mercaptan rubber-base material\textsuperscript{117,149}. The greatest disadvantages, as mentioned, was evolution of hydrogen gas\textsuperscript{30}, which, it has been suggested, has now been overcome. Custer et al\textsuperscript{41} found the custom tray and wash technique accuracy very good. Henry and Phillips\textsuperscript{74} found the particle size of the artificial stone a factor in reproduction.

**Specification:**

Although still undergoing testing, no specification has been promulgated by the Standards Association of Australia. The material has been tested against those applying to agar reversible hydrocolloid impression material. It has been noted by Clark and Phillips\textsuperscript{27} that the flow property is not markedly influenced by manipulation. It has been reported that, after a given deformation, silicone material recovers by 80\%\textsuperscript{32}. It is also considered that it can be as easily copper-plated as compound or wax\textsuperscript{33}.

**Mixing:**

The technique of mixing the silicone rubber impression material, although easier, is very similar to that of the mercaptan rubber-base material\textsuperscript{131,177}. The catalyst is supplied in either
paste or liquid form, the coloured oily liquid being the more commonly used. 

The measurement of both is rather empiric, and has been criticised on that account. To a measured length of paste is added a sufficient number of drops of the catalyst, and these two are spatulated to a thoroughly homogeneous mix for a maximum time of thirty to forty-eight seconds. It has been stressed by various authors that there must be no attempt to alter the set proportioning by manufacturers of base and catalyst in an effort to increase or decrease the polymerization time. However, this procedure remains the only method of increasing or decreasing the setting time. To alter these proportions will bring about loss of elastic properties, possible distortion and a tacky surface. It has also been suggested that the material be allowed to become very slightly elastic before seating the impression; but this the reviewer regards as a very dangerous procedure, since strains can be introduced, with possible distortion.

For the syringe material, one of the many loading operations applying to the mercaptan rubber can be used; for the tray, it is best loaded taking care not to occlude any air bubbles. After injection of the preparations, following the technique with thiokol material, the tray with silicone rubber material is placed gently into position, and held without pressure until it is set. An average time of ten minutes should be allowed from commencement of spatulation. A testing amount placed conveniently on the opposite
jaw allows the completion of polymerization to be checked\textsuperscript{177}.

While the removal of the impression is not as critical as the hydrocolloid, teasing the impression out should be restrained to a minimum. Tylman and Tylman\textsuperscript{196}, and others\textsuperscript{2,177} claim that it should be removed with a straight pull, without rocking; others that it should be removed with a firm even withdrawal.

The reviewer considers it more difficult to rock a rubber base impression out than to remove it with a direct thrust.

![Graph showing effect of room temperature on the working time of syringe type mercaptan and silicone impression materials.](image)

From Peyton et al\textsuperscript{131}. Graph showing effect of room temperature on the working time of syringe type mercaptan and silicone impression materials.

3. Technique

Manipulation

a. Copper Band:

This technique requires a copper band which, like that used with the thiokol material, is not annealed\textsuperscript{18,67,79}. Rubinstein claims the band should be annealed\textsuperscript{205}. The band is festooned and contoured\textsuperscript{22,82}. The band should be large enough so that it will fit loosely around the prepared tooth\textsuperscript{205}. 
While the use of adhesive cement usually provides the best retention\textsuperscript{67,173}, roughening or scoring of the internal wall, as well as perforations\textsuperscript{18} do aid in the retention\textsuperscript{67}. The copper bands are usually of 30 gauge and work hardened\textsuperscript{186}, or heavier gauges\textsuperscript{67}.

The occlusal end is sealed with either modelling compound\textsuperscript{18}, or with acrylic resin\textsuperscript{67}, while some have permanent end seals in the form of soldered rings\textsuperscript{21}, tin sheet\textsuperscript{8}, or a washer soldered to the end of the band\textsuperscript{120}. The band can be strengthened by compound or acrylic resin being carried over onto the buccal or lingual surfaces.

The silicone rubber-base material can be used as a single mix technique, as suggested by Blank\textsuperscript{18}. Hailey\textsuperscript{67} advises that with only one material, two consistencies can be made by adding less accelerator to the thin mix, and more accelerator to the heavy mix. This alteration of proportions is rather unwise, to the reviewer, since the elastic properties can be altered drastically.

The syringe and tray material technique gives the best results when used with copper bands\textsuperscript{177}.

b. Tray Material

Retraction is as necessary with the silicone impression material as with the thiokol – with lower viscosity, there is no displacement of tissue, and gingival retraction becomes essential for complete impressions.

Lack of adhesive properties, as with the mercaptan rubber impression materials, means very close retention is necessary
for success with this material\textsuperscript{177}. Stock perforated metal trays have been used\textsuperscript{196}, as well as individual perforated metal trays constructed from perforated sheet metal\textsuperscript{123,205}. Some of these individual trays have been refined by the addition of self-curing acrylic resin borders\textsuperscript{49}. By far the most frequently used is the contoured individual acrylic resin tray fabricated over a study model with a spacer formed of wax, tinfoil, aluminium foil, or asbestos tape\textsuperscript{22,82,105,115,131}. The use of an adhesive is still recommended to bond the silicone material to the tray\textsuperscript{177}, and the adhesive usually contains poly(dimethyl siloxane) and ethyl silicate\textsuperscript{177}. For maximum accuracy thin (two to three mms.) layers of material are required\textsuperscript{186}, and to prevent distortion\textsuperscript{41,173}, but as with the thiokol rubber-base impression materials, the tray must be rigid to prevent distortion both on securing the impression, and on removal from the mouth\textsuperscript{82}. This requirement, together with the need for thin layers of material, emphasises the desirable qualities of the individual contoured acrylic resin trays.

The reviewer considers that of all trays available, the contoured individual acrylic resin tray is by far the most satisfactory, because it offers the following advantages:

(1) It is made with relative ease, compared to bending perforated sheet metal.

(2) When fabricated on a study model, there is no danger of exothermic heat reaction causing tooth trauma.
(3) It confines the impression material better than perforated trays, which must allow some compression to be lost, particularly with the less viscous silicone impression material.

(4) It can be readily used for electro-deposition, since no metal is present.

(5) It is sufficiently rigid for all purposes.

The silicone impression tray material, of a different viscosity when mixed, usually has the catalyst liquid coloured differently to the syringe material to differentiate them\textsuperscript{196}. Mixing of the silicone materials is much easier than the thiokol materials\textsuperscript{82} because of the catalyst liquid. The colour, too, is much more attractive than that of the thiokol rubber-base, and since the silicones are both odourless and tasteless, these are added advantages\textsuperscript{51}. A further advantage is that the material is non sticky when set\textsuperscript{51}.

c. Syringe Material:

Air entrapment had become an even greater problem with the silicone impression materials\textsuperscript{149} than with the thiokol materials, because of lower viscosity. While at first only one material was developed\textsuperscript{21}, the need for a technique in which injection of fine detail to prevent occlusion of air became evident. The earlier silicones suffered from many manipulative problems\textsuperscript{121}, and much improvement has been made in the more important properties, with doubt still existing regarding their shelf life\textsuperscript{41}. The colouring of the catalyst liquid now differentiates this syringe material from the tray material\textsuperscript{196}. 

Retraction of the gingival margin of preparations is as necessary with the silicone materials as with the thiokol materials. Syringes used are of the same type as those utilized in the thiokol syringe material technique, and loading can be made by various methods outlined in that section. Of particular help is that the lower viscosity enables the syringe to be loaded by drawing up the silicone material into the barrel from a Dappen glass\textsuperscript{196}.

Johnston et al\textsuperscript{82} stress that since silicone materials flow somewhat more readily than the thiokol rubbers, they are a preferred material for duplicating small pin holes. The same use of silicone can be made as with the thiokol materials in recording minature pin holes, pin holes and post holes.

4. **Accuracy**

From the commencement of its use, there have been conflicting reports on the accuracy and dimensional changes of silicone rubber-base impression material\textsuperscript{117,121}. Schnell and Phillips\textsuperscript{160} showed dimensional changes in impressions after storage for one hour, with greater discrepancies when stored for longer periods of time. Skinner and Cooper\textsuperscript{173}, while claiming them to be adequately accurate, and dimensionally stable, stressed the need for correct manipulation and proportioning of the pastes. Gilmore et al\textsuperscript{61} showed the need for uniformly thin layers of silicone material (2 / 3 mms.), and suggested improved accuracy was possible by allowing the material to become very slightly elastic before seating the impression. Myers and Peyton\textsuperscript{121} found that the accuracy of the
silicone rubber-base impression material was acceptable, and compared favourably with other elastic impression materials. They noted, however, that results were inconsistent. Myers and Stockman\textsuperscript{122} noted that there was no gas production, but that accuracy was not as good as the thiokol rubber-base impression material.

Ayers et al\textsuperscript{7} found that reproduction of detail was excellent, and compared favourably with both the agar material and the thiokol material. Reproduction of a line of $\frac{34}{44}$ was accomplished easily $\frac{44}{44}$.

Custer et al\textsuperscript{41}, in a more recent report, found the accuracy and dimensional stability of the silicone material to be excellent. Their tests disclosed that non-recovery of silicone after setting under compression in a tray was less than 1%, compared to approximately 2% for mercaptan, and approximately 4% for alginate. They found that manipulation and techniques for using the material very definitely affected the accuracy of reproduction.

5. Discussion

The silicone rubber-base impression materials have advantages of handling and aesthetic qualities which are superior in many respects to the thiokol materials. In earlier materials they had the disadvantages of a short working time, poor shelf life, gas production after polymerization, surface tackiness of the impression, poor elastic qualities, and the difficulty of producing electro-formed dies. It was felt that they were somewhat more unstable, particularly regarding shelf life. Since they are less susceptible
to thermal and atmospheric changes, the polymerization rate was shortened or varied by increasing or varying the amount of catalyst. While it has been suggested to allow the material to become very slightly elastic before seating the impression, this procedure may result in severe distortions. Increasing the catalyst content will, at any temperature range, decrease the polymerization time, but may alter the elastic properties.

Thickness of impression material remains a critical variable, since greater thicknesses are more susceptible to distortion than thinner sections. For this reason, the acrylic resin custom tray remains the best choice of trays for greater accuracy. Second or third pourings of dies or casts in the one impression also show less accuracy than the first. With the continued polymerization of the impression material, inducing contraction, distortion can result if the cast is not poured within the first thirty minutes.

A conclusion can be made that this elastic impression material, despite aesthetic and handling properties, and excellence of reproduction, must be considered inferior to the thiokol rubber-base impression material. To the reviewer, the doubt still existing regarding the shelf life of this product must make use of it in any technique doubtful as to accuracy and dimensional stability.
CHAPTER 6

COMPARISON OF IMPRESSION MATERIALS

A. Accuracy and Reproductibility

1. Impression Compound:

   Since it is one of the thermoplastic\textsuperscript{177}, and not an elastic impression material, its use is limited to areas where no undercuts exist. With careful preparation, and adequate heating and cooling, an accurate impression can be made. Any slight undercuts can cause a flow, which at 37° C. is approximately 6%, or may cause, if a larger undercut, a fracture of the compound material. The cause of possible inaccuracy is the thermal contraction of this material upon cooling. The linear contraction in cooling from mouth to room temperature is approximately 0.3%, which varies with the room temperature\textsuperscript{131}. This property is inherent in the material.

   Reproduction is good, provided no undercuts are present, and this property is controlled by Specification.

   Impression compounds cannot compare to the elastic impression materials regarding accuracy and reproductibility in that the impression for which they can be used must be limited to areas of no undercuts.

2. Agar Impression Material:

   One of the elastic impression materials with which although slight deformation takes place on removal from undercuts, no clinical distortion takes place.
There are many investigators who classify the accuracy of the agar impression material as excellent\textsuperscript{7,44,135,174,176}. This accuracy is associated with the dimensional stability of the material, which in comparison with other elastic impression materials, can be classified under certain conditions as unstable. As a colloid, the drawbacks of syneresis and imbibition are present. There is a need for immediate pouring of the impression.

Reproduction is extremely good, with complete reproduction of 34 micron lines\textsuperscript{7,44}. As authors have pointed out, the reproduction ability of this material often exceeded the reproduction capacity of the gypsum cast materials.

With regard to accuracy and reproductibility, agar impression material must compare as equal with both mercaptan and silicone rubber-base materials.

3. Alginate Impression Material:

Also one of the elastic impression materials, with the formation of a gel which is irreversible. While the elasticity of the material is quite good, there is a tendency for it to tear more readily on severe undercuts than the agar impression material 131. Its dimensional stability is comparable to the agar impression material, but as a colloid it is subject to the drawbacks of syneresis and imbibition.

Its accuracy is very good\textsuperscript{58,78}, and equal to the agar material. Since the dimensional stability is unstable to the extent of requiring immediate pouring of the impression, the need
of fixing solutions for the stone surfaces to be smooth and dense becomes imperative. Fusayama has suggested its use in crown and bridge techniques.

Reproduction is not as good as the agar, the thiokol or the silicone rubber-base impression materials. Ayers et al. found poor reproduction of 34 micron test lines, and other authors agree with this. Despite this, Fusayama and Hosada were able to reproduce 10 micron lines with it.

With regard to accuracy and reproductibility, while the alginate impression material is as accurate as the agar material, it cannot compare, according to a majority of writers, with the agar, thiokol or silicone impression materials in reproductibility of fine detail.

4. Thiokol Impression Material:

As an elastic impression material, it is an elastomer which does not suffer from the dimensional instability of the colloids. Accuracy is regarded as the most essential of all physical properties. With correct manipulation in mixing, adequate retention to the tray, and uniformly thin sections of impression material, the accuracy of the thiokol impression material must be described as excellent. Since polymerization of the thiokol material can continue for some time, it is better to pour the cast as soon as possible.

Reproduction has also been found to be excellent, the thiokol material reproducing with ease indentation test lines of
34 microns\textsuperscript{7} and 10 microns\textsuperscript{60}.

Compared with both the agar and alginate impression materials, the thiokol is equally as accurate, and reproduces the finest indentations just as well as the agar material\textsuperscript{7,44}. It must be considered to be better than the alginate material in reproduction, and must rank as one of the truly elastic impression materials for use in conservative dentistry. A very definite advantage is that more than one cast can be poured with accuracy in the one impression.

5. Silicone Rubber-Base Impression Material:

An elastomer of a similar nature to the thiokol impression material, it is one of the truly elastic impression materials. The earlier silicone impression material had drawbacks to accuracy in a short working time, poor shelf life and gas production during polymerization. Often poor elastic properties affected the accuracy\textsuperscript{131}. These problems have now been overcome, and later reports indicate that the accuracy of the silicone material can now be regarded as very good\textsuperscript{41}. With this material, manipulation and technique of use have a very definite effect on the accuracy. Under strict adherence to manufacturer's instructions, the dimensional stability is very good\textsuperscript{41}.

Reproduction has been excellent\textsuperscript{7}, and compares favourably with the agar and thiokol impression materials\textsuperscript{44}. Indentations of test lines of 34 microns width were reproduced easily\textsuperscript{7}.

This material with its improved properties can now
compare favourably with both the agar and the thiokol impression materials as an accurate elastic impression material. Since there are advantages of no odour, no taste, attractive appearance and being more easily mixed, this material, should further improvements be made, could become the most popular of the elastic impression materials. One of the disadvantages is that successive pourings of casts and dies in the one impression are not as accurate as the first one.

B. Ease of Manipulation

1. Impression Compound:

Probably the easiest impression material to manipulate, but with its low thermal conductivity, difficulty can be experienced in complete heating of the material. A controlled temperature water bath helps in this respect.

Cooling is also a problem, since the outside of the mass cools first. Adequate time must be allowed for hardening to be complete throughout the mass.

Compared to the elastic impression materials, the impression compound manipulation is completely simple. Provided the technique of softening and cooling is carefully followed, and no undercut areas near gingival tissues are encountered, an impression can be formed with ease in which the reproduction of the cavity or preparation is completely accurate.
2. Agar Impression Material:

Manipulation of the agar elastic impression material is one of the critical factors of accuracy of this material\textsuperscript{131}. The gel must be liquefied, and while it liquefies at 140\degree to 160\degree F.\textsuperscript{131}, boiling at 212\degree F. for a specific time allows the formation of the sol. When the sol is formed, it may be stored for several hours \textsuperscript{131}, and kept ready for use by immersion in water at 145\degree to 150\degree F. When needed, the agar sol may be loaded into a tray, and tempered at 115\degree F. for varying times suggested by the manufacturer. Gelation is brought about by circulating cool water at 60\degree to 70\degree F. for not less than five minutes.

Thus the preparation for an agar reversible hydrocolloid impression is a relatively complicated procedure, in which strict adherence to specified temperatures and times are required for accurate results.

It is perhaps the most complicated manipulation of any of the elastic impression materials. Clinical accuracy and dimensional stability regarding relaxation of stress, demand a standardised and meticulous technique.

3. Alginate Impression Material:

While the manipulation of the alginate impression material may appear simple, all the manipulative factors affect the gel strength\textsuperscript{177}, and consequently the accuracy. The proportioning of the powder / water ratio, before mixing, is critical if consistent results are to be obtained\textsuperscript{131}. The mixing time is one minute\textsuperscript{131}, and this should be timed. The mix should be
stirred vigorously at approximately 200 to 225 r.p.m. until a smooth, creamy mass is produced. It is necessary for accuracy that the correct type of tray be used. Since the setting time is influenced by the temperature of the mixing water, adequate time for complete gelation must be allowed. The strength of the alginate gel increases for several minutes after the initial gelation, so two to three minutes after gelation should be allowed for strength increase before removal of the tray. The impression can be held in the mouth too long, when a definite distortion results.

The ease of manipulation of alginate impression material, despite the factors required for accuracy, is much simpler than the agar impression material. It compares favourably with the silicone impression material, and must be considered simpler in mixing than the thiokol impression materials.

4. Thiokol Impression Material:

Manipulation of the thiokol impression material consists of the mixing together of two pastes of proper length. Two stages can be recognised in the setting process. Usually mixing takes place by incorporating the brown paste into the white until the mixed paste is of a uniform colour, and mixing should be completed in approximately one minute or less. The presence of air bubbles should be controlled as far as possible in this mixing. The mixing time can be quite critical. This material is quite sensitive to temperature during curing, and a higher
temperature usually shortens the polymerization time. A working and setting time of approximately ten minutes is usual for this impression material. Trays need to be of a suitable nature for strength and rigidity, and to control the impression material into thin sections. The first stage of the setting leads to the initial set, and the second ends with the final set\textsuperscript{131}. Since the initial set is accompanied by the development of elastic properties, clinical manipulation and impression taking must be completed before this stage occurs\textsuperscript{131}.

The ease of manipulation of the thiokol impression material is more difficult than with the alginate material. Since the mixing is harder in that a uniform colour demands heavy pressure, it must be considered more difficult than the silicone impression material. With the silicone, the liquid nature of the catalyst improves the ease of mixing\textsuperscript{82}. The preparation of liquefying, storing and tempering the sol of the agar impression material compares unfavourably in ease of manipulation with the mixing of two pastes in the thiokol impression material technique.

5. Silicone Rubber-Base Impression Material:

Silicone impression material is similar to the thiokol material in the form of its manipulation. Two pastes, or a paste and a liquid\textsuperscript{177} are mixed in essentially the same manner as the thiokol material. While the mixing is easier\textsuperscript{131}, care must be taken to disperse the catalyst thoroughly throughout the silicone base. Failure to secure a homogeneous mix usually results in
incomplete polymerization of some areas, with poor elastic properties\textsuperscript{131}. Air bubbles do not form as readily as with the thiokol impression material. The manufacturer's instructions regarding proportioning and mixing time must be followed carefully\textsuperscript{131}.

This material is not so sensitive to changes in temperature and humidity, and these have but a small influence on the setting time. The same care must be observed with trays and retention.

The ease of manipulation of this material compares closely with the alginate impression material. It must be considered easier to manipulate than the thiokol impression material, and certainly much easier than the manipulation of the agar impression materials.

C. Possible Die Materials

1. Impression Compound:

Impression compound is most versatile in that many types of dies can be formed with an impression compound impression. An amalgam die can be formed by packing amalgam into a compound impression\textsuperscript{82,196}. While copper amalgam was used before the advent of the elastic impression material, it has now largely been replaced by silver amalgam\textsuperscript{177}. The accuracy of such a die is dependent upon the usual factors which affect the dimensional stability of the amalgam\textsuperscript{177}. 
Silico phosphate cement can also be used to make a die from a compound impression. These dies are harder than dental stone, but the hazard of air occlusion, and since the cement shrinks on setting, the dies are not as accurate as those made from other materials\textsuperscript{131}.

Dental stone, either Class I or Class II can be poured to form a die. Class II stones are those of choice, and are dimensionally stable over long periods of time\textsuperscript{131}.

Compound impressions can be copper-plated to form metal dies which can be completed either by pouring in stone, pouring in low-fusing alloy metal, or have self curing acrylic resin root forms packed into them.

2. Agar Impression Material:

While claims have been made that the agar impression material is capable of being electro-plated\textsuperscript{188}, they are, in clinical use, difficult to electro-plate, and the process is not feasible for dental use\textsuperscript{177}. This stems from the main difficulty, lack of dimensional stability, when placed in either a hypotonic or hypertonic solution. Unless a rigid metal film is rapidly deposited on the impression, distortion of the hydrocolloid occurs.

Since hydrocolloid impression materials are extremely elastic, die materials are restricted to those which can be poured or packed without pressure\textsuperscript{112}.

Agar hydrocolloid impressions can be poured in the gypsum products, either plaster or stone. Plaster has more
application as study models, and not as a die material. Both Class I and Class II stones can be used readily with these impressions. Any of the five methods of forming dies or casts can be utilized with the agar impression material, but stability must be maintained with the use of storage in 100% relative humidity during setting.

3. Alginate Impression Material:

Plaster or stone dies are the only dies which can be used with this impression material. Class I and Class II stones are used, the Class II stones being the most frequently poured, since the setting expansion of approximately 0.05% is lower than the Class I stones. They also possess a superior surface smoothness.

While technically it is possible to use any of the five methods of preparing stone dies or casts, the problem of maintaining stability is again the difficulty. Both the use of a 2% potassium sulphate solution for stone surfaces, and storage in 100% relative humidity becomes necessary.

4. Thiolkol Impression Material:

The thiolkol impression material can be completed to die or cast form in two materials: stone or electro-formed metal.

Stone dies are poured readily in Class I or Class II stones, and have the advantage with this impression material that more than one pouring can be made from the one impression. Since the dimensional stability is such that changes occur with time.
it has been suggested that the first pouring be made within the first two hours. Then the second pouring can be made approximately three hours after removal from the mouth. All methods of pouring dies and casts are possible, with the maintenance of dimensional stability in the setting of the stone being much simpler.

One of the most frequently stated advantages of the rubber-base impression materials over the hydrocolloids is the ease with which the rubber-base can be electroplated. Investigators have experienced difficulties with copper plating of thiokol impressions. Skinner and Cooper, although able to obtain a smooth layer of copper deposition, observed distortions. They reported that all attempts to obtain an accurate die by means of electro-deposition with copper failed. Phillips and Schnell tested both thiokol and silicone impression materials for copper and silver electro-deposition, and reported that both can be plated. Their investigation revealed that both the "throwing power" and reliability of the basic silver bath was markedly greater than for the acid copper bath, and that the most accurate dies, with best surface detail, were the silver plated thiokols. Other authors support the silver plating of thiokol rubber-base impressions.

5. Silicone Impression Material:

These impression materials are more frequently poured in stone, either Class I, or for better results, Class II stones. Any of the five methods of preparing dies and casts can be used,
but there should be more care in pouring second or third casts from the first impression, with possibly less accuracy. In earlier silicones there was an inferior surface produced by immediate pouring of stone into the impression \textsuperscript{121}.

It has been claimed that copper or silver plated dies may be made from silicone impressions \textsuperscript{196}. Phillips and Schnell\textsuperscript{144}, after testing both thiokol and silicone, stated that both can be plated, either in acid copper sulphate bath, or in the basic silver cyanide. They noted that the copper electroformed die showed less distortion than the silver plated die with silver rubber impressions. They considered that the copper plated die could not be recommended because of the distortion of the impression during plating. Skinner and Cooper\textsuperscript{173} were unsuccessful in electroplating, because of slight distortion. Miller and Myers\textsuperscript{117} found the presence of globular voids, which did not reproduce on stone dies, present in electroformed dies. Eberle\textsuperscript{51} lists as one of the advantages of the silicone over the thiokol impression material that the silicone can be easily copper-plated. Myers and Peyton\textsuperscript{121} found the silicone impression material to be less easily electroplated than the thiokol rubber compound.

If an electro-deposited die surface were required from a silicone impression material, the safer technique would be to copper-plate it, but it would be necessary to check carefully the result for dimensional changes and distortion.
Discussion

Some types of dies are possible from all impression materials. The impression compound material is perhaps the most versatile, in that four types of dies can be formed in it, viz. amalgam, cement, stone, and electro-deposited metal. The disadvantage of not being an elastic impression material unfortunately limits its use to areas without undercuts. Of the elastic impression materials, thiokol must be considered more versatile than either of the hydrocolloid impression materials, since both stone and electro-deposited silver can be formed in the impression. Silicone too can have stone and electro-deposited copper formed in it, but, from the findings of investigators, the copper deposited die may be of doubtful accuracy. Both agar and alginate hydrocolloid impression materials can only have stone dies poured in them.
CHAPTER 7

DIE, CAST AND MODEL MATERIALS

In the indirect technique, a die, cast or model is poured on which the restoration can be fabricated. Certain properties are demanded of these dies, casts or models regarding surface detail, surface smoothness and resistance to deformation. The type of impression material employed is intimately related to both the type and quality of die and cast that is produced\textsuperscript{131}.

Dental stone, dental plaster, casting investment, silico-phosphate cement, amalgam, electro-deposited silver and copper are some of the materials used to make dies and casts from dental impressions. The selection of one of these is determined by the particular impression material in use, and the purpose for which the die or cast is to be used\textsuperscript{131}.

Desirable Qualities of a Cast or Die Material\textsuperscript{131}

(1) The material is required to reproduce an impression accurately, and to remain dimensionally stable under normal conditions of use and storage.

(2) It should reproduce fine detail satisfactorily, and have a smooth, hard surface.

(3) It is required to be strong and durable, and to withstand the subsequent manipulative procedures without the surface abrading or the cast fracturing.

(4) The colour of the cast or die should contrast materials used to facilitate manipulative procedures.
(5) There should be an ease of adaptation of the material to the impression.

(6) A minimal time required after fabrication of the die before it can be used.

It is not proposed in this Chapter to cover fully the structure chemistry and properties of all the die and cast materials, but to give a brief outline of the type and technique of possible die and cast materials used frequently with the impression materials covered in previous chapters.

A. Materials

1. Dental Plaster:

This material is not used extensively for the production of dies or casts in clinical conservative dentistry, but has more application in its use as study models \(^{177}\), or for record purposes only \(^{131}\).

2. Dental Stone:

Dental stone is used quite extensively to make both dies and casts \(^{131}\). These materials are strong and resist abrasion, and are used whenever a restoration is to be made on the cast \(^{131}\). They have been divided into Class I and Class II stones \(^{177}\), the latter being much harder, with a dry compressive strength of perhaps 10,000 lb. per square inch. They have a setting expansion of 0.06%, while the setting expansion of the Class I stones
are generally higher (0.10% to 0.13%)$^{177}$. The surface of the Class II stone dies is harder, and more resistant to abrasion$^{132}$. The die or cast is ready for one hour after pouring$^{177}$, but full strength is not attained before twenty-four hours$^{131}$. The manufacturers' instructions$^{131}$, and special techniques for low water / powder ratios$^{177}$ produce hard surfaces. There is a disadvantage in that the surface of the die can be abraded during wax pattern carving$^{177}$, attempts to lay down a platinum matrix$^{82}$, or the burnishing or finishing of cast restorations on its surface.

**Technique:**

Care must be taken to follow carefully the manufacturers' instructions regarding the correct water / powder ratio$^{131}$. For better results the stone and water should be vacuumed mixed, with mechanical spatulation$^{141}$. All excessive potassium sulphate solution or water should be carefully removed$^{130}$, and the use of careful vibration helps to condense the stone$^{82,130,177}$. The water is placed in the bowl, and the powder sifted into the water. When the powder sinks into the water without an agglomeration of the particles, less air is carried down$^{177}$.

3. **Casting Investment:**

Casting investment can be used to form a die or cast on which a wax pattern is carved, but once the wax pattern is luted to the investment$^{78}$, the die or cast must of necessity be destroyed in the casting procedure. This material does not, from its structure, possess the strength or the abrasive resistance of the
stone die. Hollenback\textsuperscript{78} reports this as a technique which has never become popular because of the lack of strength and surface hardness of the investment; he also questions the dimensional accuracy of many of the investment materials used for this purpose. He does feel that the phosphate silica investments of a high fusing nature could be more successful when used in this procedure.

4. Silico-phosphate Cement:

These cements are sometimes used to make dies in compound impressions\textsuperscript{131}. They are harder than those made from dental stone. Air bubbles are easily trapped in the deeper areas of the impression, when packing these cements, but can be controlled by centrifuging the impression and die after packing. Dies can be removed from the impression after one hour. The cement shrinks on setting, and the dies are not as accurate as those made from other materials. The surface of the cement loses water upon standing, and becomes friable\textsuperscript{131}.

5. Amalgam:

Amalgam dies had been used extensively prior to the advent of the elastic impression materials\textsuperscript{177}. Although copper amalgam was then used most frequently, the copper amalgam has now been replaced by a silver amalgam\textsuperscript{177}. No specification exists for model amalgam, and information on composition and properties is limited\textsuperscript{177}. Amalgam produces satisfactory models on which wax patterns can be made and gold restorations finished\textsuperscript{131}. Possible
dimensional changes accompanying the setting of the amalgam, and the influence of the manipulation of the amalgam on these changes during packing must be guarded against. Electroplating of the compound impression frequently replaces the amalgam die. Condensation of the amalgam into the impression requires some skill and is time consuming. After packing, the die must be laid aside for twelve hours before separation of the die and impression. Since amalgam is a good conductor of heat, the rapid cooling of wax applied to it may produce internal stresses with possible distortion of the wax pattern.

**Technique:**

For the amalgam die, the compound impression is boxed with wax, and invested in either an inlay ring with investment, or a rubber ring with plaster. It is suggested that the crown section be condensed and packed with a pointed or bevelled orange-wood stick, but that the root form should be condensed with regular amalgam condensers so that excess mercury is eliminated. After setting for six hours, the die is removed from the amalgum and the root portion trimmed and shaped.

6. **Electro-deposited Copper:**

Dies may be formed by electro-depositing (or electro-plating) the impression with copper. In compound impressions, the copper electro-deposition reproduces the dimension and detail of the impression very accurately. No dimensional changes in
the form of expansion or contraction, encountered in the setting of other die materials, occur\textsuperscript{131}. The die is tough and of good strength characteristics.

**Technique:**

In this technique, the preparation side of the impression is metalized\textsuperscript{131,177}. Although many agents can be used in metalizing, the most effective seems to be through the chemical reduction of silver nitrate\textsuperscript{140}. A film of pure silver two-millionth of an inch thick is deposited on the surface of the impression. After metalizing, the impression is waxed to the cathode holder, and attached to the negative pole, the copper anode to the positive pole. The plating bath is an acid solution of copper sulphate\textsuperscript{131}. The danger of air entrapment must be guarded against, and plating is then carried out, checking the impression regularly for an even deposition of the copper. The current required is approximately twenty milliamperes per impression\textsuperscript{82}. After plating, the impression is filled with stone or acrylic resin\textsuperscript{82}, or low fusing alloy, to form a root form\textsuperscript{115}.

7. **Electro-deposited Silver:**

Electro-deposited silver dies may be formed in a similar manner to the electro-deposited copper dies. They have the same metal characteristics of being tough and of good strength\textsuperscript{131}. Since the alkaline silver bath softens the surface of impression compounds, compound impressions cannot be silver plated\textsuperscript{131}. The process of silver electro-deposition is easier than the copper-
plating procedure. With the polysulhide rubber impression material, the reliability and "throwing power" of the silver bath is better for results, and the dimensional stability of the thiokol material is better in this alkaline silver bath.

**Technique:**

With this procedure, after the impression has been washed with tap water and dried, a fine silver powder is burnished into all areas with a soft brush. The powder should contact the copper band, or with a quadrant impression, silver powdered wax strips leading to the wire copper or silver cathode. The cathode holder or, in the case of a quadrant impression, the wire cathode contacts the impression at some non-critical point. The copper band is masked beyond the open end and waxed onto the cathode holder and all conducting surfaces not to be plated are waxed.

The metalized impression is filled with the alkaline silver cyanide bath liquid and lowered into the electrolyte. The end of the cathode is attached to the negative pole, and the silver anode to the positive power, approximately four inches away. Plating is carried out for approximately twelve hours at ten milliamperes per square centimetre of impression surface.

No one cast or die material is ideal in all qualities, or compatible with all impression materials. Several die materials possess acceptable qualities. Properties of accuracy, durability, strength, and convenience of use are those sought in these materials.
B. Methods of Preparing Stone Dies and Casts

There are several methods of making dies and models in stone material:

1. Two Separate Impressions Required:

Into the first impression individual dies are poured, and are used for making and finishing the wax patterns. The second impression is poured into a solid master model which gives the correct occlusion and contact points \(^{82,196}\). This method of forming dies and casts is more suited to the hydrocolloid materials, with the rubber base two pourings, particularly with thiokol, can be managed from the one impression.

2. One Master Model Method:

A method in which individual dies are poured and formed with tapered root forms. After shaping, replacing, and lubricating the die forms, the cast is completed in stone \(^{66,68,71,82,196}\).

3. Separate Dies Method:

With this method, the first pouring of individual dies, after they are set is removed, and a solid master cast is then poured into the impression \(^{82,196}\).

From Johnston et al \(^{82}\).

Cast made into individual dies.
4. Individual Removable Stone Dies:

This method employs one impression with two pourings of stone. The dies are poured firstly with dowel pins inserted into each die. After setting and lubrication, the second layer of stone is poured. Separation is made either by:-

(i) Saw cuts through interproximal spaces with a fine saw blade, or

(ii) By separating each die with thin steel matrix strips (0.002 inches) thick, inserted mesially and distally, and tapering apically.

From Tylman and Tylman. Tapered base stone die with dowel.
5. Keyed Base Method:

This method utilizes one master impression which is immediately poured in stone and seated on a keyed plastic or metal base\textsuperscript{196}. Dies are cut with a fine blade from the model, cutting both from the gingival and the base of the cast, then fracturing.

From Benfield and Lyons\textsuperscript{13}.

Stone model with keyed base.
DISCUSSION AND CONCLUSION

The nature and use of impression materials in conservative dentistry have been reviewed. There is one aspect remaining which should be discussed - the influence of dimensional changes common to impression materials on the actual fit of the small and often complex castings required in conservative dentistry.

In the direct technique, the wax pattern would appear to be the greatest source of dimensional error, both from the large coefficient of thermal expansion, and the fact that strains induced in the material during manipulation are readily released with temperature changes. There has been strong criticism of inlay wax used in direct patterns in that, due to the basic physical nature of wax, distortion of the wax pattern is a continual hazard.

In the indirect technique, the multiplicity of materials, each contributing a dimensional variation, would appear to amplify the problem of achieving an accurately fitting casting.

Impression materials will exhibit a shrinkage when measured in the unrestrained state. In the case of thiokol impression material, this varies from 0.19 per cent to 0.39 per cent. This does not mean that the mould space of an impression has shrunk. In the confinement of a tray, there may be even a slight expansion of cavity dimensions. The final dimensional change, provided the material has been correctly manipulated, will
undoubtedly be within the stated tolerance of $\pm 0.2$ per cent.

Class II stone, used as a die material, and again correctly manipulated, expands slightly, the accepted figures being $+0.05$ per cent to $+0.1$ per cent. So it would appear that there is almost automatic compensation, there being little difference in the dimensions of the impressed preparation and its reproduction in the die.

Obviously any macroscopic deficiencies visible in the adaptation of the wax pattern to such a die can be repaired by the operator. So there should be only minimal discrepancies in the fit of the wax pattern to be invested to the preparation, as temperature changes are negligible.

Theoretically, therefore, there should be a linear difference of approximately $0.4$ per cent between direct and indirect patterns taken from the same cavity, this figure representing the usually accepted shrinkage of the direct pattern from mouth to room temperature. It would appear that this should be taken into account and compensation made in the subsequent thermal or hygroscopic expansion investment techniques.

Such compensation is rarely made; the same investments and techniques are usually used whether the pattern is obtained directly or indirectly. Yet satisfactory clinical results are achieved by most operators. It is indeed fortunate that relatively gross discrepancies of fit are necessary before recurrent caries ensues.
A conclusion can be made that there are factors other than the minute dimensional changes of correctly manipulated materials which affect the fit of small castings. Jorgensen has pointed out that the angle of convergence of a preparation combined with the 20 μ to 30 μ thickness of a cement lute can have an effect on the marginal fit of castings far outweighing any considerations of dimensional changes in impression materials. Research in the future must be directed towards the synthesis of a micro-thin luting agent which is insoluble in the oral environment. The continuing trend in the development of impression materials has been in simplification of manipulation and the manufacture of materials which are less sensitive to external environment.

Impression materials, with many methods and techniques possible, are capable, with correct manipulation of giving results which are clinically acceptable. It should be stressed that each step of a technique must be followed with meticulous care. Each material has its advantages and its disadvantages. No one technique or material can be universal in its use, and cover all possible needs and conditions. A knowledge of the physical properties and limitations, together with the unswerving integrity of the operator can give the best possible results, with the best ease of manipulation.

To the average practitioner of dentistry, this ease
of manipulation has meant a developing confidence in indirect procedures, and a consequent renascence of interest in crown and bridge work.


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